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Virginia Tech Weed Identification Guide

These pages are intended to aide in the identification of common weeds and weed seedlings found throughout Virginia and the Southeastern U.S. The weed pictures in this guide are arranged alphabetically by common name and may be viewed by clicking on one of the letters to the left. Please take some time to view a list of references used in the assembly of the botanical descriptions for weeds contained within this guide. Descriptions for all weeds are not complete at this point. However, additions are being made daily. Only pictures of the highest quality have been included in this guide, therefore each page may take some time to download.

Try our GRASS WEED IDENTIFICATION KEY. By answering a series of questions about your unknown grass sample, this identification key will narrow down your choices and provide you with the identity of your unknown grass sample .

View and download our extension publications on the identification and control of perennial weeds in Virginia.

NEW! **Try our new scientific name index. This new option allows you to search all of the weeds in this guide alphabetically according to scientific name.**

Feel free to e-mail any comments or suggestions to:

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Virginia Cooperative Extension

Knowledge for the CommonWealth

Common Weed Names: A

Common Name	Scientific Name
Alligatorweed	*Alternanthera philoxeroides*
Amaranth, Palmer	*Amaranthus palmeri*
Amaranth, Prostrate	*Amaranthus blitoides*
Amaranth, Spiny	*Amaranthus spinosus*
American Burnweed	*Erechtites hieracifolia*
American Elderberry	*Sambucus canadensis*
American Speedwell	*Veronica americana*
American Water Plantain	*Alisma subcordatum*
American Water Willow	*Justicia americana*
Annual Bluegrass	*Poa annua*
Annual Fleabane	*Erigeron annuus*
Annual Jewgrass	*Microstegium vimineum*
Annual Ryegrass	*Lolium multiflorum*
Annual Sowthistle	*Sonchus oleraceus*
Apple-of-Peru	*Nicandra physalodes*
Arrowhead, Long-beaked	*Sagittaria australis*
Arrowleaf Sida	*Sida rhombifolia*
Arrow-leaved Tearthumb	*Polygonum sagittatum*
Arthraxon, Jointhead	*Arthraxon hispidus*
Artichoke, Jerusalem	*Helianthus tuberosus*
Asian Dayflower	*Murdannia keisak*

Asian Spiderwort	*Murdannia keisak*
Asiatic Dayflower	*Commelina communis*
Aster, White Heath	*Aster pilosus*
Autumn Olive	*Elaeagnus umbellata*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Alligatorweed: *Alternanthera philoxeroides*

Weed Description: **Aquatic mat-forming perennial that usually spreads vegetatively by fragmentation. Alligatorweed is an invasive aquatic weed that can be found in the coastal plain from Virginia to Florida and westward to Texas. This weed is now also found in coastal California.**

Leaves: **Opposite, elliptic in outline, from 2 to 4 inches in length. Leaves have a distinctive midrib, are without hairs (glaucous), and are without petioles.**

Stems: **Fleshy and succulent, light to dark green or pink to purplish in color, and reach 3 feet in length. Stems root at the nodes and are usually floating or trailing along the ground except for the tips that turn upward (decumbent). Stems are generally without hairs (glabrous) except for a few that occur at the leaf base.**

Roots: **Fibrous roots occur at the stem nodes. Roots can be free-floating in water or occur in the soil.**

Flowers: **Relatively small (13 mm in diameter) and white in color. Flowers occur on flower stalks (peduncle) that are approximately 1/2 to 3 inches in length. Flowering usually occurs from April through October.**

Identifying Characteristics: **Aquatic mat forming perennial with hollow stems, opposite leaves, and solitary white flowers.**

Virginia Tech Weed Identification Guide

Select a Resource...

Palmer Amaranth: *Amaranthus palmeri*

Weed Description: **An erect summer annual that may reach 6 1/2 feet in height. Palmer amaranth closely resembles many other pigweed species, and is found throughout the southern United States from southern California to Virginia.**

Seedling:
Stems below the cotyledons (hypocotyls) are without hairs (glabrous) but may sometimes be slightly hairy, and are often red in color. Cotyledons are narrow (10-12 mm long) and green to reddish in color on the upper

surface. Lower surfaces of cotyledons have a reddish tint. First true leaves are alternate, ovate in shape, and are slightly notched at the tip of the leaf blade (apex).

Leaves: Alternate, without hairs (glabrous), and lance-shaped or egg-shaped in outline. Leaves are 2 to 8 inches long and 1/2 to 2 1/2 inches wide with prominent white veins on the undersurface. Leaves occur on relatively long petioles.

Roots: Taproot that is often, but not always, reddish in color.

Fruit: A single seeded utricle that reaches 2 mm in length and are wrinkled when

dry. Each utricle splits open in the middle to expose a single glossy black to dark brown seed that is 1 to 1.2 mm long.

Stems: One central stem occurs from which several lateral branches arise.

Flowers: **Small, green, inconspicuous flowers are produced in dense, compact, terminal panicles that are from 1/2 to 1 1/2 feet in length. Smaller lateral inflorescences also occur between the stem and the leaf petioles (leaf axils). Male and female flowers occur on separate plants. Each terminal panicle contains many densely packed branched spikes that have bracts that are 3 to 6 mm long.**

Identifying Characteristics: **Dense, compact terminal panicles and relatively tall plants with alternately arranged leaves with petioles that are longer than the leaves. Palmer amaranth is often confused with other similar pigweed species. However, no other pigweed species have terminal panicles that reach 1 1/2 feet in length. Additionally, the terminal spike of palmer amaranth is much smoother and narrower and less spike-like than either Redroot Pigweed (*Amaranthus retroflexus*) or smooth pigweed (*Amaranthus hybridus*). The leaves of palmer amaranth are**

also without hairs and have prominent white veins on the undersurface unlike those of redroot pigweed. These species may also resemble Common Lambsquarters (*Chenopodium album*) in the cotyledon stage, however common lambsquarter's cotyledons often have a mealy gray cast and the first true leaves are alternate, unlike any of the pigweed species.

Virginia Tech Weed Identification Guide

Select a Resource...

Redroot Pigweed: *Amaranthus retroflexus*

Weed Description: **An erect summer annual that may reach 6 1/2 feet in height. Redroot pigweed is an abundant seed producer that may be found throughout the United States in horticultural, nursery, and agronomic crops, landscapes, roadsides, and also in pastures and forages.**

Seedling:
Stems below the cotyledons (hypocotyls) are without hairs (glabrous) but may sometimes be slightly hairy, and are often red in color, especially near the base. Cotyledons are narrow (10-12 mm long) and

green to reddish in color on the upper surface. Lower surfaces of cotyledons have a reddish tint. First true leaves are alternate, ovate in shape, and are slightly notched at the tip of the leaf blade (apex). Hairs may occur on the leaf margins and along veins, especially along the lower leaf surfaces.

Leaves: Alternate, ovate in outline, with petioles that reach 1/2 inch in length. Leaves have wavy margins and hairs that occur along the veins of the lower leaf surfaces.

Stems: **Stout, erect, branched, and reaching 6 1/2 feet in height. Stems usually have short hairs, especially near the upper portions of the plant.**

Roots: **A shallow taproot that is often, but not always, reddish in color.**

Fruit: **A single seeded utricle that reach 2 mm in length and are wrinkled when dry. Each utricle splits open in the middle to expose a single glossy black to dark brown seed that is 1 to 1.2 mm long and ovate in outline.**

Flowers: **Small, green, inconspicuous flowers are produced in dense, compact, terminal panicles that are approximately 3/4 inch wide and from 2 to 8 inches in length. Smaller inflorescences also occur between the stem and the leaf petioles (leaf axils). Male and female flowers occur on the same plant (monoecious). Each terminal panicle contains many densely packed branched spikes that have bracts that are 4 to 8 mm long and 2-3 times longer than the sepals.**

Identifying Characteristics: **Dense, compact terminal panicles and relatively tall plants with alternately arranged leaves. Redroot pigweed is often confused with other similar pigweed species. For example, smooth pigweed is very similar, however this species has terminal panicles that appear less dense, compact, and bristly than those of redroot pigweed. Additionally, the bracts of smooth pigweed are only slightly longer than the sepals, unlike those of redroot pigweed. Palmer Amaranth (*Amaranthus palmeri*) also resembles redroot and smooth pigweed, however the terminal panicles of this species are much longer and narrower than the other pigweed species. These species may also resemble Common Lambsquarters (*Chenopodium album*) in the cotyledon stage, however common lambsquarter's cotyledons often have a mealy gray cast, and the first true leaves are alternate, unlike any of the pigweed species.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Lambsquarters: *Chenopodium album*

Weed Description: **Summer annual to 3 1/2 feet in height capable of producing thousands of seeds.**

Seedling: **Cotyledons elliptic (12-15 mm long), dull green with a mealy gray cast on the upper surface and maroon on the underside, turning green with age. Hypocotyls are hairless, green or tinged with maroon. The first pair of true leaves are opposite, all other leaves are alternate. Seedling leaves are triangular and also have a mealy gray cast.**

Leaves: **Alternate, light green, rounded, triangular, 1 1/4 to 10 inches long and on a long petiole.**

Stems: **Erect, hairless, grooved, branching and light green with red coloration in varying degrees.**

Roots: **Short, much-branched taproot.**

Flowers: **Small and clustered into panicles at tips of branches and upper leaf axils. Flowers are green, inconspicuous, without petals and occur from June to September.**

Fruit: **An utricle with a thin papery covering over the seeds.**

Identifying Characteristics: **Cotyledons and seedling leaves have a mealy gray cast. Cotyledons of common lambsquarters and Redroot Pigweed (*Amaranthus retroflexus*) are similar, however redroot pigweed cotyledons have a prominent midvein while lambsquarter cotyledons do not.**

Prostrate Pigweed or Prostrate Amaranth: *Amaranthus blitoides*

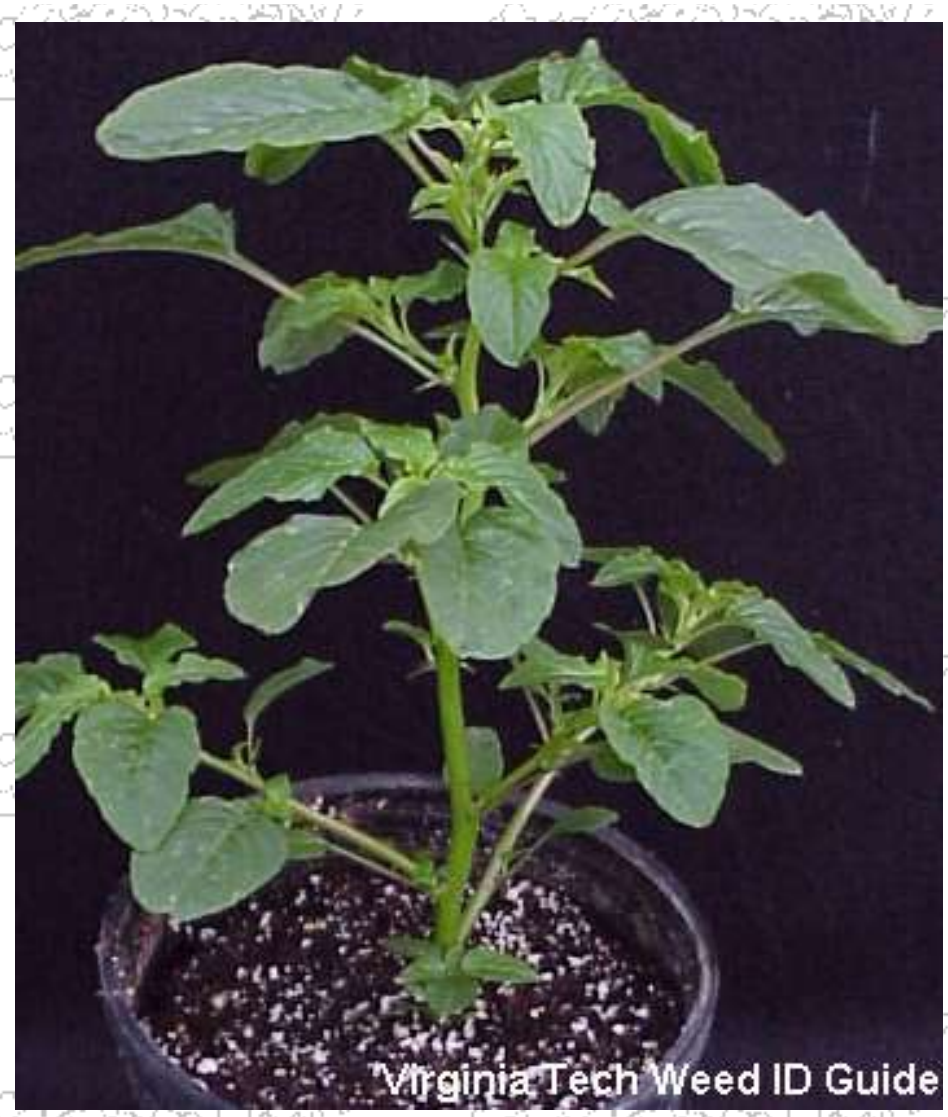
Virginia Tech Weed Identification Guide

Select a Resource...

Spiny Amaranth or Spiny Pigweed: *Amaranthus spinosus*

Weed Description: A summer annual that is very similar in appearance to other pigweeds but has spines along the stems. Spiny amaranth is primarily a weed of pastures and hay fields, and occurs less often in agronomic crops and turfgrass. Spiny amaranth is found throughout the eastern half of the United States.

Seedling: Stems below the cotyledons (hypocotyls) are usually reddish in color but sometimes green, without hairs. Cotyledons are without hairs, long and narrow.



Leaves: **Alternately arranged along the stem, ovate in outline. Leaves are approximately 1 1/4 to 2 1/2 inches long, without hairs, and occur on long petioles.**

Stems: **Erect, branching, without hairs, reaching 5 1/2 feet in height. A pair of spines that are from 5 to 10 mm long occurs at the base of most of the leaf petioles.**

Flowers: Seedheads occur at the ends of stems and also in small clusters in the area where the leaf petioles meet the stem (leaf axils).

Fruit: An utricle that is 1 1/2 to 2 mm long.

Identifying Characteristics: Plants that resemble most other pigweed species but with pairs of spines at the base of the leaf petiole and the central stem. The spines of spiny amaranth help to distinguish it from all other closely related pigweed species, like Redroot Pigweed (*Amaranthus retroflexus*), Palmer Amaranth (*Amaranthus palmeri*), and smooth pigweed. This weed may also be confused with Spiny Cocklebur (*Xanthium spinosum*) however the spines of this weed are 3-parted unlike those of spiny amaranth.


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Spiny Cocklebur: *Xanthium spinosum*

Weed Description:
A summer annual with 3-parted spines that arise at the base of each leaf and the characteristic 'cocklebur' fruit. Spiny cocklebur is found throughout the southern United States. It is primarily a weed of agronomic crops, nurseries, and pastures.

Seedlings:
The stem below the cotyledons (hypocotyl) is purple at the base and often green in the upper portion. Cotyledons are linear to lanceolate in outline, waxy,

smooth, fleshy, and thick.

Leaves:
Arranged alternately along the stem, approximately 1 to 2 1/2 inches long, 5 to 25 mm wide. Leaves are lance-shaped in outline with irregular lobes or teeth along the margin. Leaves are without hairs above, but have many soft white hairs below and have conspicuous white veins on the upper leaf surfaces. Leaves occur on petioles that range from 1/4 to 1 inch in length. A very distinctive yellow 3-parted spine (1/2 to 1 inch long) occurs at the base of each leaf petiole.

Flowers: **Inconspicuous, greenish in color, arising from the area between the leaf petioles and the stems (axillary flowers) and at the ends of the erect stems (terminal flowers).**

Fruit: **An elliptic to egg-shaped two-chambered bur, 1/2 to 1 1/2 inches long and covered with hooked prickles. Each bur contains two seeds, one that grows during the first year and one that grows a year later.**

Stems: **Erect, branched, slender, hairy, reaching as much as 3 1/2 feet in height.**

Roots: **A taproot.**

Identifying Characteristics:

The relatively large, linear to oblong waxy cotyledons helps to distinguish this weed from most other species when in the early stages of development. Additionally, the lance-shaped leaves, yellow 3-parted spines, and distinctive prickly cocklebur fruit are all features that help in the identification of this weed. Common Cocklebur (*Xanthium strumarium*) is a closely related and similar species, however, unlike spiny cocklebur, this weed does not have the very distinctive 3-parted spines that arise at the base of each leaf. This weed has also been confuse with Spiny Amaranth (*Amaranthus spinosus*), however the spines of this weed are not 3-parted as in spiny cocklebur.

Common Cocklebur: *Xanthium strumarium*

Weed Description: **A summer annual that produces a conspicuous prickly 'cocklebur' and ranges from 1/2 to 6 1/2 feet in height. Common cocklebur is found throughout the United States and is primarily a weed of agronomic and horticultural crops, nurseries, and occasionally pastures.**

Seedlings: **The stem below the cotyledons (hypocotyl) is purple at the base and often green in the upper portion. Cotyledons are linear to oblong in outline, waxy, smooth, fleshy, thick, approximately 3/4 to1 3/4 inches long and usually no more than 1/2 inch wide. The first true leaves are opposite, while all subsequent leaves are alternate.**

Leaves: **The first true leaves are opposite, all subsequent leaves are alternate. Leaves are triangular to ovate in outline, have stiff hairs, and are approximately 2 to 6 inches long. Leave are irregularly lobed with leaf margins that have relatively inconspicuous teeth. Leaves occur on long petioles and also**

have three prominent veins on the upper surface of the leaf that arise from the same point.

Stems: **Erect, branched, stout and covered with a dense cover of short stiff ascending hairs and 'bumps'. Stems are ridged longitudinally and green with maroon to black spots. Stems may reach 6 1/2 feet in height.**

Roots: A taproot.

Flowers: Inconspicuous, greenish in color, arising from the area between the leaf petioles and the stems (axillary flowers) and at the ends of the erect stems (terminal flowers).

Fruit: An elliptic to egg-shaped two-chambered bur, 1/2 to 1 1/2 inches long and covered with hooked prickles. Each bur contains two seeds, one that grows during the first year and one that grows a year later. Two prickles that are longer and wider than the remaining prickles project from the tip of the bur.

Identifying Characteristics: The relatively large, linear to oblong waxy cotyledons helps to distinguish this weed in the early stages of development. Additionally, the long-petiolated triangular leaves, stems with maroon to black stem lesions, and the distinctive prickly cocklebur fruit are all features that help in the identification of this weed. In the early stages of development, this weed might be confused with Giant Ragweed (*Ambrosia trifida*), however the cotyledons of common cocklebur are much longer and more linear than those of giant ragweed. Spiny Cocklebur (*Xanthium spinosum*) is a closely related and similar species, however, unlike common cocklebur, this weed has very distinctive 3-parted

spines that arise at the base of each leaf.

Virginia Tech Weed Identification Guide

Select a Resource...

Giant Ragweed: *Ambrosia trifida*

Weed Description: **Erect summer annual that may reach 16 feet in height. Leaves are large and distinctively 3-lobed, or less often 5-lobed. Primarily a weed of agronomic crops that thrives in fertile soils. Found throughout the U.S. except the Pacific Coast, areas of the Southwest, and portions of Florida and Maine.**

Seedling: **Cotyledons round to oblong, thick, and 3-4 times larger than those of common ragweed. The stem below the cotyledon (hypocotyl) is often purple. The first pair of true leaves is unlobed and lanceolate in shape, with toothed margins.**

Roots: **Taproot.**

Stems: **Erect, freely branched, hairy.**

Leaves: **All leaves subsequent to the first pair of true leaves are 3-lobed, or less often 5-lobed. Lobes arise from the same point (palmately lobed), and each lobe is lanceolate in shape with toothed margins. Leaves are opposite, hairy, occur on long petioles and are large (4-8 inches wide by 6**

inches long).

Flowers: **Occur in long slender racemes at the ends of branches (male) or in the leaf axils of the upper leaves (female). Individual flowers are small and greenish.**

Fruit: **A large (6-12 mm long) black crown-shaped achene.**

Identifying Characteristics: **Large, 3-lobed leaves and crown-shaped achene. The first true unlobed leaves of giant ragweed may lead to the confusion of this weed with Common Cocklebur (*Xanthium strumarium*). However, the leaves of cocklebur are alternate.**

Virginia Tech Weed Identification Guide

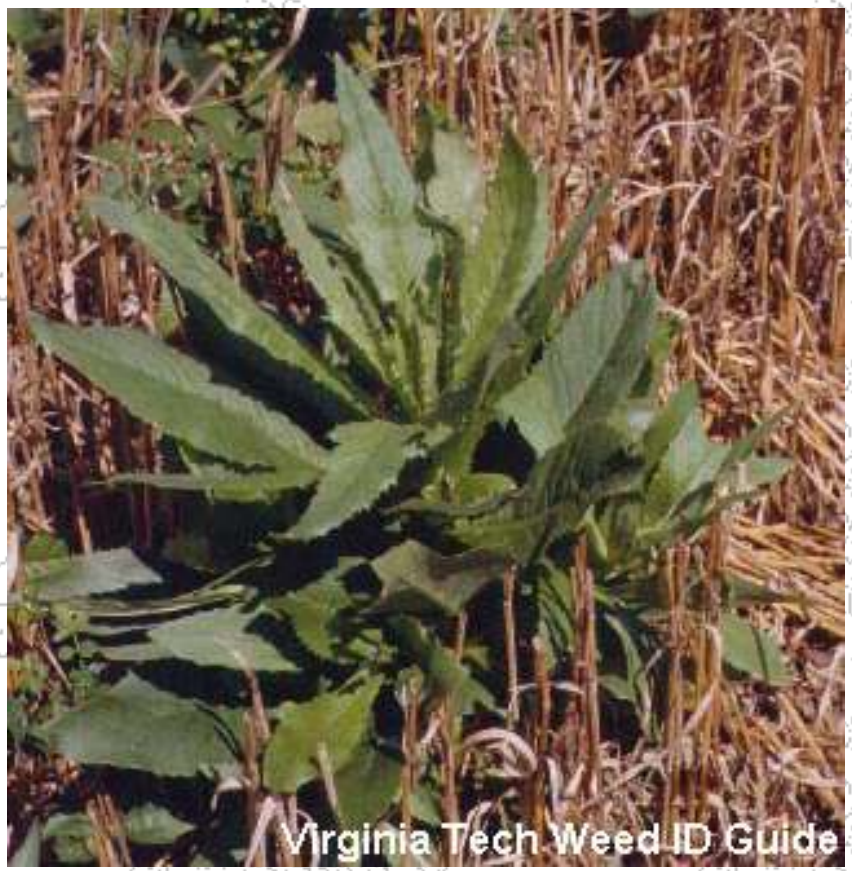
Select a Resource...

Fireweed or American Burnweed: *Erechtites hieracifolia*

Weed Description: **An erect summer annual with alternate, lanceolate leaves that have toothed margins. Fireweed is primarily a weed of pastures, abandoned fields, and some agronomic crops.**

Leaves: **Alternate, elliptic to lanceolate in outline, approximately 2 to 8 inches long, 1/2 to 2 1/2 inches wide. Leaves have a sharp-pointed apex (acute) and margins that are irregularly toothed.**

Stems: **Erect, solid, usually without hairs but occasionally slightly hairy. Stems may range from 1 1/3 to 10 feet in height.**



Flowers: **Flowers occur in panicles at the ends of stems. Individual flower heads are 3 to 10 mm wide, and cream to pinkish in color.**

Fruit: **A nutlet that contains many white pappus' that disperse the seed.**

Identifying Characteristics: **Erect plants with alternate, lanceolate leaves that have toothed margins. When mature, the feathery white seedheads are also key features of these plants.**

Elderberry or American Elder: *Sambucus canadensis*

Virginia Tech Weed Identification Guide

Select a Resource...

American Speedwell: *Veronica americana*

Weed Description:
Aquatic speedwells with attractive light blue flowers that are usually partly in and partly out of the water. American speedwell can be found in swamps or along the banks of streams and ponds. American speedwell is somewhat rare but can be found in Virginia, North Carolina, Tennessee, Kentucky, and West Virginia.

Stems: Growing prostrate along the ground with the flowering tips upright (decumbent growth habit). Stems may reach as much as 2 feet in length as they are capable of rooting at the nodes.

Leaves:
Generally oval to elliptic in outline, widest at the base and pointed at the tip. Leaves are approximately 3/4 to 2 1/2 inches long,

1/2 to 3/4 inch wide. Leaves are usually shallowly toothed and occur on short petioles. The leaves that occur on the upper flowering stems clasp the stem at their base.

Fruit: A capsule.

Flowers: Occur in clusters at the ends of the erect flowering stems. Flower clusters range from 2 to 6 inches in total length and contain many small light purple to light blue flowers. Each flower consists of 5 petals and is approximately 4 to 5 mm in total width.

Identifying Characteristics: The aquatic growth habit, oval to elliptic leaves with petioles, and small light blue flowers are all characteristics that help in the identification of American speedwell. Water speedwell (*Veronica anagallis-aquatica*) is very similar in appearance and growth habit, however this

species has leaves without petioles (sessile) unlike American speedwell. This weed may also be confused with Creeping Primrose (*Ludwigia palustris*), however this aquatic weed generally has some portion of the plant under water, often has red-tinged foliage, and does not have blue flowers.

Creeping Primrose: *Ludwigia palustris*

Weed Description:
A creeping aquatic weed that grows along shorelines, in shallow water, and less often submersed in shallow water.

Leaves:
Arranged oppositely along the stem, oval-shaped to elliptic in outline, approximately 1/2 to 1 inch long. The leaves of creeping primrose are highly variable in color, from green to slightly red-tinged or entirely red- or purple-tinged. Leaves are without hairs (glabrous).

Stems:
Creeping and rooting at the nodes.

Flowers: **Arise from the areas between the stems and the leaves (leaf axils) and are inconspicuous and without petals.**

Identifying Characteristics: **Aquatic plant primarily of shorelines with opposite leaves and stems that root at the nodes. Additionally, the red- or purple-tinged leaves that sometimes occur help in the identification of creeping primrose. Several other primrose species occur as aquatics, however creeping primrose is the species most commonly encountered.**

Virginia Tech Weed Identification Guide

Select a Resource...

American Water Plantain: *Alisma subcordatum*

Weed Description:
Aquatic perennial with erect or floating leaves. Found in shallow water, marsh areas, and pond and stream borders from Massachusetts to Minnesota and from Florida to Texas.

Leaves: **Oval or elliptic, approximately 1 1/4 to 8 inches long, 1 1/4 to 6 inches wide, and sharply pointed at the leaf apex (acute). Leaves have petioles that are often longer than the leaf blade.**

Flowers: **Occur on flowering stems (scapes) in panicles with whorled branches of flowers within each panicle. Flowering stems (scapes) range from 4 inches to 21 inches in height and are spreading. Petals are 1 to 2 mm long and pink in color.**

Fruit: **An achene approximately 1.5 to 2.5 mm long.**

Identifying Characteristics: **Aquatic plants that are found in shallow water and resemble the common plantain weeds often found in turfgrass and lawns.**

Virginia Tech Weed Identification Guide

Select a Resource...

Water Willow or American Water Willow: *Justicia americana*

Weed Description: **A perennial from rhizomes that is capable of forming large colonies. Water willow is primarily found along the shorelines or in shallow water of lakes, ponds, or streams.**

Leaves: **Arranged oppositely along the stem and are elliptic to linear in outline, approximately 6 inches long. Leaves have a distinctive white midvein that runs the length of the entire leaf.**

Stems: **May reach 2 1/2 feet in height and are stout with prominent white lines.**

Fruit: **A capsule that is approximately 1/2 inch long.**

Flowers: **Arranged oppositely on crowded spikes at the ends of long flower stalks (peduncles) that originate from the position between the leaf and the stem (leaf axils). Petals are white with purple tinges. Flowers have a distinctive lower lip that is approximately 3/4 inch long.**

Identifying Characteristics:

The linear leaves with a white midrib, the prominent white lines along the stems, and the colonizing growth habit along shorelines are all characteristics that help to distinguish water willow from most other shoreline plants.

Virginia Tech Weed Identification Guide

Select a Resource...

Annual Bluegrass: *Poa annua*

Weed Description: **An erect or clump-forming annual grass that tolerates close mowing, or may reach 11 inches in height. Primarily a weed of lawns and turfgrass, found throughout the United States.**

Leaves: **Light green in color, especially when compared to the dark green color of other closely related turfgrass species (for example Kentucky Bluegrass, *Poa pratensis*). Leaf blades are 0.5-5 inches long, 1-5 mm wide, folded in the bud and lack hairs on either surface. Leaves are 'keeled' and have a distinctive boat-shaped tip. The ligule is slightly pointed and membranous. Leaf sheaths are somewhat compressed and flattened, without hairs.**

Stems: **May be either erect or bending, and may root at the base of the tillers.**

Flowers: **The seedhead is an open panicle, 3/4 to 2.5 inches long, and pyrimidal in outline.**

Roots: **Fibrous.**

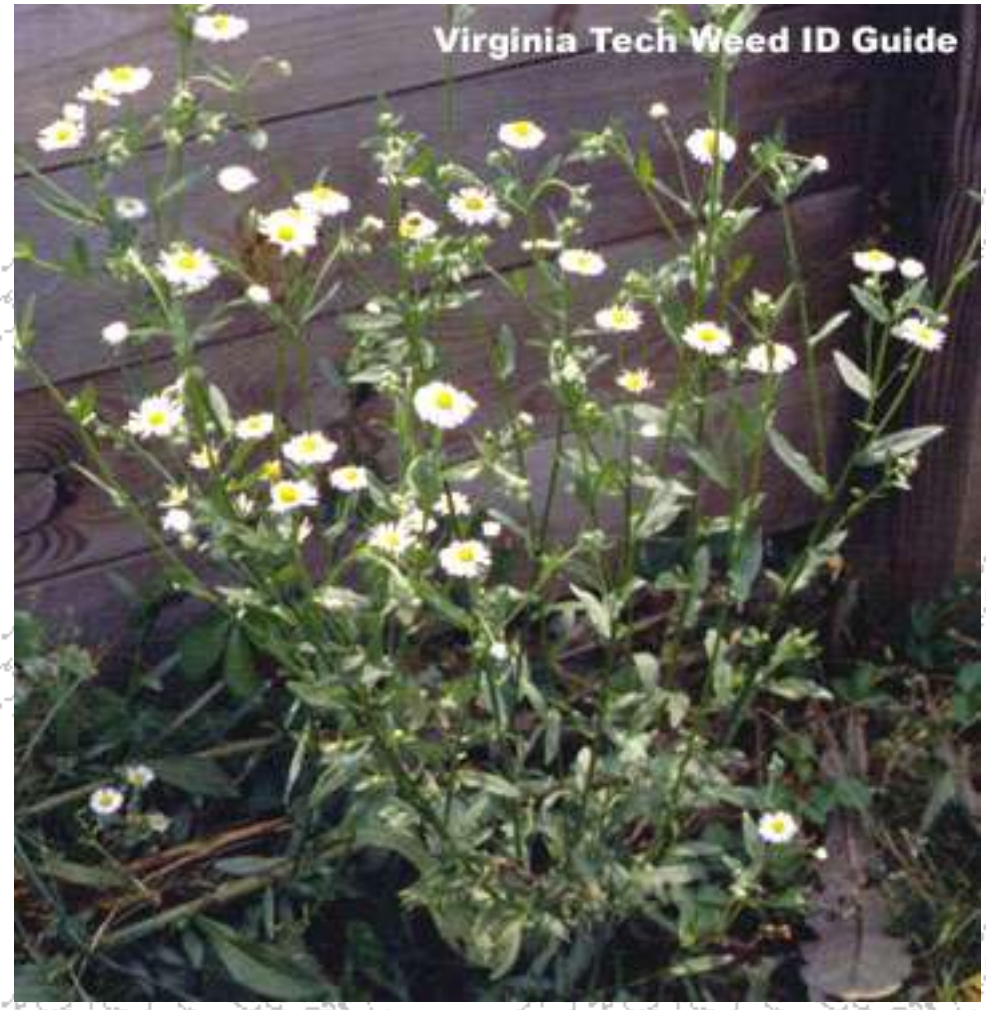
Identifying Characteristics: **Light green grass with a boat-shaped leaf tip that resembles other lawn and turfgrass species. This weed is very similar to Kentucky Bluegrass (*Poa pratensis*), but is much lighter in color and lacks rhizomes.**

Annual or Daisy Fleabane: *Erigeron annuus*

Weed Description: **A summer annual or sometimes biennial reaching 1 to 2 ft in height with prominent white and yellow flowers. Primarily a weed of abandoned fields or pastures, but occasionally associated with agronomic crops. Found throughout the southeastern United States.**

Leaves: **Occur mostly at the stem base. Basal leaves are egg-shaped (ovate) or widest near the middle and tapering to both ends (lanceolate), 2-6 inches long, 1-3 inches wide, and have petioles. Upper leaves are long and narrow (linear) or slightly lanceolate, much smaller than the basal leaves and may occur on short petioles or lack petioles. All leaves are prominently toothed and sparingly hairy.**

Stems: **Solid with many soft hairs.**



Flowers: **Arranged in clusters forming a flat-topped inflorescence, with the outer flowers opening first (corymb). Outer ray flowers are white or less often light purple, 5-10 mm long, with an inner core of yellow disc flowers.**

Identifying Characteristics: **Solid stem, white flowers with a yellow center, ovate-lanceolate basal leaves, linear-lanceolate upper leaves.**

Virginia Tech Weed Identification Guide

Select a Resource...

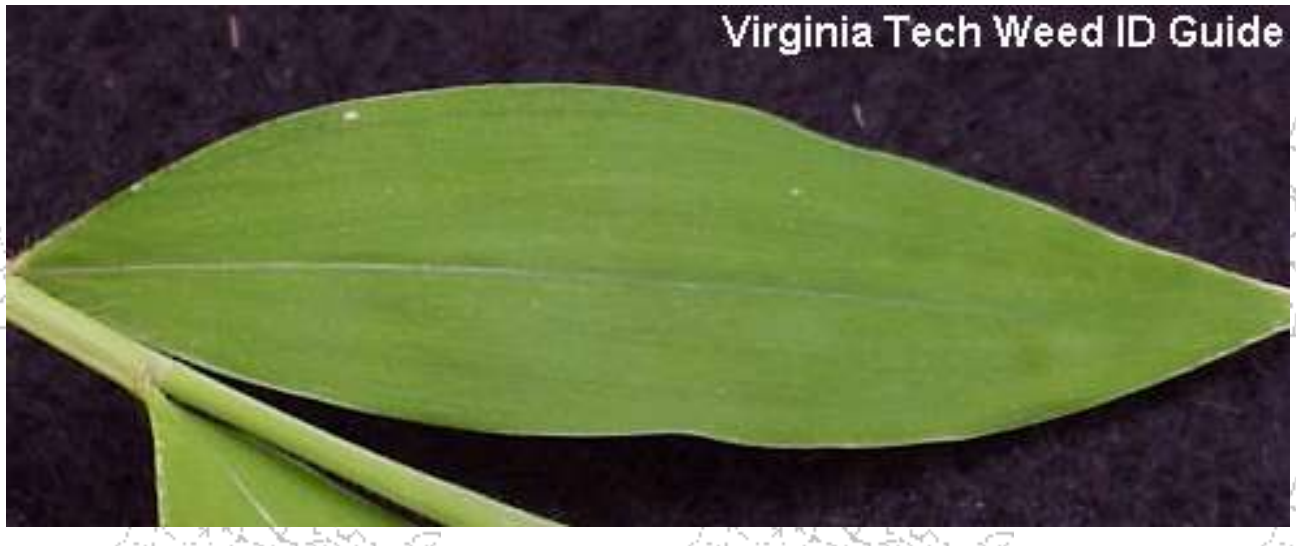
Annual Jewgrass, Basketgrass, Mary's Grass, or Microstegium:

Microstegium vimineum var. *imberbe*

Weed Description:

Prostrate to erect summer annual grass that thrives in shaded areas. This grass weed roots at the nodes and therefore may quickly spread into shaded areas like backyard lawns, ditches, roadsides, etc.

Leaves: **Rolled in the shoot, 3 to 10 mm wide, sparsely hairy on both surfaces. Most leaves have a distinct white midvein, however a key identifying feature of this grass is that the midvein does not divide the leaves into equal halves. For example, one side of the leaf separated by the midvein will be much larger than the other side of the leaf (shown in picture below). Leaves have a very short (0.2 mm), ciliate membranous ligule and no auricles.**



Stems: **Round, often hairy at the top, and capable of rooting at the nodes (shown in picture above).**

Roots: **A fibrous root system.**

Flowers: **Seedhead composed of 1 to 6 terminal spike branches.**

Identifying Characteristics: **Leaf shape and habitat (shade-loving) are the primary features that help to distinguish this grass from other grasses. Few, if any, grass weeds have a midvein that does not proportionally separate an individual leaf.**

Annual or Italian Ryegrass: *Lolium multiflorum*

Weed Description: **A winter annual that may reach 3 ft in height with conspicuous auricles and a distinctive seedhead. Found throughout the United States, primarily as a weed of small grains.**

Stems: **Leaf sheaths are often tinged red at the base.**

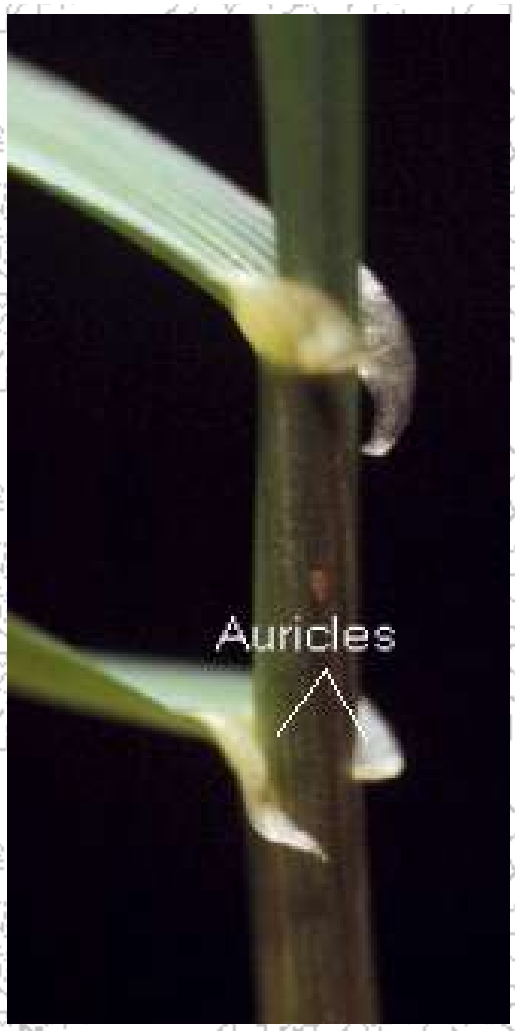
Leaves: **Rolled in the bud with conspicuous claw-like auricles in the collar region. Leaf blades are 2 1/2 to 8 inches long, 4-10 mm wide when mature, and have a membranous ligule. Leaves usually have a glossy**

appearance on the lower surfaces.

Roots: **Fibrous.**

Flowers: **The seedhead is a spike (4-16 inches long) with spikelets that have long awns arranged alternately up the stem.**

Identifying Characteristics: **The auricles that occur in the collar regions distinguishes this grass from other similar weeds, as relatively few grass weeds have this feature. Additionally, the red-tinged base of annual ryegrass helps to distinguish this weed from perennial ryegrass (*Lolium perenne*), which is very similar in growth habit and appearance.**


Auricles

Virginia Tech Weed Identification Guide

Select a Resource...

Annual Sowthistle: *Sonchus oleraceus*

Weed Description: **An annual with bluish-green leaves and stems that secretes a milky sap when cut. Found throughout the United States.**

Seedling: **Cotyledons egg-shaped and have petioles. Young leaves are alternate, egg-shaped, and form a rosette. Both young leaves and cotyledons have a whitish coating.**

Leaves:

Rosette leaves alternate, egg-shaped, with toothed margins. Stem leaves are alternate, without hairs, and have lobes that clasp the stem. Leaf

margins are toothed and only slightly prickly.

Roots: **Taproot.**

Stems:
Unbranched, 1-4 ft in height, and emit a milky sap when cut.

Flowers: **Several occur in clusters at the end of the stems, pale yellow, 1/4 to 3/4 inch wide.**

Fruit: **An achene. Mature seed have a white feathery pappus that collectively form a white "puff ball" similar to dandelion.**

Identifying Characteristics: **The leaves with very prickly margins that initially develop as a basal rosette and then occur alternately along the flowering stem, the bluish-green color of the leaves, and the yellow flowers with a 'puff-ball' seedhead are all characteristics that help in the identification of annual sowthistle. Spiny Sowthistle (*Sonchus asper*) is very similar in appearance, however this species has rounded lobes that clasp the stem whereas annual sowthistle has distinctly pointed lobes. Also, the leaf margins of spiny sowthistle are much more spiny or prickly than those of annual sowthistle. Both of the sowthistles can be distinguished from 'true' thistles by the milky sap they emit when broken. The sowthistles might also be confused with Prickly Lettuce (*Lactuca serriola*), however the midvein on the leaf undersides of this weed has distinct spines or prickles, whereas those of the sowthistles do not.**

Spiny Sowthistle: *Sonchus asper*

Weed Description: An annual that may reach as much as 6 feet in height with bluish-green leaves and stems that emit a milky sap when cut. Spiny sowthistle is primarily a weed of landscapes, winter small grains, pastures, hay fields, orchards, and roadsides. It is found throughout the United States.

Seedlings: Cotyledons are egg-shaped, approximately 3 to 8 mm long, and occur on petioles. Young leaves form a basal rosette. Both young leaves and cotyledons have a whitish coating.

Stems: **Unbranched, erect, reaching as much as 6 feet in height but generally around 2-3 feet in height. Stems emit a milky sap when broken.**

Leaves: **Leaves initially develop as a basal rosette and for this reason are often confused with thistles. All of the leaves are deeply cut with two rows of lateral appendages (pinnatifid), and range from 2 1/2 to 12 inches in length and 1/2 to 6 inches in width. Leaves are generally hairless (glabrous), egg-shaped in outline and have prickly margins. Leaves that occur on the flowering stem are are alternate and have rounded lobes that clasp the stem. Leaves emit a milky sap when broken.**

Roots: **A taproot.**

Flowers: **Occur in clusters at the ends of stems. Individual flowers range from 1/2 to 1 inch in diameter and are yellow in color.**

Fruit: **A brown, wrinkled achene approximately 4 mm long. Mature seed have a white feathery pappus that collectively form a white**

"puff ball" similar to that of dandelion.

Identifying Characteristics: The leaves with very prickly margins that initially develop as a basal rosette and then occur alternately along the flowering stem, the bluish-green color of the leaves, and the yellow flowers with a 'puff-ball' seedhead are all characteristics that help in the identification of spiny sowthistle. Annual Sowthistle (*Sonchus oleraceus*) is very similar in appearance, however this species has distinctly pointed lobes that clasp the stem whereas spiny sowthistle has rounded lobes. Also, the leaf margins of annual sowthistle are much less spiny or prickly than those of spiny sowthistle. Both of the sowthistles can be distinguished from 'true' thistles by the milky sap they emit when broken. The sowthistles might also be confused with Prickly Lettuce (*Lactuca serriola*), however the midvein on the leaf undersides of this weed has distinct spines

or prickles, whereas those of the sowthistles do not.

Virginia Tech Weed Identification Guide

Select a Resource...

Prickly Lettuce: *Lactuca serriola*

Identifying Characteristics:
An annual or biennial weed with prickly leaves that emit a milky sap when cut. Prickly lettuce is most commonly a weed of nurseries, orchards, roadsides, and agronomic crops and is found throughout the United States.

Seedlings: **Cotyledons are oval. Young leaves are also oval with spiny leaf margins and spines along the midvein of the lower leaf surface.**

Leaves: **Arranged alternately along the stem, ranging from 2 to 14 inches long. Most leaves are distinctly lobed and have leaf bases that clasp the stem. All leaves have prickles that occur along the leaf margins and along the midvein on the lower leaf surfaces. Leaves emit a milky sap when cut and become progressively smaller up the flowering stem.**

Stems: **Erect, hollow, light green to white, reaching 5 feet in height. One stem emerges from the central rosette and this stem then branches in the upper portions of the plant. Stems emit a milky sap when cut.**

Roots: **A taproot.**

Fruit: **An achene containing a single seed.**

Flowers: **Many flowers are produced in the upper portions of the plant that branches outwards and resembles a cone. Individual flowers are approximately 10 mm wide and are composed of 5 to 12 yellow toothed petals.**

Identifying Characteristics: **This weed has leaves with prickles along the margins and on the midveins of the lower leaf surfaces. Additionally, all parts of the plants emit a milky sap when cut. All of these characteristics help to distinguish prickly lettuce from similar species, such as Annual Sowthistle (*Sonchus oleraceus*) and other sowthistles.**

Virginia Tech Weed Identification Guide

Select a Resource...

Apple-of-Peru: *Nicandra physalodes*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide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Virginia Tech Weed Identification Guide

Select a Resource...

Long-beaked Arrowhead: *Sagittaria australis*

Weed Description: **A shallow perennial aquatic weed with leaves shaped like an arrow. Leaves are usually above the water, but sometimes may be under or floating on the water.**

Leaves: **Arrow-shaped, with the lobes turned downward (sagittate), 4-12 inches long. The leaves occur on petioles that may reach 3 feet in length. Distinct veins can be observed on the leaves that arise from a common point (palmate veination, illustrated in the picture below).**

Stems: **The flowers and fruit are produced on leafless stems (scapes) that may reach 1 1/2 to 3 feet in height.**

Fruit:
Egg-shaped achenes that are widest at the apex (obovate),

and approximately 2 inches in length. Several achenes may occur on each scape.

Flowers: **Usually consist of 3 sepals and 3 white petals that are 8-14 mm long.**

Roots: **A corm which is often a thickened base that resembles a bulb.**

Identifying Characteristics: **Arrow-shaped leaves with distinct palmate veination and scapes that are usually longer than the leaves.**

Virginia Tech Weed Identification Guide

Select a Resource...

Arrowleaf Sida: *Sida rhombifolia*

Weed Description: **A summer annual with yellow flowers and very small spines at the base of each leaf and branch. This plant most often occurs as a weed of peanuts, cotton, and soybeans in the southeastern United States from Virginia south to Florida and Texas.**

Seedlings: **Both cotyledons are generally heart-shaped with a small indentation at the cotyledon apexes. The first true leaves are widest above the middle and tapering toward the leaf base (rhombic in outline).**

Leaves: **Arranged alternately along the stem, approximately 3/4 to inches long, with petioles that are less than 1/3 the length of the leaves. Leaves are widest at or above the middle and taper toward the leaf bases (rhombic). The upper 1/2 of the leaves**

have toothed or serrated margins while the remainder of the leaves are untoothed. Petioles have small spines (stipules) that occur at their bases.

Fruit: A capsule.

Flowers: Occur singly on flower stalks (peduncles) that arise from the area between the stems and leaf petioles. Flowers consist of 5 yellow petals that are 4 to 8 mm long.

Stems: **Erect, branched, reaching as much as 3 1/3 feet in height. Stems are covered with hairs and also have short spines (stipules) at the base of each leaf petiole.**

Roots: **A taproot.**

Identifying Characteristics: **The seedlings with 2 heart-shaped cotyledons, the small spines that occur at the base of each leaf petiole, and the 'rhombic' leaves are all characteristics that help in the identification of arrowleaf sida. Velvetleaf (*Abutilon thophrasti*), Spurred Anoda (*Anoda cristata*), and Prickly Sida (*Sida spinosa*) seedlings are very similar to those of arrowleaf sida. However, arrowleaf and prickly sida have 2 heart-shaped cotyledons unlike the round and heart-shaped cotyledons of velvetleaf. Spurred anoda also has two heart-shaped cotyledons like arrowleaf and prickly sida, however the first true leaf of spurred anoda is not as coarsely toothed as that of arrowleaf or prickly sida. The cotyledons of arrowleaf sida are essentially identical to those of prickly sida, however the first true leaf of arrowleaf sida is rhombic in outline and tapers to the base unlike the first true leaf of prickly sida.**

Velvetleaf: *Abutilon theophrasti*

Weed Description: **Erect summer annual with leaves and stems that are covered with hairs. Primarily a weed of agronomic crops found throughout most of the United States.**

Seedling: **Stems below the cotyledons (hypocotyls) are covered with soft hairs. Seedlings have one round and one heart-shaped cotyledon, and cotyledons are also covered with short, soft hairs. The first true leaves are alternate,**

heart-shaped, covered with hairs on both surfaces, and have toothed margins.

Leaves:
Alternate, heart-shaped, and gradually tapering to a point (acuminate). Leaves are approximately 2 to 6 inches long and wide, densely hairy on both surfaces, and have toothed margins. Leaf veins originate from a common point (palmate venation), and leaves emit an unpleasant

odor when crushed.

Roots: A taproot and fibrous root system.

Stems: **Erect, reaching 7 feet in height. Stems are also covered with soft hairs, are mostly unbranched, and also emit an unpleasant odor when crushed.**

Flowers: **Produced on short flower stalks (pedicels) in the upper portions of the plant between the stems and the leaf petioles (leaf axils). Flowers are solitary, approximately 1/2 to 1 inch wide, and consist of 5 orange-yellow petals.**

Fruit: **A circular capsule reaching about 1 inch in diameter. Each capsule contains a ring of 'prickles' around the upper edge.**

Identifying Characteristics:

Seedlings with 1 round and 1 heart-shaped cotyledon, plants covered with short, soft hairs, and plants that emit an unpleasant odor when crushed. Prickly Sida (*Sida spinosa*) seedlings are often confused with those of velvetleaf, however this weed has 2 heart-shaped cotyledons unlike the round and heart-shaped cotyledons of velvetleaf. Spurred Anoda (*Anoda cristata*) seedlings are also very similar to velvetleaf, however the first true leaves of spurred anoda are much more coarsely toothed than those of velvetleaf.

Virginia Tech Weed Identification Guide

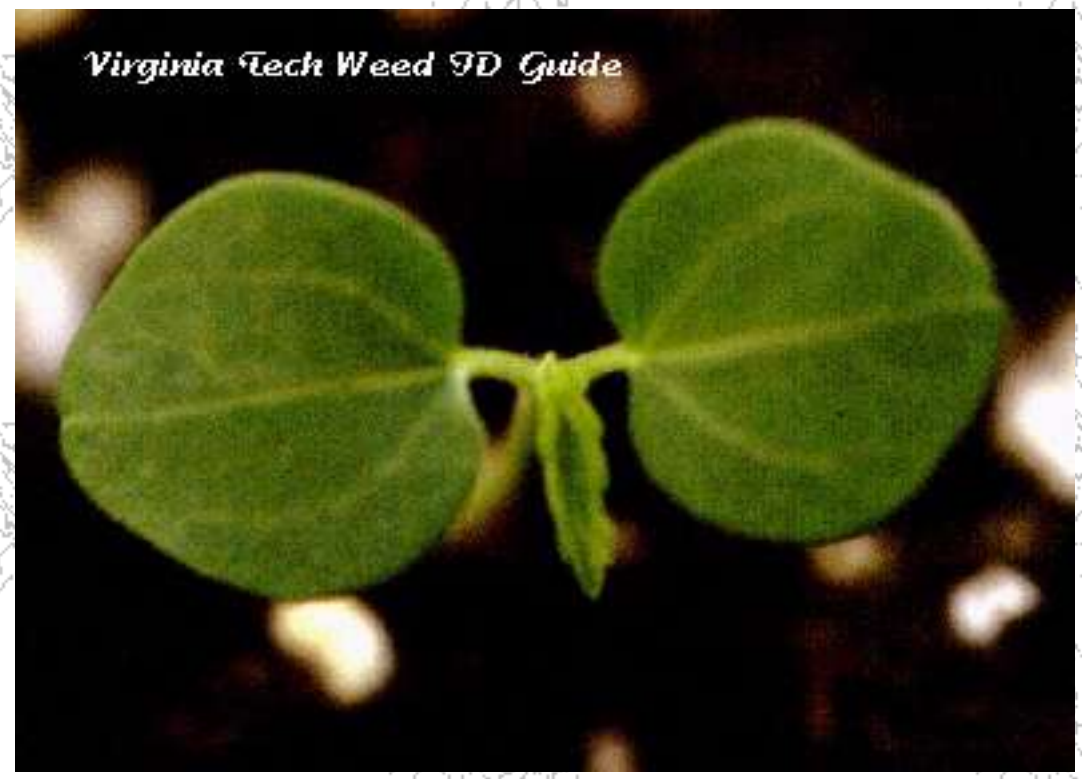
Select a Resource...

Prickly Sida or Teaweed: *Sida spinosa*

Weed Description: **A summer annual with yellow flowers and very small spines at the base of each leaf and branch. This weed is one of the ten most common and troublesome weeds in peanuts, cotton, and soybeans in most of the southern states. Prickly sida is primarily a weed of agronomic crops, but can also be found in horticultural crops, landscapes, pastures, hay fields, and gardens.**

Seedlings: **Both cotyledons are generally heart-shaped with a small indentation at the cotyledon apexes. The cotyledons and the stems below the cotyledons (hypocotyls) are covered with short hairs.**

Leaves: **Arranged alternately along the stem, approximately 3/4 to 2 inches long, and inconspicuously hairy. Leaves are oval to lanceolate in outline with toothed margins. Leaves occur on petioles that are 1/2 to 1 1/4 inches long and have small spines (stipules) that are 5 to 8 mm long at the base of each leaf petiole.**



Stems: **Erect, branched, ranging from 8 to 20 inches in height. Stems also have hairs.**

Roots: **A taproot and a fibrous root system.**

Flowers: **Occur singly or in clusters on flower stalks (peduncles) that arise from the area between the stems and leaf petioles. Flowers consist of 5 yellow petals that are 4 to 6 mm long.**

Identifying Characteristics: **The seedlings with 2 heart-shaped cotyledons, and the small spines that occur at the base of each leaf petiole are both features that help in the identification of prickly sida. Velvetleaf (*Abutilon thophrasti*), Spurred Anoda (*Anoda cristata*), and Arrowleaf Sida (*Sida rhombifolia*) seedlings are very similar to those of prickly sida. However, prickly and arrowleaf sida have 2 heart-shaped cotyledons unlike the round and heart-shaped cotyledons of velvetleaf. Spurred anoda also has two heart-shaped cotyledons like prickly and arrowleaf sida, however the first true leaf of spurred anoda is not as coarsely toothed as that of prickly or arrowleaf sida. The cotyledons of arrowleaf sida are essentially identical to those of prickly sida, however the first true leaf of arrowleaf sida is rhombic in outline and tapers to the base unlike the first true leaf of prickly sida.**

Virginia Tech Weed Identification Guide

Select a Resource...

Spurred Anoda: *Anoda cristata*

Weed Description: **Erect annual with alternate, triangular-shaped leaves that are coarsely toothed. Spurred anoda is freely branching from the base and may reach 3 1/2 feet in height. Primarily a weed of agronomic crops found in the southern United States.**

Seedling: **Stems below the cotyledons (hypocotyls) are green and covered with hairs. Seedlings generally have one round and one heart-shaped cotyledon with hairs along the margins. First true leaves are alternate, triangular-shaped, and hairy along the margins and on both leaf surfaces.**

Leaves: **Alternate, hairy on both surfaces, approximately 2 to 4 inches long, and triangular in outline. Leaves are coarsely toothed and have three distinct lobes. Leaf petioles often have stipules at the base.**

Stems: **Erect, reaching 3 1/2 feet in height, and branching, especially at the base. Stems are covered with hairs and are often ridged in the upper portions of the plant.**

Roots: **A taproot.**

Flowers: **Solitary flowers arise from the area between the petioles and the stem (leaf axils). Flowers are 7 to 12 mm wide with petals that are light blue to lavender in color.**

Fruit: **A capsule containing 10 to 20 segments each with one 2.8 to 3.2 mm long kidney-shaped brown or black seed.**

Identifying Characteristics: **Seedlings with 1 round and 1 heart-shaped cotyledon, and plants with triangular-shaped, coarsely-toothed leaves. Prickly Sida (*Sida spinosa*) seedlings are often confused with those of spurred anoda, however this weed has 2 heart-shaped cotyledons unlike the round and heart-shaped cotyledons of spurred anoda. Velvetleaf (*Abutilon theophrasti*) seedlings are also very similar to spurred anoda, however the first true leaves of spurred anoda are much more coarsely toothed than those of velvetleaf.**


Virginia Tech Weed ID Guide

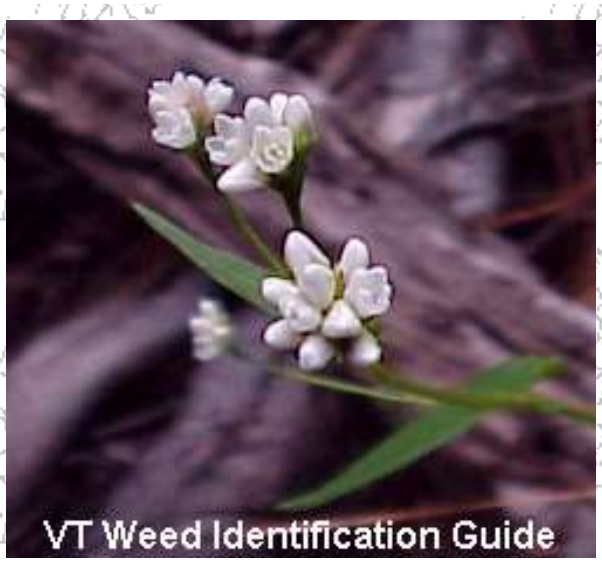
Virginia Tech Weed Identification Guide

Select a Resource...

Arrow-leaved Tearthumb: *Polygonum sagittatum*

Weed Description: **A branched annual with arrow-shaped leaves and stems with many prickles that are turned backward. Arrow-leaved tearthumb primarily occurs as an aquatic weeds of shorelines, marshes, and swamps.**

Leaves: **Without hairs, approximately 1 1/4 to 3 inches long, overall arrow-shaped in appearance. Leaf bases often encircle the stem and give the leaves even more of an arrowhead appearance.**



Stems: **Branching, with many prickles turned oppositely (retrorsely barbed) from the direction of the stem.**

Flowers: **Occur in small clusters at the ends of branches. Flowers are white to pink in color and occur on the ends of leafless flower stalks (peduncles).**

Fruit: **A brown to black nutlet.**

Identifying Characteristics: **The arrow-shaped leaves and prickly stems helps to distinguish arrow-leaved tearthumb from most other aquatic shoreline weeds. However, Tearthumb (*Polygonum arifolium*) is very similar in appearance and growth habit but has much larger hairy leaves with lobes that point outward unlike those of arrow-leaved tearthumb.**

Virginia Tech Weed Identification Guide

Select a Resource...

Tearthumb: *Polygonum arifolium*

Weed Description:
A branched annual with arrow-shaped leaves and stems with many prickles that are turned backward. Tearthumb primarily occurs as an aquatic weeds of shorelines, marshes, and swamps.

Leaves:
Leaves are arrow-shaped, but with the basal lobes pointing outward (hastate). Leaves are hairy, approximately 4 to 4 1/2 inches long, and occur on petioles that

range from 1 1/4 to 4 1/2 inches in length.

Stems: **Branching, with many prickles turned oppositely (retrorsely barbed) from the direction of the stem.**

Flowers: **Occur in terminal spikes at the ends of branches with each spike containing 2 to 4 flowers. Flowers are white to pink in color and occur on the ends of leafless flower stalks (peduncles).**

Fruit: **A reddish brown, globular nutlet.**

Identifying Characteristics: **The arrow-shaped leaves with bases that point outward and prickly stems help to distinguish tearthumb from most other aquatic shoreline weeds. However, Arrow-leaved Tearthumb (*Polygonum sagittatum*) is very similar in appearance and growth habit but has much smaller, hairless leaves with lobes that encircle the stem unlike those of tearthumb.**

Virginia Tech Weed Identification Guide

Select a Resource...

Jointhead Arthraxon: *Arthraxon hispidus*

Weed Description:

A low-growing annual grass with short, wide leaves. Jointhead arthraxon is primarily a weed of pastures, hay fields, and ditches found primarily in the piedmont areas of North Carolina, Virginia, Georgia, Florida, Alabama, Mississippi, and Tennessee.

Leaves: **Leaves are broad and taper to a point, approximately 2 1/2 inches long by 3/4 inches wide. Leaf bases encircle the sheath and have conspicuous hairs along the margins. Leaves are without auricles and have a thin membranous ligule (often with hairs) that is from 1 to 2 mm long.**

Flowers: **Many spikelets that resemble 'fingers'.**

Sheaths: **Low-growing, branching and rooting at the lower nodes. Sheaths are without hairs.**

Roots: **A fibrous root system with sheaths that root at the**

nodes.

Identifying Characteristics:
A low-growing grass with short, wide leaves with bases that encircle the stem and have hairs along the margins. This weed may be confused with Deer-Tongue Grass, but has spikelets instead of a panicled seedhead like that of deer tongue grass. Additionally, the leaves of deer-tongue grass are generally much longer than those of jointhead

arthraxon, and the stems of deer-tongue grass do not root at the nodes like those of jointhead arthraxon. Jointhead arthraxon may also be confused with Common or Asiatic Dayflower (*Commelina communis*), which also has broad grass-like leaves and a prostrate growth habit. The two can be distinguished by the presence of a distinct ligule on jointhead arthraxon, which is not present on common or asiatic dayflower.

Virginia Tech Weed Identification Guide

Select a Resource...

Deer-tongue Grass or Deer-tongue Panic Grass:

Panicum clandestinum or *Dichanthelium clandestinum*

Weed Description: A prostrate summer annual grass weed with leaves that resemble a "deer's tongue." Primarily a weed of pastures and hayfields in the mountainous and piedmont areas of the southeastern United States. This grass has traditionally been grouped in the genus *Panicum* but is now being classified by some as a *Dichanthelium*.

Leaves: **Blades reaching 7 1/2 inches long, 12 to 25 mm wide, without hairs (glabrous) on either surface. The bases of the leaf blades completely surround the sheath and are heart-shaped (cordate). Hairs may also be present on the leaf bases. Ligules reach 1 mm in length and are membranous but may occasionally also have a fringe of hairs (ciliate). Leaves are rolled in the shoot.**

Stems: **Reaching 4 inches in length, usually without hairs (glabrous) but nodes and internodes may occasionally have long, soft hairs.**

Roots: **A fibrous root system.**

Flowers: **A panicle that is typically 3 1/2 to 5 1/2 inches long and 2 1/2**

to 3 1/2 inches broad.

Identifying Characteristics:

The wide leaves and prostrate growth habit of deer-tongue grass make it fairly easy to distinguish from most other grass weeds. This weed may be confused with Jointhead Arthraxon (*Arthraxon hispidus*), but has a panicled seedhead unlike the spikelets of jointhead arthraxon. The leaves of deer-tongue grass are generally much longer than those of jointhead arthraxon, and the stems of deer-tongue grass do not root at the nodes like those of jointhead arthraxon. Deer-tongue grass may also be confused with Common or Asiatic Dayflower (*Commelina communis*), which also has broad grass-like leaves and a prostrate growth habit. The two can be

distinguished by the presence of a distinct ligule on deer-tongue grass, which is not present on common or asiatic dayflower.

Virginia Tech Weed Identification Guide

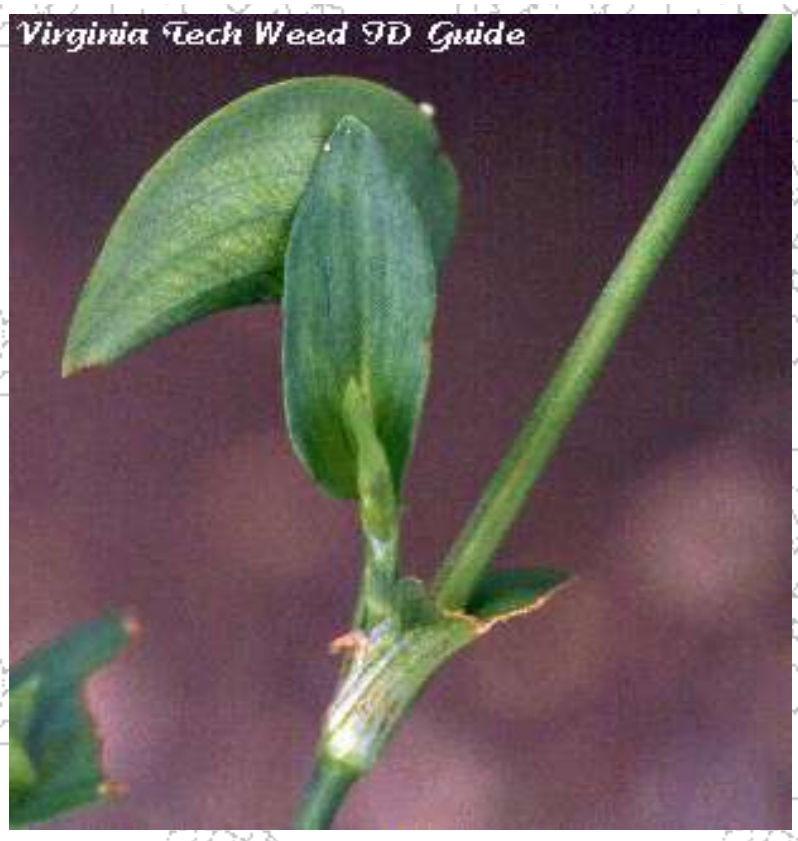
Select a Resource...

Common or Asiatic Dayflower: *Commelina communis*

Weed Description: **An erect or more often creeping annual monocot often mistaken for a broadleaf weed due to it's attractive blue flowers. Usually only found in shady and/or damp areas and most often a weed of landscapes and nursersies.**

Leaves: **Leaf blades are lanceolate in outline with parallel leaf veins and often have hairs on both the upper and lower surfaces. Leaves are 2-4 inches long, 2/3-1.5 inches wide, and lack petioles and ligules. Leaves clasp the stem at the base and hairs are often present in this area.**

Stems: **Thick, reaching 2 1/2 feet in length, swollen at the nodes, and often rooting when nodes come into contact with soil.**



Roots: **Fibrous root system and plants often root at the nodes when in contact with the soil.**

Flowers: **Occur on long flower stalks arising from the region between the stem and leaf (leaf axils). Flowers consist of 2 blue petals and 1 white petal. Each flower will appear for only one day.**

Fruit: **A two-celled capsule.**

Identifying Characteristics: **Prior to flowering, this weed is often misidentified as a common grass weed of landscapes or nurseries. For example, Deer-tongue Grass (*Panicum clandestinum*) is very similar to common dayflower in both appearance and growth habit. However, the lack of ligules and attractive blue and white flowers help to distinguish this weed from most grasses.**

Virginia Tech Weed Identification Guide

Select a Resource...

Jerusalem Artichoke: *Helianthus tuberosus*

Weed Description: **A troublesome perennial that resembles a sunflower and may reach as much as 10 feet in height. Jerusalem artichoke is primarily a weed of pastures, hayfields, roadsides, noncrop areas, nurseries, and landscapes. It is found throughout the eastern half of the United States and also along the Pacific coast.**

Leaves: **First true leaves are oppositely arranged and elliptic in outline. Leaves are covered with short hairs and are 4 to 10 inches long and 1 1/2 to 5 inches wide.**

Mature leaves become more lanceolate in outline and taper to a point. All leaves have toothed margins and occur on petioles. Upper leaves on the flowering stem are alternate unlike the lower leaves which are opposite.

Stems: **May reach 10 feet in height, are robust, and are covered with hairs.**

Flowers: **Bright yellow, showy flower heads are produced at the ends of the stems. Each flower head is approximately 2 inches in diameter and contains 8 to 20 outer yellow flowers (ray flowers) that enclose the dark yellow to brown disk flowers.**

Fruit: **An achene that may reach 8 mm in length.**

Roots: **Rhizomes that end in oval tubers that are relatively large and reddish in color. Jerusalem artichoke is sometimes grown for its edible tubers.**

Identifying Characteristics:

The robust stems, presence of tubers, and unique arrangement of leaves on the lower and upper portions of the plant are all characteristics that help to distinguish Jerusalem artichoke from most other weeds. Common sunflower and many other Helianthus spp. are very similar in appearance to Jerusalem artichoke, however none of these other species have tubers like Jerusalem artichoke.

Marsh Dayflower, Asian Dayflower, or Asian Spiderwort:

Murdannia keisak

Weed Description:
A succulent annual that is usually emersed and grows along stream banks, swamps, and along the edges of ponds and lakes. Found primarily in the piedmont and coastal plain regions of the southeastern United States.

Leaves:
Alternately arranged, lanceolate in outline, up to 3 inches long and 5 mm wide. The bases of the leaves clasp and surround the stems.

Stems:
Succulent, rooting at the nodes. Stems grow

prostrate along the ground and eventually ascend to approximately 18 inches in height.

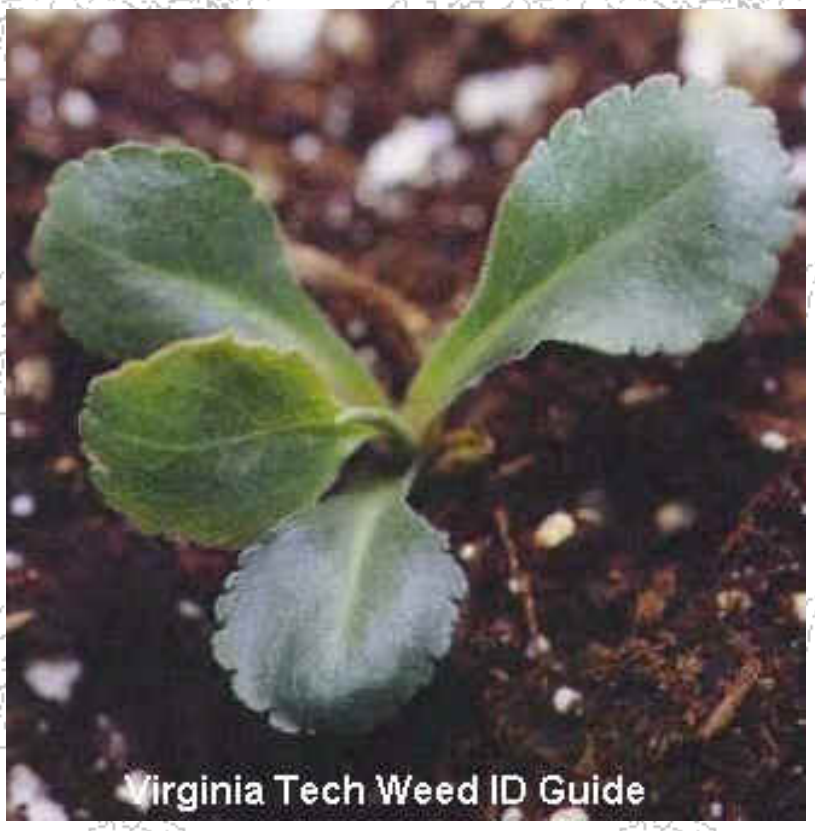
Fruit: A capsule that is approximately 1/3 inch long.

Flowers: The flowers occur at the ends of the stems or arise from the position between the stems and leaves (leaf axils). Flowers can occur singly or in clusters of 2 to 4. All flowers occur on short flower stalks (pedicels) and consist of 3 pink to purple petals that are approximately 1/3 inch long.

Identifying Characteristics:

Emersed aquatic plants that usually grow along the edges of ponds, lakes, or in marshes. Additionally, the stems that root at the nodes, lanceolate leaves, and flowers with 3 pink to purple flowers are all characteristics that help in the identification of marsh dayflower.

White Heath Aster: *Aster pilosus*



Weed Description: **A branching perennial with white and yellow flowers that may reach as much as 5 1/2 feet in height. Primarily a weed of pastures, forages, and noncrop areas, this weed may be found from New England south to northern Florida and west to Minnesota, Nebraska, Kansas, and Louisiana.**

Seedling: **Stems below the cotyledons (hypocotyls) are green or purple in color. Cotyledons are egg shaped and have relatively wide petioles. The first true leaves are alternate and without hairs. Seedlings are less common than sprouts from rhizomes.**

Roots: **Short rhizomes can or cannot occur on individual plants, but most plants have a basal crown of woody stems that facilitate vegetative reproduction. Fibrous roots originate from these woody stems.**

Stems: **Stems are erect, becoming woody, and branched especially in the upper portions.**

Leaves: **Basal leaves are lanceolate, upper leaves are linear and 3/4 to 4 inches long, 2 to 15 mm wide. Basal and upper leaves are without petioles (sessile) and feel rough to the touch (scabrous).**

Fruit: **A 1 mm long brown achene.**

Flowers:
Many flowers are produced in panicles at the end of stems. Individual flowers are about 3/4 inch in diameter and consist of outer white (ray) flowers and a yellow center (disk flowers). Approximately 20 to 30 white ray flowers occur on each flower.

Identifying Characteristics:
Perennial plants that are branched extensively in the upper portions and have many white and yellow flowers. The flowers and growth habit of Annual Fleabane (*Erigeron annuus*) are similar to white heath aster, however annual fleabane has more than 30 white ray flowers unlike white heath aster. White heath aster might also be confused with White Campion (*Silene alba*) in the early stages of growth, however white heath aster has more lanceolate leaves with slightly toothed margins unlike white campion.

White Campion: *Silene alba*

Weed Description: **Am erect or low-growing perennial with 'bladder-like' flowers. White campion is primarily a weed of pastures and hay fields, but may also occur along roadsides or in other forage crops. This weed occurs throughout most of the northern half of the United States.**

Seedlings: **Cotyledons are without petioles (sessile), oval in outline and taper to the base. Cotyledons are covered with many soft hairs. The first true leaves are opposite, oval-shaped, and hairy.**

Leaves: **Leaves initially develop as somewhat of a basal rosette. Basal leaves have short petioles but the majority of leaves (stem leaves) are without petioles. Leaf shape is somewhat variable, ranging from lanceolate to oval-shaped to relatively broad and elliptical. Leaves are approximately 1 1/4 to 4 1/2 inches long and 6 to 30 mm wide and hairy on both surfaces.**

Stems: **Erect or occasionally growing prostrate along the ground with the tips ascending (decumbent growth habit). Stems are also covered with many short, soft hairs.**

Roots: **A taproot along with lateral roots.**

Flowers: **Occur in clusters or singly on flower stalks (peduncles). Individual flowers consist of white petals (approximately 5) that are split or lobed and resembling a "V". Flowers also have a characteristic bladder-like case which are actually fused inflated sepals with 10 (male flowers) or 20 (female flowers) distinct veins.**

Fruit: **A capsule with 10 teeth.**

Identifying Characteristics:

The hairy, opposite leaves and lobed, bladder-like flowers are all characteristics that help in the identification of white campion. Bladder Campion (*Silene vulgaris*) is very similar in appearance and growth habit, but does not have hairs on the leaves like white campion. White campion might also be confused with White Heath Aster (*Aster pilosus*) in the early stages of growth, however this weed has more lanceolate leaves with slightly toothed margins unlike white campion.

Virginia Tech Weed Identification Guide

Select a Resource...

Bladder Campion: *Silene vulgaris*

Weed Description: **An erect or low-growing perennial from rhizomes with 'bladder-like' flowers. Bladder campion is primarily a weed of pastures and hay fields, but may also occur along roadsides or in other forage crops. This weed occurs throughout most of the United States.**

Seedlings: **Cotyledons are 3 to 12 mm long, 1 to 2 1/2 mm wide, elliptical in outline, without hairs, and yellowish green in color.**

Leaves: Initially develop as somewhat of a basal rosette. Leaves are ovate to lance-shaped, and are easily confused as the leaves of a grass when this occurs as a weed in grass forages. Leaves are approximately 1 1/4 to 3 inches long and are without hairs.

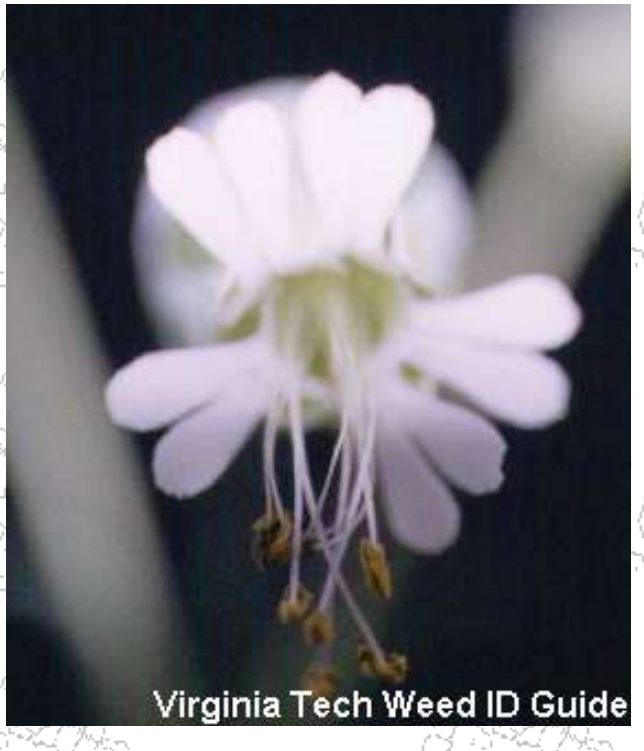
Stems: Erect, branching, reaching 3 1/3 feet in height. Stems are without hairs.

Roots: Rhizomes and a fibrous root system.

Fruit: **A round capsule within the 'bladder.' Each fruit is approximately 1/2 inch long.**

Flowers: **Occur in clusters of 5 to 30 white flowers that are each approximately 20 mm in width. Individual flowers consist of 5 white petals that are deeply lobed or split and resemble a "V". The flowers also have bladder-like cases which are actually fused inflated sepals with 20 distinct pink to white veins.**

Identifying Characteristics: **The hairless, opposite leaves and lobed, bladder-like flowers are all characteristics that help in the identification of bladder campion. White Campion (*Silene alba*) is very similar in appearance and growth habit, but has hairs on the leaves and stems unlike bladder campion.**


Virginia Tech Weed ID Guide

Autumn Olive: *Elaeagnus umbellata*

Weed Description:
A woody shrub that may reach up to 20 feet in height with yellow to cream colored flowers that appear in the spring and bunches of red berries that appear in the early fall. Autumn olive was introduced into the United States from east Asia in the 1830's and is now an invasive weed of pastures, hay fields, roadsides, and rights-of-way. Autumn olive is found from Maine to Virginia, and west to Wisconsin.

Leaves: **Alternate, elliptic to ovate in outline, approximately 1 1/4 to 3 inches long, 1/2 to 1 1/4 inches wide. Upper leaf surfaces are dark green while leaf undersides are covered with grayish or silver 'scales'. Leaf**

margins are often wavy (undulate) and are untoothed.

Stems:
Woody, branching, reaching 20 feet in height.

Flowers: **Occur in clusters of 5 to 10 in the region between the central stem and branches (axillary clusters). Individual flowers are approximately 1/2 inch long, are creamy white to yellow in color, and are also covered with silvery 'scales'.**

Fruit: **A red to pink berry, speckled with scales, and also occurs in axillary clusters throughout the plant.**

Identifying Characteristics: **Woody, invasive shrubs that have a silvery cast and conspicuous red berries. Autumn olive is similar in appearance to russian olive, but russian olive has leaves that are much more elliptic to lanceolate, and has branches that are usually thorny.**

Common Weed Names: B

Common Name	Scientific Name
Bachelor's Buttons	*Centaurea cyanus*
Balm, Field	*Calamintha nepeta*
Balloonvine	*Cardiospermum halicacabum*
Bamboo, Japanese	*Polygonum cuspidatum*
Barley, Little	*Hordeum pusillum*
Barnyardgrass	*Echinochloa crus-galli*
Basil, Wild	*Satureja vulgaris*
Basketgrass	*Microstegium vimineum*
Bear-grass	*Yucca filamentosa*
Bearsfoot	*Smallanthus uvedalia*
Bedstraw, Smooth	*Galium mollugo*
Bee-balm	*Monarda fistulosa*
Beef-steak Plant	*Perilla frutescens*
Beggarticks, Coreopsis	*Bidens polylepis*
Beggarticks, Devils	*Bidens frondosa*
Beggarweed, Florida	*Desmodium tortuosum*
Bergamot, Wild	*Monarda fistulosa*
Bermudagrass	*Cynodon dactylon*
Berry, Coral	*Symphoricarpos orbiculatus*
Bigroot Morningglory	*Ipomoea pandurata*
Bindweed, Field	*Convolvulus arvensis*

Bindweed, Hedge	*Calystegia sepium*
Birdsfoot Trefoil	*Lotus corniculatus*
Bittercress, Hairy	*Cardamine hirsuta*
Bittersweet Nightshade	*Solanum dulcamara*
Black Locust	*Robinia pseudoacacia*
Black Nightshade	*Solanum nigrum*
Black Medic	*Medicago lupulina*
Blackseed Plantain	*Plantago rugelii*
Bladder Campion	*Silene vulgaris*
Bladderworts	*Utricularia* spp.
Bloodroot	*Sanguinaria canadensis*
Blue-Bottles	*Muscari racemosum*
Bluegrass, Annual	*Poa annua*
Bluegrass, Roughstalk	*Poa trivialis*
Blue Phlox	*Phlox divaricata*
Blueweed	*Echium vulgare*
Bouncingbet	*Saponaria officinalis*
Brambles	*Rubus* spp.
Brazilian Elodea	*Egeria densa*
Brittleleaf Naiad	*Najas minor*
Broadleaf Dock	*Rumex obtusifolius*
Broadleaf Plantain	*Plantago major*
Broadleaf Signalgrass	*Brachiaria platyphylla*
Brome, Downy	*Bromus tectorum*

Broomsedge	*Andropogon virginicus*
Browntop Millet	*Brachiaria ramosa*
Buckbrush	*Symphoricarpos orbiculatus*
Buckhorn Plantain	*Plantago lanceolata*
Buckwheat, Wild	*Polygonum convolvulus*
Bulbous Tall Oatgrass	*Arrhenatherum elatius* var. *bulbosa*
Bull Thistle	*Cirsium vulgare*
Buffalobur	*Solanum rostratum*
Burcucumber	*Sicyos angulatus*
Burdock, Common	*Arctium minus*
Burweed, Lawn	*Soliva pterosperma*
Buttercup, Bulbous	*Ranunculus bulbosus*
Buttercup, Corn	*Ranunculus arvensis*
Buttercup, Smallflower	*Ranunculus abortivus*
Butterfly Milkweed	*Asclepias tuberosa*
Buttonweed, Common	*Diodia teres*
Buttonweed, Virginia	*Diodia virginiana*

Home

Cornflower or Bachelor's Buttons: *Centaurea cyanus*

Weed Description: **An erect winter annual with long white hairs and blue, white, or pink flowers. Plants may reach 3 ½ feet in height and primarily occur as weeds in winter small grains. Found throughout the eastern half of the United States and also from California north to Washington.**

Seedling: **Stems below the cotyledons (hypocotyls) are stout and without hairs (glabrous). Cotyledons are without hairs but the first true leaves have hairs and a grayish appearance.**

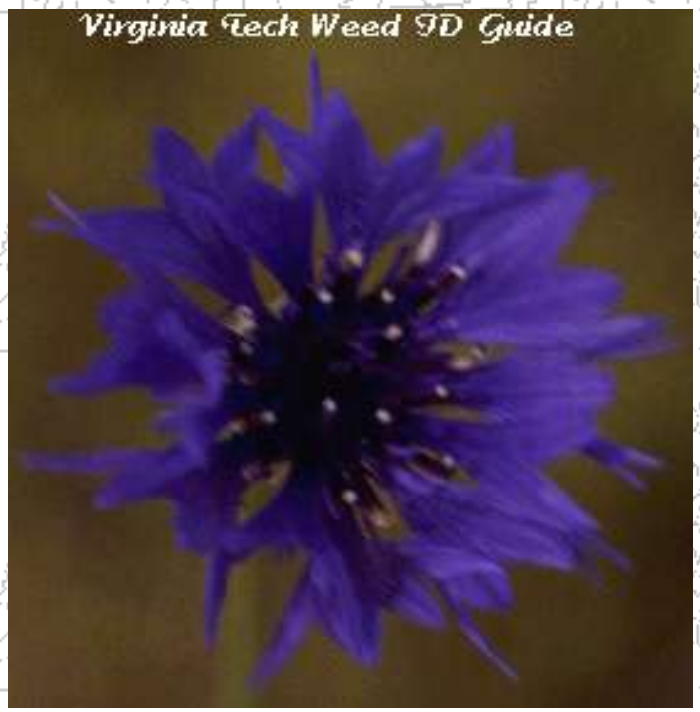
Leaves: **Leaves are narrow, approximately 2 to 6 inches long and ½ inch wide. Due to the leaf appearance, these plants are often confused for a grass. Leaves are alternate, linear in outline, and covered with long white hairs.**

Stems: **Erect, branching, and also covered with long white hairs.**

Roots: **Taproot.**

Fruit: **An achene that is approximately 4 mm long and 2 mm wide.**

Flowers: **Many solitary heads are produced on long flower stalks (pedicels). Individual flower heads are approximately 1 to 2 inches wide and blue to purple, white, or pink in color.**



Identifying Characteristics: **Winter annual with leaves and stems that are covered with long white hairs and leaves that resemble a grass. This weed is sometimes confused with both Spotted Knapweed (*Centaurea maculosa*) and corn cockle (*Agrostemma githago*). However, spotted knapweed forms a basal rosette of leaves during the first year of growth and its leaves are much more deeply lobed than those of cornflower. Additionally, the leaves of corn cockle are joined across the stem and the stems of this plant are swollen at the nodes whereas neither of these characteristics occurs with spotted knapweed or cornflower.**

Virginia Tech Weed Identification Guide

Select a Resource...

Spotted Knapweed or Star Thistle: *Centaurea maculosa*

Weed Description: **A biennial or occasionally perennial that forms a basal rosette during the first year of growth and produces a flowering stem during the second year. Spotted knapweed is primarily a weed of pastures, hayfields, roadsides, and sometimes turfgrass.**

Seedling: **Cotyledons round at the apex and narrowing to the base. The first true leaves are similar but narrow to a petiole.**

Leaves: **Leaves form a basal rosette during the first year of growth, are deeply lobed, and are approximately 6 inches long. Leaves that are produced on the flowering stems are alternate and finely dissected. Leaf surfaces often have inconspicuous short hairs but leaf margins have more noticeable tough hairs.**

Stems: **Flowering stems are slender and wiry, branching, and covered with downy hairs.**

Roots: **Taproot.**

Flowers: **Solitary flowers are produced at the ends of branches and are approximately 8 to 15 mm wide. Individual flowers are pink to purple in color and have a "cone" of bracts below.**

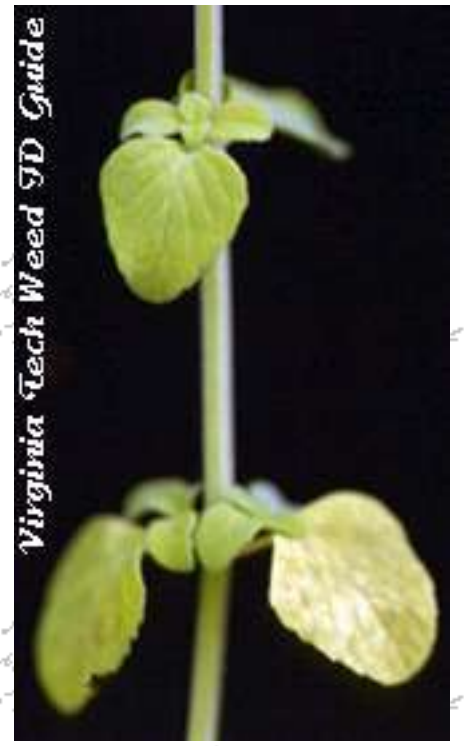
Fruit: **An achene that is light green to brown in color and approximately 3 mm long by 2 mm wide.**

Identifying Characteristics: **The finely dissected leaves and bracts below the pink to purple flowers help to distinguish this weed but this weed is commonly confused with both Cornflower (*Centaurea cyanus*) and corn cockle (*Agrostemma githago*). However, the rosette and flowering stem leaves of spotted knapweed are much more deeply lobed than those of cornflower or corn cockle. Additionally, the leaves of corn cockle are joined across the stem and the stems of this plant are swollen at the nodes, whereas neither of these characteristics occurs with cornflower or corn cockle.**

Virginia Tech Weed Identification Guide

Select a Resource...

Field Balm or Calamint: *Calamintha nepeta*



Weed Description: **A perennial herb with showy flowers and a distinctive minty odor. Primarily a weed of pastures, fields, and noncrop areas found from Maryland south to South Carolina and also in Alabama, Indiana, Kentucky, and Arkansas.**

Leaves: **Ovate in outline with the apex usually sharp-pointed (acute). The lower leaf margins are toothed along both edges. Lower leaves are ½ to 1 inch long, the upper leaves become progressively smaller up the stem. All leaves are arranged oppositely along the stem.**

Stems: **Stout, branched, and hairy.**

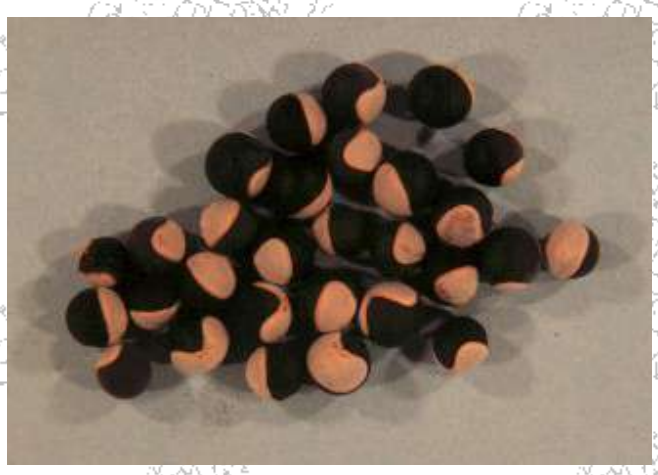
Flowers: **Individual flowers are about 4 mm long and light purple and/or white in color.**

Identifying Characteristics: **The distinctive minty smell and showy flowers help to distinguish this plant from most other weeds.**

Virginia Tech Weed Identification Guide

Select a Resource...

Balloonvine: *Cardiospermum halicacabum*



Virginia Tech Weed Identification Guide

Select a Resource...

Japanese Bamboo or Japanese Knotweed: *Polygonum cuspidatum*

Weed Description:
An invasive perennial that spread by rhizomes and seeds. Japanese knotweed can grow to a height of 13 feet, and has stems that resemble bamboo when mature. Japanese knotweed was introduced to the United States from Japan as an ornamental, and now occurs as a weed of riverbanks, landscapes, abandoned fields, or other moist areas.

Leaves:
Arranged alternately along the stem, egg-shaped in outline, approximately 4 to 6 inches long, 2 /12 to 4 1/4 inches wide. Leaf bases are essentially straight across (truncate).

Roots:
Rhizomes that are capable of producing new plants, often resulting in thick colonies of this species.

Stems:
Stout, hollow, jointed, resembling those of bamboo, especially in older plants. A thin membranous sheath (ocrea) encircles the stem at each joint. Stems may reach as much as 13 feet in height.

Flowers: **Occur in clusters (4 to 5 inches long) that arise from the area between the leaf petiole and the stem (leaf axils). Flowers are small and white in color.**

Fruit: **A nutlet.**

Identifying Characteristics: **The broad, egg-shaped leaves and stems that resemble bamboo are some of the key features of this plant. Giant knotweed (*Polygonum sachalinense*) also occurs in some of the northeastern states, but this weed generally has larger leaves than those of Japanese knotweed and leaves with heart-shaped leaf bases.**

Virginia Tech Weed Identification Guide

Select a Resource...

Little Barley: *Hordeum pusillum*

Weed Description: **A short winter annual grass that resembles barley or wheat when mature. Little barley rarely reaches more than 2 feet in height and may occur as a weed of pastures, hay fields, and roadsides in Virginia, Georgia, Florida, Alabama, Mississippi, Tennessee, and Kentucky.**

Stems: **Little barley ranges from 4 to 24 inches in height. Stems turn brown in the spring once this plant has matured. Leaf sheaths are round and usually without hairs but may occasionally have hairs present. The sheath also has split, overlapping, translucent (hyaline) margins.**

Leaves: **Leaves are rolled in the bud and without auricles. Leaf blades may reach as much as 8 inches in length and range from 1 1/2 to 6 mm in width. Leaves may be without hairs or may have short hairs above and below. Leaves have a membranous ligule that is cut squarely across the top and not tapered or rounded (truncate). Ligules are very small and usually range from 0.2 to 0.6 mm in length.**

Roots: **A fibrous root system.**

Flowers: **Seed heads consist of flattened spikes that also turn tan to brown when mature. Each spikelet contains awns that may range from 2 to 12 mm in length.**

Identifying Characteristics: **A small winter annual grass that generally has a bluish-green color like that of many winter small grains. Additionally, little barley turns distinctly tan to brown in color in the early spring when mature. These characteristics, along with the grain-like seedhead, help to distinguish little barley from most other winter annuals.**

Virginia Tech Weed Identification Guide

Select a Resource...

Barnyardgrass: *Echinochloa crus-galli*

Weed Description: **A summer annual with thick stems that may reach 5 feet in height. One of the few grass weeds in which ligules are absent. Found throughout the United States, Canada, and Mexico as a weed of many agronomic crops, nurseries, landscape, and turf.**

Seedling: **Leaves are without hairs (glabrous), auricles, and ligules, and the leaf sheaths are often tinted red or maroon at the base.**

Leaves: **Rolled in the shoot, smooth and without ligules or auricles. Leaves range from 4 to 20 inches in length and may be 5-30 mm wide. Leaves have a distinct white midvein that becomes keeled toward the basal potions of**

the leaf. A few short hairs may occur at the leaf bases.

Stems: **Usually erect, thick, without hairs (glabrous), often branched at the lower nodes, and may be tinted red to maroon at the base.**

Roots: **A fibrous root system.**

Flowers:
Seedhead a terminal panicle ranging from 4 to 16 inches in length. Panicles may be green to purple in color and are comprised of individual spikelets that may develop a 2 to 10

mm long terminal awn (picture on right).

Identifying Characteristics:
Prior to seedhead formation, Fall Panicum (*Panicum dichotomiflorum*) and barnyardgrass are often confused due to their similar growth habit and appearance. However, the characteristic absent ligule of barnyardgrass helps to distinguish this weed from most other grasses in both the seedling and mature stage of growth.

Fall Panicum: *Panicum dichotomiflorum*

Weed Description: **A summer annual with large round, smooth sheaths that are often bent at the nodes. This weed may reach 7 feet in height and is found throughout most of the United States in various agronomic and horticultural crops, turfgrass, nurseries, landscapes, and noncrop areas. A primary identifying characteristic of this grass weed is the 'zigzagged' growth pattern it takes on due to bending at the nodes.**

Seedling:

Fall panicum seedlings are much different from the mature plants in that the seedlings have many hairs on the lower surface of the leaf blades. Leaves are rolled in the shoot, the ligule is a fringe of hairs to 2 mm in length, and auricles are absent.

Leaves: **Rolled in the shoot, 15 to 20 mm wide, 4 to 20 inches long, and auricles are absent. The ligule is a fringe of hairs reaching 2 to 3 mm in length and is often fused at the base. Leaf blades have a conspicuous midvein and are smooth above but sometimes slightly hairy near the leaf tip or leaf base. The lower leaf surfaces of mature plants are without hairs (glabrous) and glossy.**

Stems: **Stems are without hairs (glabrous), round, and sometimes glossy. Nodes along the stem are usually swollen and bent in different directions, which contributes to the rather unusual growth habit of this weed.**

Roots: **A fibrous root system with stems that are capable of rooting at the nodes.**

Flowers: **The seedhead is a wide, spreading panicle that develops a purplish tint when mature. Individual spikelets are yellow and approximately 3 mm long by 2 mm wide.**

Identifying Characteristics: **Fall Panicum is often mistaken for Johnsongrass (*Sorghum halepense*) or Barnyardgrass (*Echinochloa crus-galli*) prior to seedhead formation. However, johnsongrass has a membranous ligule unlike that of fall panicum and johnsongrass seedlings also do not have hairs on the lower leaf surface like those of fall panicum. Additionally, barnyardgrass does not have a ligule at all and barnyardgrass seedlings might only have hairs near the leaf base.**
















Virginia Tech Weed Identification Guide

Select a Resource...

Johnsongrass: *Sorghum halepense*

Weed Description: **A perennial from rhizomes that may reach 6 1/2 feet in height. Johnsongrass is capable of rapidly colonizing a variety of different environments due to the large amounts of seed and rhizomes produced by this plant. Originally introduced as a forage crop, this weed is now one of the most common and troublesome weeds of most agronomic and horticultural crops, as well as roadsides, pastures, and hay fields. Found in the United States from Massachusetts to Iowa, south to Florida and Texas, and also in southern California.**

Seedling: **Leaves are rolled in the shoot, auricles are absent, and the ligule is membranous and may be toothed at the top. Leaf blades are without hairs (glabrous) on both surfaces and develop a prominent white midvein with maturity.**

Leaves: **Rolled in the shoot, without auricles, 6 to 20 inches long by 10 to 30 mm wide, with a prominent white midvein. Leaf blades are usually without hairs (glabrous) on both surfaces, however some hairs may be present at the base of the leaf blade. The ligules are 3 to 4 mm long, membranous, and often toothed at the top. With maturity, some ligules may develop a fringe of hairs in the upper portion of the ligule, and remain membranous towards the base.**

Stems: **Round to somewhat flattened, usually without hairs but sometimes hairs may be present along the margins. Sheaths may be green to maroon, especially near the base of the plant.**

Roots: **A fibrous root system and thick rhizomes.**

Flowers: **Seedhead a large, open panicle, often with a purplish tint. Seed are oval, 3 to 5 mm in length, and dark red to black at maturity.**

Identifying Characteristics: **Johnsongrass is often mistaken with Barnyardgrass (*Echinochloa crus-galli*) and/or Fall Panicum (*Panicum dichotomiflorum*) prior to seedhead formation. However, johnsongrass has a membranous ligule unlike that of fall panicum or barnyardgrass and johnsongrass seedlings do not have hairs on the lower leaf surface like those of fall panicum. Johnsongrass seedlings and mature plants also resemble shattercane (*Sorghum bicolor*), but shattercane does not have rhizomes like johnsongrass.**

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Basil: *Satureja vulgaris*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Yucca or Bear-grass: *Yucca filamentosa*

Weed Description: **A hearty perennial with thick strap-like leaves that may reach as much as 4 or 5 feet in height when flowering. American Indians often used the leaves of this plant to produce baskets. Yucca is often planted as an ornamental but may also be found in pastures, along roadsides, in non-crop areas, and around old homesteads.**

Roots: **Hearty thick rootstock with underground stems that are capable of producing new plants.**

Leaves:
Young seedlings and plants emerging early in the year from previous cutting may initially resemble a grass, but plants quickly develop into a basal rosette. Leaves are tough, thick, and may reach as much as 2 feet in length. Fibers often become noticeably separated from the edges of the leaves and become twisted, reaching as much as 3 or 4 inches in length.

Stems: **Upright, erect flowering stems are only produced late in the season when these plants begin to flower. Stems can reach as much as 4 or 5 feet in height in the mid-Atlantic United States, but the height of the flowering stem produced is largely dependant on climate. Stems do not contain leaves.**

Flowers: **Many (~12 to 24) showy white flowers occur on the erect flowering stem. Individual flowers range from 1 to 2 1/4 inches in length and occur on short flower stalks (pedicels) that attach to the flowering stem.**

Fruit: **A capsule 1 to 2 inches long and approximately 3/4 inch in diameter. Capsules contain many flattened black seed.**

Identifying Characteristics: **The rosette growth habit and tough, strap-like leaves with frayed margins helps to**

identify most yucca species. However, several different species occur throughout the United States.

Virginia Tech Weed Identification Guide

Select a Resource...

Yellow-flowered Leaf-cup or Bearsfoot: *Smallanthus uvedalia*

Weed Description: **A perennial that may reach as much as 10 feet in height, with lobed or dissected leaves that resemble a "bear's foot." Yellow-flowered leaf-cup is primarily a weed of pastures, hay fields, fencerows, and roadsides.**

Leaves: **Lobed or dissected, 4 to 12 inches in length and about as wide. Leaves are rough to the touch on the upper leaf surfaces. Leaves occur oppositely along the stem.**

Roots: **Thick, fleshy, perennial in nature. Stems arise from a basal crown.**

Stems: **Arising from a basal perennial crown. Stems are hollow and erect, ranging from 3 1/3 to 10 feet in height. Some stems also have purplish striations.**

Flowers: **Occur in clusters at the ends of the erect stems. Flowers occur on flower stalks (peduncles) and consist of yellow ray flowers that are approximately 3/4 to 1 inch in length.**

Fruit: **A round nutlet, 4 to 6 mm long.**

Identifying Characteristics:

The lobed or dissected leaves that resemble a "bear's foot", stems that are hollow and often with purple striations, and the yellow ray flowers that occur in clusters are all characteristics that help in the identification of yellow-flowered leaf-cup. Due to the tall, erect growth habit and yellow flowers, this weed may be confused with Jerusalem Artichoke (*Helianthus tuberosus*). However, jerusalem artichoke has hairy stems and leaves that are lanceolate in outline unlike yellow-flowered leaf-cup.

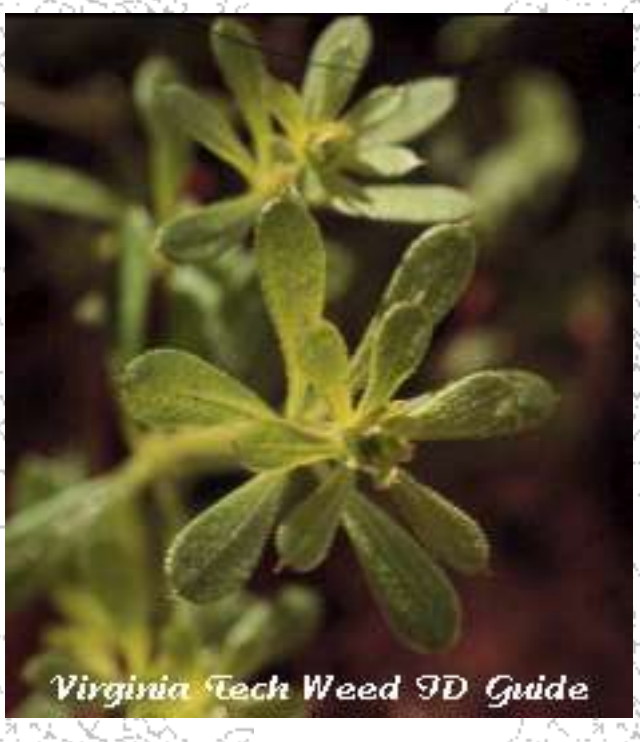
Virginia Tech Weed Identification Guide

Select a Resource...

Smooth Bedstraw: *Galium mollugo*

Weed Description:
A perennial with square stems and whorls of 6 to 8 leaves. Smooth bedstraw is primarily a weed of landscapes, nursery crops, turfgrass, and lawns that is found throughout the United States.

Seedling:
Plants normally spread via rhizomes and stolons therefore seedlings are rarely encountered. Cotyledons oval and occur on petioles that are notched at the apex.



Leaves: **Occur in whorls of 6 to 8. Leaves are without hairs but may occasionally have hairs along the margins. Leaves are approximately 1/2 to 1 1/4 inches long by 2 to 4 mm wide. Leaves are without petioles (sessile).**

Stems: **Stems are square in cross-section and without hairs.**

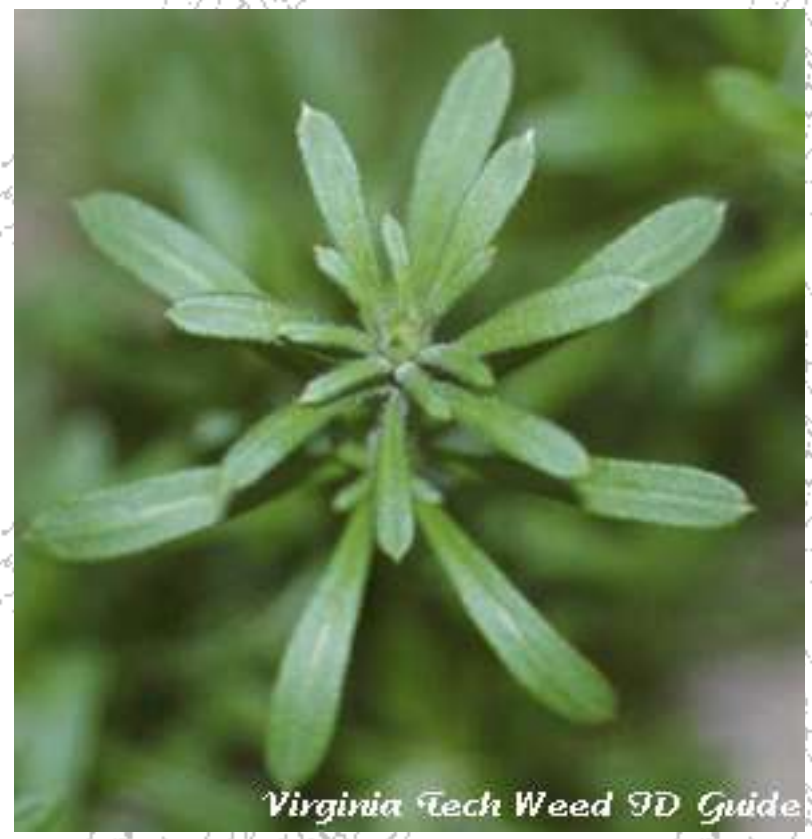
Roots: **Rhizomes and stolons occur.**

Flowers: **Produced in clusters on a flower stalk that arises from the area between the stem and leaves (leaf axils). Flowers consist of 4 white petals.**

Fruit: **A 2-parted capsule that separates at maturity.**

Identifying Characteristics:

The whorled leaves of this plant makes it easily distinguishable from most other weeds except catchweed bedstraw (*Galium aparine*) and Field Madder (*Sherardia arvensis*), which are both very similar in appearance and growth habit. However, catchweed bedstraw has hairs on the upper leaf surfaces and also has stems with tiny prickles. Additionally, catchweed bedstraw does not have rhizomes or stolons like smooth bedstraw. Field madder generally has smaller leaves than the bedstraws and the leaves occur in whorls of 4 to 6. The leaves of field madder are also more lanceolate and have much more of a distinct point than those of the bedstraw species.



Virginia Tech Weed Identification Guide

Select a Resource...

Field Madder: *Sherardia arvensis*

Weed Description: **A prostrate winter annual with whorled leaves, square stems, and pink to purple flowers. Field madder is primarily a weed of turfgrass, lawns, and occasionally winter small grains. This weed is distributed throughout the southern United States.**

Leaves: **Whorled with 4 to 6 leaves at each node. Leaves are lanceolate to elliptic in outline, approximately 5 to 15 mm long and 2 to 4 mm wide. Leaves taper to a distinct tip and are hairy.**

Stems: **May be either prostrate along the ground (typical), erect, or prostrate with some tips ascending. Stems are square in cross-section**

and also hairy.

Flowers: Occur in clusters at the ends of the stems. Individual flowers are 3 to 4 mm in length and pink to purple in color.

Identifying Characteristics: The square stems, whorled leaves, and pink to purple flowers are all characteristics that help in the identification of field madder. Field madder is often mistaken for either Smooth Bedstraw (*Galium mollugo*) or catchweed bedstraw (*Galium aparine*). However, the leaves of the bedstraws are generally larger and occur in whorls of 6 to 8 unlike field madder. Additionally, the leaves of field madder are more lanceolate and have much more of a distinct point than those of the bedstraw species.

Virginia Tech Weed Identification Guide

Select a Resource...

Bee-balm or Wild Bergamot: *Monarda fistulosa*

Weed Description: A perennial with attractive pink to purplish flowers that may reach 4 feet in height. Bee-balm or wild bergamot is most often viewed as a wildflower and actually sold as an ornamental. However, this plant can occur as a weed in some pasture and rangeland environments. Bee-balm or wild bergamot is found throughout the United States except in Florida and along the West coast.

Leaves: Leaves are generally lanceolate in outline with slighted toothed (serrated) leaf margins. Leaves may range from 1 1/2 to 4 1/2 inches in length.

Stems: May reach as much as 4 feet in height. Stems are often angled and contain hairs.

Flowers: Usually pink to purplish in color with distinctive bracts beneath.

Fruit: An

oblong mericarp.

Identifying Characteristics:

Perennial herbs with distinctive pink to purplish flowers (and aroma) and angled, pubescent stems.

Virginia Tech Weed Identification Guide

Select a Resource...

Perilla Mint or Beef-steak Plant: *Perilla frutescens*

Weed Description:
An erect herb with distinctive green or purplish-green leaves with toothed margins. These plants emit a distinctive minty odor, especially when mature. Perilla mint is primarily a weed of pastures, hay fields, fencerows, and roadsides. This plant is extremely toxic to all kinds of cattle, sheep, and horses.

Leaves:
Arranged oppositely along the stem, green in color, most often with a distinct purple tinge. Individual leaves are oval-shaped, approximately 2 to 5 inches long, 1 1/2 to 4 inches wide. Leaves occur on petioles, have distinctly toothed margins and emit a minty odor when crushed.

Stems:
Erect, from 1/2 to 2 feet in height.

Flowers: **Many flowers occur in terminal clusters giving the mature plant a 'bottle-brush' appearance. Individual flowers are small, white to whitish-purple in color, hairy, with an upper lip that is 3-toothed and a lower lip that is 2-toothed.**

Identifying Characteristics: **The distinctive minty odor and oval, green to purple leaves with toothed margins are all characteristics that help in the identification of perilla mint. Hophornbeam copperleaf (*Acalypha ostryifolia*) has similar leaves and growth**

habit, but does not have the characteristic minty odor and greenish purple leaves like those of perilla mint.

Virginia Tech Weed Identification Guide

Select a Resource...

Coreopsis Beggarticks: *Bidens polylepis*

Weed Description: **Summer annual with dissected leaves and showy yellow flowers reaching 5 1/2 feet in height. Primarily a weed of pastures, roadsides, and noncrop areas that can be found throughout Virginia, North Carolina, South Carolina and Georgia.**

Leaves: **Opposite, with short hairs that are closely pressed (appressed) against the margins and veins. Leaves are finely dissected and have 2 to 3 rows of lateral leaflets that are lanceolate to relatively linear in outline.**

Each leaflet is approximately 1 1/4 to 4 inches long and 1/4 to 3/4 inches wide. Leaves occur on relatively long (1 to 2 inches) petioles.

Flowers:
Showy, bright yellow, and approximately 1 inch in diameter. Individual flowers are composed of outer yellow ray flowers that are from 1 to 1 1/2 inches long and 8 to 17 mm wide. Flowering heads are

surrounded by outer bracts that are green and approximately 1/4 to 3/4 inches long.

Identifying Characteristics:
Summer annual with leaves that are dissected 2 to 3 times and have showy, bright yellow flowers. Coreopsis beggarticks seedlings are similar in appearance to those of Common Ragweed (*Ambrosia artemisiifolia*) and Spanishneedles (*Bidens bipinnata*), however the cotyledons of common ragweed are much more rounded than those of coreopsis beggarticks or spanishneedles.

Additionally, common ragweed seedlings do not have the characteristic maroon highlights on the cotyledon and leaf undersurfaces like those of spanishneedles. Devils Beggarticks (*Bidens frondosa*) is also similar in appearance to coreopsis beggarticks and spanishneedles, however devils beggarticks does not have leaves that are dissected 2 to 3 times. Coreopsis beggarticks can also be confused with spanishneedles, however coreopsis beggarticks has flowers that are much larger and more showy and leaflets that are more linear than those of spanishneedles.

Virginia Tech Weed Identification Guide

Select a Resource...

Common Ragweed: *Ambrosia artemisiifolia*

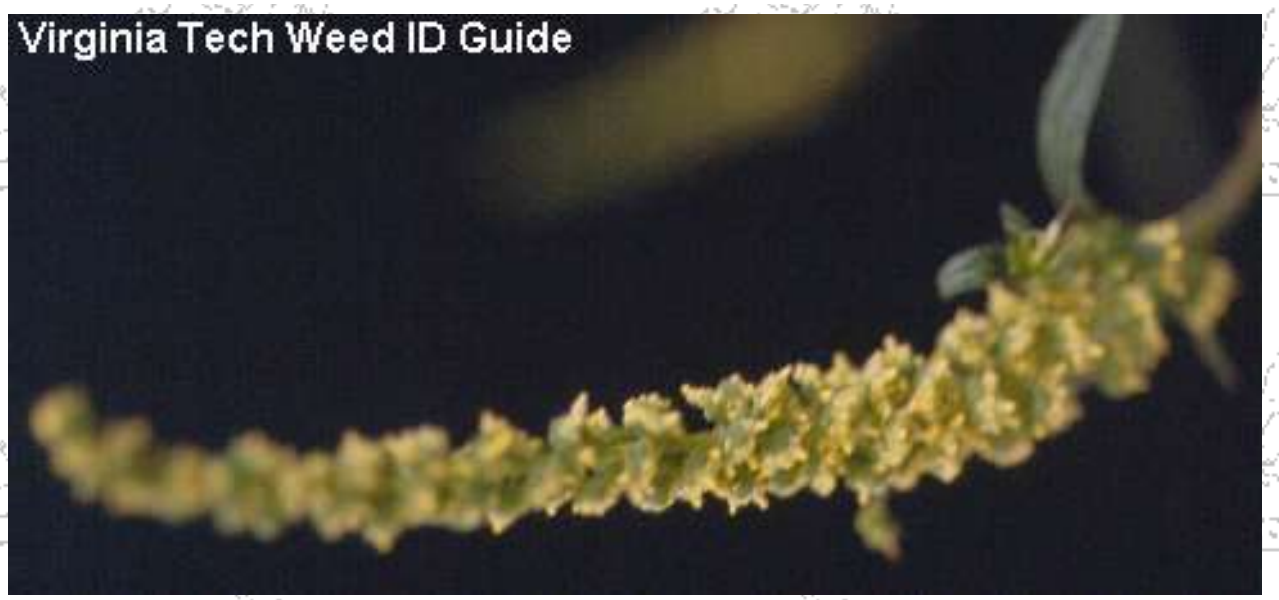
Weed Description:
Summer annual, 0.2-2.5 m tall, found throughout the United States, producing abundant pollen that is a primary cause of hay fever.

Leaves:
Leaves are 4 to 10 cm long, egg-shaped in outline and once or twice compound (pinnatifid). Leaves hairy on upper surface and margin, densely appressed on lower surface.

Seedling: **Stems below cotyledons (hypocotyls) are green, usually spotted with purple. Cotyledons are roundish to oblong, purple underneath. Young leaves opposite, becoming alternate with age, dense pubescence over entire leaf surface.**

Stems: **Erect, branched, with long, rough hairs.**

Flowers: **Flower heads small (2-4 mm broad), green, and arranged in slender inverted racemes at the ends of branches. Male and female flowers are in separate heads on the same**

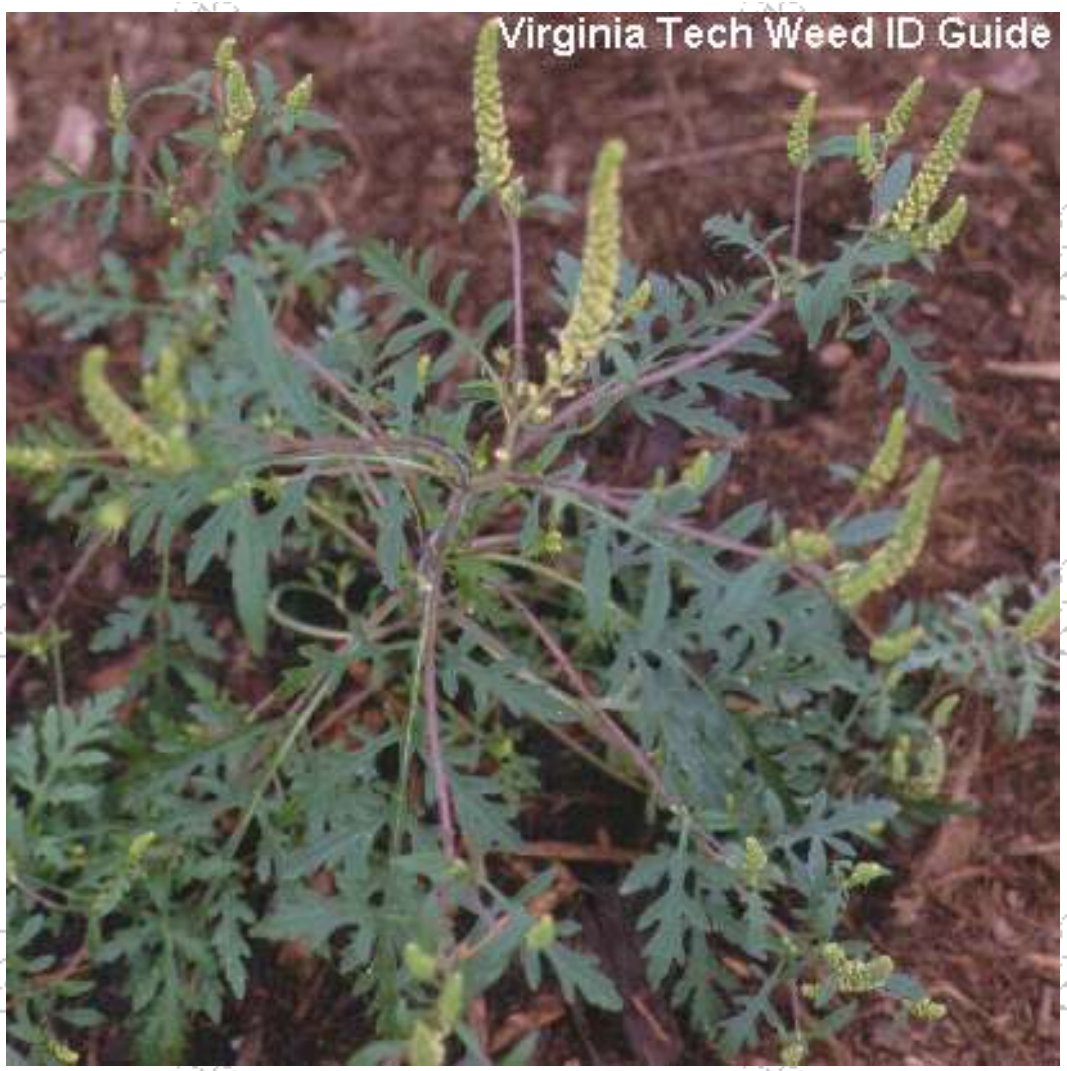


plant, the male flowers, usually drooping, are at the top of the plant, while the female flowers are in the upper leaves and bases of leaves.

Roots: **Shallow taproot.**

Fruit: **Woody achene, yellowish- to reddish-brown, 3-4 mm long and 1.8-2.5 mm wide, 1-2 mm central protuberance surrounded by 4-7 shorter projections. Resembles a crown.**

Identifying Characteristics: **Cotyledons with purple underside.**



Fruit an achene resembling a queen's crown.

Spanishneedles: *Bidens bipinnata*

Weed Description: **Summer annual with dissected leaves and yellow flowers reaching 5 1/2 feet in height. Primarily a weed of pastures, roadsides, and noncrop areas that can be found throughout Virginia, Georgia, Florida, Alabama, Tennessee, Kentucky, and West Virginia.**

Seedling: **Stems below the cotyledons (hypocotyls) are maroon or slightly maroon-tinted and square. Cotyledons green on the upper surface and maroon-tinted on the lower surface. The upper surfaces of the cotyledons have a distinctive midvein. First true leaves are opposite and deeply dissected.**

Leaves: **Opposite, with short hairs along the margins and veins that are pressed closely against the leaves (appressed). Leaves are finely dissected and have 2 to 3 rows of lateral leaflets that are ovate to lanceolate in outline.**

Stems: **Erect, square in cross-section, branching in the upper section, and with small tufts of hairs at the nodes.**

Flowers: **Occur in solitary heads on long stalks. Flowers are yellow and are composed of inner disk flowers and outer ray flowers. Ray flowers are sometimes absent but are approximately 1/2 inch long and 3 mm wide. Flowering heads are surrounded by green bracts that are approximately 2 to 7 mm long and narrow.**

Fruit: **An achene that is approximately 8 to 18 mm**

long, linear in outline, and dark brown in color. Achenes have 3 to 4 spines at the apex that are pointed downward.

Roots: **A taproot.**

Identifying Characteristics: **Summer annual with leaves that are dissected 2 to 3 times and have yellow flowers. Spanishneedles seedlings are similar in appearance to those of Common Ragweed (*Ambrosia artemisiifolia*), however the cotyledons of common ragweed are much more rounded than those of spanishneedles. Additionally, common ragweed seedlings do not have the characteristic maroon highlights on the cotyledon and leaf undersurfaces like those of spanishneedles. Devils Beggarticks (*Bidens frondosa*) is also similar in appearance to spanishneedles, however devils beggarticks does not have leaves that are dissected 2 to 3 times. Spanishneedles can also be confused with Coreopsis Beggarticks (*Bidens polylepis*), however coreopsis beggarticks has flowers that are much larger and more showy and leaflets that are more linear than those of spanishneedles.**

Devils Beggarticks or Stick-tights: *Bidens frondosa*

Weed Description:

A summer annual that may reach as much as 3 1/2 feet in height. Devils beggarticks has prickly fruit that facilitate seed dispersal by sticking to the fur and clothing of any animal or human that brushes by this weed when mature. Devils beggarticks is primarily a weed of pastures, hay fields, roadsides, landscapes, and nurseries. It is found

throughout the United States.

Roots: A taproot.

Seedlings: Cotyledons areoblong in outline (up to 25 mm long) and appear to be on petioles. The first true leaves are arranged oppositely along the stem. Subsequent leaves are divided into at least 3 leaflets.

Leaves: Leaves are arranged oppositely along the stem and occur on petioles. Leaves are divided into 3 to 5 leaflets that are lanceolate in outline and have toothed margins. Leaflets may have a few short hairs.

Stems: Erect, branching in the upper portions, reaching as much as 3 1/2 feet in height but more commonly around 12 inches in height.

Flowers: Consist of inner disk flowers that are brownish in color and outer ray flowers that are yellow to orange in color. Flowers are 1 inch in width and are fairly inconspicuous.

Fruit: An achene that ranges from 6 to 12

mm in length and is brown in color. Achenes have 2 distinctive spines with 'barbs' that help the fruit to stick to whatever they come into contact with.

Identifying Characteristics: Leaves that are divided into 3 to 5 leaflets that are lanceolate and have toothed margins and the distinctive 'barbed' fruit. Devils beggarticks is similar in appearance to Coreopsis Beggarticks (*Bidens polylepis*) and Spanishneedles (*Bidens bipinnata*), however both of these weeds have leaves that are dissected into more leaflets than those of devils beggarticks. Additionally, coreopsis beggarticks has flowers that are much larger and more showy than either devils beggarticks or Spanishneedles.

Virginia Tech Weed Identification Guide

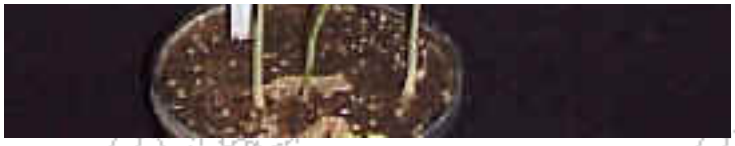
Select a Resource...

Florida Beggarweed: *Desmodium tortuosum*

Weed Description: **Summer annual, reaching 3-9 feet in height. Leaves and stems covered with short, stiff hairs that often stick to clothing.**

Seedling: **Cotyledons round to oval with smooth margins, 3-5 mm wide, 5-8 mm long.**

Leaves: **Alternate, consisting of 3 elliptic to oblong leaflets in upper leaves (trifoliate), perhaps only 1 leaflet in the lower leaves. Leaves occur on petioles and stipules occur where the petiole meets the stem. Each leaflet 3-4 inches long, ovate to lance-shaped.**



Stems: **Erect, may be reddish-purple, 3-9 feet tall, usually covered with short stiff hairs.**

Roots: **Taproot.**

Flowers: **Occur near the top of plants as racemes or branched panicles. Petals are bluish-purple to purple, 5-7 mm long.**

Fruit: **A loment of 2-7 oval to circular segments, each 3-5 mm long, 3-4 mm broad. Each segment encloses a seed and is densely covered with short, stiff hairs that stick to clothing.**

Identifying Characteristics: **Distinctive segmented fruit that sticks to clothing, hairy leaves and stems, and presence of stipules are all features that aide in the identification of this weed.**

Bermudagrass or Wire Grass: *Cynodon dactylon*

Weed Description: **A perennial grass that has both rhizomes and stolons and is capable of forming a turf or mat of fine leaves. Several varieties of bermudagrass are cultivated for use as lawn and pasture grasses, however this weed has developed into a very troublesome and hard-to-control weed in agronomic crops, landscapes, nurseries, and turfgrass. Bermudagrass is found throughout the southern United States, as far north as southern New Jersey.**

Seedling: **Leaves are rolled in the bud, leaf blades are smooth on both surfaces, and the ligule is a row of hairs approximately 1/2 mm long.**

Leaves:

Leaves are rolled in the bud, without auricles, and have a ligule that is a fringe of hairs approximately 1/2 mm long. Hairs occur at least on the leaf margins

in the collar region (the region where the leaf blades join to the sheath). Leaf blades are approximately 2 to 7 inches long by 2 to 5 mm wide and smooth to only sparsely hairy above but usually only with a few hairs near the leaf base. Leaves emerge from opposite sides of the stem and have margins that are slightly rough.

Stems: Leaf sheaths are usually distinctly flattened with relatively long hairs (1 to 3 mm) near the collar only.

Roots: Rhizomes and stolons both occur on the same plant. Rhizomes are scaly and often form an almost impenetrable

mat. Stolons are flat, smooth, usually bent and root at the nodes.

Flowers: Inflorescence consists of 3 to 7 fingerlike spikes that originate from a single point. Individual spikes are approximately 1 to 3 inches long and flattened. Spikelets are arranged in 2 rows on each spike and each of these spikelets produces a single lance-shaped seed (1 1/2 mm long).

Identifying Characteristics: A persistent grass weed with both scaly rhizomes and stolons that root at the nodes. Additionally, the tuft of hairs in the collar region helps to distinguish this weed from most other grasses. Nimblewill (*Muhlenbergia schreberi*) is similar in appearance and growth habit, however nimblewill plants are generally smaller than those of bermudagrass and have a

membranous ligule unlike the ligule that is a fringe of hairs on bermudagrass.

Nimblewill: *Muhlenbergia schreberi*

Weed Description: **A perennial grass with stolons that forms dense mats and closely resembles bermudagrass. Nimblewill is primarily a weed of lawns and turfgrass, but can also occur in nurseries, orchards, and landscapes.**

Roots: **Nimblewill has a fibrous root system as well as stolons that run along the soil surface and root at the nodes.**

Seedlings: **First leaves are long and wide. Leaves are rolled in the bud, without auricles , and with a very short membranous ligule.**

Leaves: **Leaf blades are relatively small, ranging from 3/4 to 3 inches in length and 2 to 4 mm in width. Leaf blades are mostly hairless except for some hairs near the ligule. Leaves are rolled in the bud and auricles are absent. The ligule is very short (<1/2 mm) and membranous with distinctive teeth along the top.**

Stems: **Stems are branching, forming thick mats, and root at the nodes. Stems and stolons die early in the fall and form distinctive brown patches throughout lawns and turfgrass that are otherwise green. Leaf sheaths and stems are sometimes maroon-tinted near the base.**

Flowers: **Seedheads are slender panicles, reaching as much as 6 inches in length. Each spike within the panicle contains spikelets that are approximately 2 mm long.**

Identifying Characteristics: **The relatively short, narrow leaves, mat-forming habit, and stolons are all features that help to distinguish nimblewill from most other grass species. Additionally, nimblewill does not tolerate cool weather and forms very distinctive brown patches throughout the winter. Nimblewill is very similar to Bermudagrass (*Cynodon dactylon*), but does not have rhizomes and is generally smaller and more wiry in appearance than bermudagrass. Nimblewill is very similar in appearance to creeping bentgrass (*Agrostis stolonifera*), but this species has a much larger membranous ligule when compared to that of nimblewill.**

Virginia Tech Weed Identification Guide

Select a Resource...

Coral-Berry, Indian Currant, Devil's Shoestring, or Buckbrush:

Symphoricarpos orbiculatus

Weed Description: **A low-growing perennial shrub with rhizomes and distinctive red berries that persist well into the winter. Coral-berry is a very common and difficult-to-control weed of pastures, hay fields, and roadsides that is found primarily in the piedmont and mountains of Virginia, Alabama, Mississippi, Tennessee, and Kentucky.**

Leaves: **Arranged oppositely along the stem, approximately 3/4 to 4 3/4 inches long and 1/2 to 1 1/4 inches wide. Leaves are oval-shaped to elliptical in outline with many soft**

hairs on the lower surfaces.

Stems: **Ranging from 1 1/2 to 6 1/2 feet in height but rarely more than 3 or 4 feet. Stems and twigs are densely hairy and become woody with age.**

Roots: **A fibrous root system and rhizomes.**

Flowers: **Occur as clusters in the positions between the stem and leaves (leaf axils). Flowers are greenish in color, small, and relatively inconspicuous.**

Fruit: **A round berry that is red to purple in**

color. Berries are 5 to 8 mm long and persist well into the winter.

Identifying Characteristics:
The shrubby growth habit, rhizomes, and hairy leaves and stems are all features that help to distinguish this weed from most other species that typically occur in Virginia pastures and hay fields. There are other *Symphoricarpos* species in the United States, but the only other species that might be

encountered in the southeastern United States is snowberry (*Symphoricarpos albus*), which has much larger white berries.

Virginia Tech Weed Identification Guide

Select a Resource...

Bigroot Morningglory: *Ipomoea pandurata*

Weed Description: **A perennial trailing or climbing vine from a large storage root that may reach 10 ft in length. Found throughout the eastern United States, north to Ontario, Canada.**

Seedling: **The cotyledon attachment to the stem below the cotyledons (the hypocotyl) remains below ground.**

Leaves: **Alternate, entire or with indented sides, heart-shaped, with or without hairs, 4 inches long, 3.5 inches wide, and on long petioles.**

Stems: **Trailing or climbing to 10 ft in**

length, with or without hairs.

Roots: Large, tuber-like root.

Flowers: Produced on flower stalks (peduncles) in clusters of 1-5. Flowers are white with a lavender or purple center, 2-3 inches long.

Fruit: A capsule containing 2-4 dull reddish brown seed that are densely hairy around the margin.

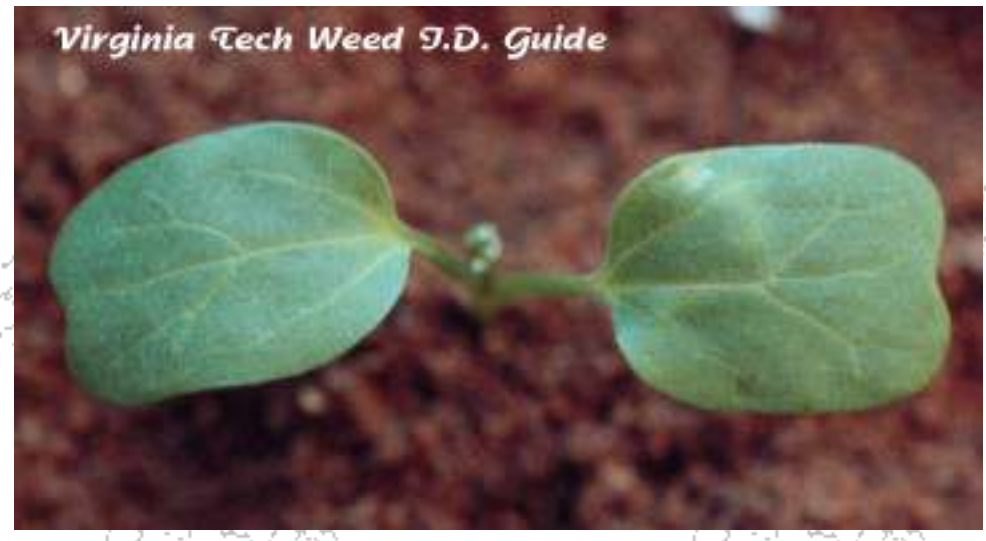
Identifying Characteristics:

Large tuber-like root and white flowers with lavender or purple center should distinguish this weed from other morningglories with white flowers.

Virginia Tech Weed Identification Guide

Select a Resource...

Field Bindweed: *Convolvulus arvensis*



Weed Description: **A perennial trailing or climbing weed with white morningglory-like flowers that may reach 3 1/3 feet in length. Field bindweed is primarily a weed of nurseries, agronomic crops, and fencerows that can be found throughout the United States.**

Seedling: **Cotyledons are dark green with relatively prominent white- to light green veins. The cotyledons are almost perfectly square, approximately as long as they are wide, and are slightly indented at the tip.**

Leaves: **Alternate, occur on petioles, and are triangular in outline. Leaves can occur either**

without hairs (glabrous) or can have hairs. The leaf bases are pointed and have lobes that point outward.

Stems: Trail along the ground or climb onto crop plants, fences, etc. Stems may also be either with or without hairs.

Roots: A twisting taproot that extends very deep into the soil serves as the overwintering perennating organ of field bindweed.

Flowers: White to pink in color and approximately ¾ to 1 inch long. Flowers take on the shape of a funnel and also have bracts that are relatively small and separate from the flowers.

Fruit: An oval to round capsule.

Identifying Characteristics: Trailing or climbing vine with triangular leaves and lobes that point outward. Additionally, the small bracts that are separate from the flowers of field bindweed help to distinguish this from other similar species. Hedge Bindweed (*Calystegia sepium*) is similar in appearance and is often mistaken for field bindweed, however the leaf bases of hedge bindweed are cut squarely (truncate) and this weed also has large bracts beneath the flowers unlike field bindweed. Field bindweed is also often confused with Wild Buckwheat (*Polygonum convolvulus*), however wild buckwheat has inward-pointing bases and an ocrea at the base of

each petiole.

Virginia Tech Weed Identification Guide

Select a Resource...

Hedge Bindweed: *Calystegia sepium*

Weed Description: **Perennial from rhizomes, trailing or climbing vine to 10 feet long, with distinct triangular leaves. Found throughout the eastern United States to the Great Plains, and also in the upper northwestern states.**

Roots: **System of branched rhizomes.**

Seedling: **No cotyledons are present when plants emerge from rhizomes, as is usually the case. However, cotyledons are as long as broad, almost square, without hairs, and slightly indented at the tip. Youngest leaves of sprouts from rhizomes are triangular in outline, with either a heart-shaped or sharply lobed base.**

Fruit: **A capsule containing 2-4 seeds.**

Leaves: **Petioled, alternate, triangular in outline, 2 to 4 inches long, most often found without hairs. Leaves have a pointed tip and distinctive angular bases that are cut squarely across the top (truncate), and resemble the ears of a dog.**

Stems: **Trailing along the ground or climbing, may be with or without hairs.**

Flowers: **On long flower stalks (2 to 6 inches), solitary in leaf axils, usually white, sometimes pink. Two leafy bracts are present at the base of the flower, and the flowers are fused into a funnel-like structure.**

Identifying Characteristics: **Flowers have two leafy bracts at the base, leaves are triangular in outline with 'dog-ears'. This weed is often mistaken for Field Bindweed (*Convolvulus arvensis*). However, field bindweed leaves are smaller, with a more rounded apex and bases that are pointed or rounded, but not cut off squarely across the top as in hedge bindweed.**

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Buckwheat: *Polygonum convolvulus*

Weed Description: **An annual twining or trailing vine that may reach as much as 3 1/2 feet in length. Wild buckwheat is found throughout the United States.**

Seedling: **Cotyledons are linear, approximately 20 mm long and 3 mm wide, without hairs. Stems are without hairs. First leaves occur on petioles and are without hairs.**

Stems: **Stems are erect at first, then become twining or creeping and branched at the base. A membranous sheath (ocrea) surrounds the stem at the base of each leaf petiole.**

Flower: **Flowers are clustered in racemes from the leaf axils (the position between the stem and a leaf), are inconspicuous and greenish-white in color.**

Roots: **Fibrous root system.**

Leaves: **Leaves are alternate, triangular to heart-shaped with a pointed tip. Basal lobes point inward toward the petiole. Leaves have a continuous, untoothed margin.**

Fruit: **A 3-angled achene that is black, 3-4 mm long, and enclosed in the green, winged sepals.**

Identifying Characteristics: **The ocrea at base of each petiole and the triangular leaves with basal lobes that point inward are both characteristics that help to distinguish this weed from most other plants. This weed is often confused with Field Bindweed (*Convolvulus arvensis*). However, the inward-pointing bases of wild buckwheat leaves versus the outward-pointing bases of field bindweed leaves are characteristics that may be used to distinguish between the two. Additionally, the ocrea present in wild buckwheat and not in field bindweed is a distinguishing characteristic.**

Virginia Tech Weed Identification Guide

Select a Resource...

Birdsfoot Trefoil: *Lotus corniculatus*


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Hairy Bittercress: *Cardamine hirsuta*

Weed Description: **Most often a summer annual but occasionally a winter annual weed of landscapes, container-grown plants, and greenhouses. Hairy bittercress is found throughout the northern half as well as the southeastern United States.**

Seedlings: **Cotyledons are round and occur on petioles. Cotyledons and first true leaves have hairs. Subsequent leaves consist of alternately arranged leaflets.**

Stems: **Erect, branched at the base, reaching as much as 12 inches in height.**

Roots: **A taproot.**

Leaves: **Leaves consist of 2 to 4 pairs of leaflets that are arranged alternately along the central leaf stem. Individual leaflets are round in outline. Each leaf occurs on a petiole that is usually distinctly hairy. Lower leaves may be hairy but not as distinctly hairy as the upper leaves. Upper leaves are smaller than the lower basal leaves.**

Flowers: **Occur in clusters at the ends of the flowering stems. Individual flowers are small (2-3 mm) and consist of 4 white petals.**

Fruit: **A silique, which is a long (3/4 to 1 1/4 inches), narrow capsule with many seeds. Siliques explosively spread the seed as much as 10 feet from the parent plant.**

Identifying Characteristics: **The long narrow siliques and round leaflets that are arranged alternately are both characteristics that help in the identification of hairy bittercress. This plant might be confused with Calepina (*Calepina irregularis*), however calepina does not have 2 to 4 pairs of round leaflets like hairy bittercress.**

Calepina: *Calepina irregularis*

Weed Description:

An erect winter annual that produces a basal rosette of leaves and leaves that occur along a flowering stem. This weed is fairly rare and has been introduced into both Virginia and North Carolina probably as a contaminant of alfalfa seed. Calepina is fairly localized to Goochland, Powhatan, Cumberland, and Amelia counties in Virginia and to Buncombe County in North Carolina. It is primarily a weed of alfalfa.

Leaves: **Initially plants develop a basal rosette of leaves. Basal leaves are oval to lanceolate in outline but widest at the apex of the leaf and tapering to the base. Basal leaves range from 3/4 to 4 inches in length and rarely reach more than 3/4 inch in width The basal leaves are deeply lobed and have a prominent white midvein. Leaves that occur along the flowering stems are much smaller than the basal leaves, ranging from 1/2 to 1 1/2**

inches in length. These upper leaves are not lobed like those of the basal rosette, but have toothed margins. Leaves may be either without hairs (glabrous) or with a few hairs on the leaf undersides.

Stems:
Erect, branching, ranging from 4 to 20 inches in height but usually around 4-8 inches. Stems are mostly without hairs but may have a few hairs toward the base.

Flowers: Occur in clusters at the ends of the erect flowering stems. Each flower occurs on a flower stalk (peduncle) and is white in color.

Fruit: A silique. Siliques contain a single seed.

Roots: A taproot and fibrous root system.

Identifying Characteristics: The lobed basal leaves but unlobed stem leaves, winter annual growth habit, and small white flowers that occur in clusters at the ends of the flowering stems are all characteristics that help in the identification of Calepina. Calepina could easily be misidentified as Shepherd's-purse, however the young leaves of

this weed usually have star-shaped hairs (branched hairs), the flowering stems do not have leaves, and the seed pods are triangular unlike those of calepina. Young calepina plants may also be confused with Hairy Bittercress (*Cardamine hirsuta*), however the leaves of this weed have round leaflets arranged alternately along the central leaf stem unlike the leaves of calepina.

Virginia Tech Weed Identification Guide

Select a Resource...

Bittersweet Nightshade: *Solanum dulcamara*

Weed Description: **A trailing or climbing perennial vine with purple and yellow flowers and spreading stems that may reach up to 10 feet in length. Bittersweet nightshade is found throughout most of the United States, most common in the eastern and north-central states. All parts of the plant are toxic.**

Flowers:
Star-shaped, with purple petals and a yellow or orange center, 12-16 mm in diameter.

Leaves: **Dark green to sometimes dark purplish, 1-4 inches long, petiolated, alternate, and often have 2 basal lobes or leaflets at the base. Leaves not lobed in this manner are ovate to oval. All leaves have smooth, entire margins and may have an unpleasant odor. Lobed leaves are a good identifying characteristic, however they are not always present as illustrated here.**

Stems: **Becoming semi-woody with age, creeping, prostrate, and rooting at the nodes.**

Fruit: **Bright-red, egg-shaped berries arranged in clusters. Berries contain flat, round, yellowish seeds.**

Identifying Characteristics:
Perennial vine that roots at the nodes, often with leaves that have 2 basal leaflets at the base. Eastern Black Nightshade (*Solanum ptycanthum*) is often confused with bittersweet nightshade, but is an annual with an upright growth habit, and has wavy leaf margins and black berries.

Virginia Tech Weed Identification Guide

Select a Resource...

Eastern Black Nightshade: *Solanum ptycanthum*

Weed Description: **An erect summer annual, reaching as much as 1 1/3 feet in height. Eastern black nightshade is primarily a weed of agronomic crops, pastures, and hay fields that is found throughout the United States east of the Rocky Mountains.**

Roots: **A taproot with a branched fibrous root system.**

Seedlings: **Stems below the cotyledons (hypocotyls) are covered with small hairs and are green or sometimes tinted maroon. Cotyledons are green on the upper surface, purple- or maroon-tinted on the lower surface.**

Leaves: **Young leaves remain purple- or maroon-tinted on the undersurface. Leaves are simple, alternate, ovate or ovate-lanceolate. Leaf margins may be entire or with blunt teeth. Leaf hairiness is variable, however leaves are most often found to be slightly hairy.**

Stems: **Branching, round or angular, smooth or only partially hairy, and becoming woody with age.**

Flowers: **Star-shaped (4-10 mm in diameter), white or purple-tinged, in umbel-like clusters of 5-7.**

Fruit: **A berry, 5-12 mm in diameter, green when immature, turning purplish-black at maturity. Berries contain 4-15 sclerotic granules.**

Identifying Characteristics: **Cotyledons of young leaves are purple- or maroon-tinted on the undersurface. Emerging plants might be confused with Bittersweet Nightshade (*Solanum dulcamara*) seedlings, however most bittersweet nightshade plants spread via creeping stems that root at the nodes and do not have a purple- or maroon-tinted leaf undersurface. Additionally, mature nightshade plants may be distinguished by berry color (eastern black nightshade: purplish-black; bittersweet nightshade: red).**

Virginia Tech Weed Identification Guide

Select a Resource...

Black Locust: *Robinia pseudoacacia*

Weed Description: **A tree that may reach as much as 100 feet in height when mature, but the seedlings of these trees often occur as weeds of landscapes, pastures, hay fields, gardens, and roadsides.**

Leaves: **Arranged alternately along the stem, approximately 8 to 12 inches in length. Leaves are divided into two rows of 7 to 19 leaflets that are elliptic to oval shaped in outline and range from 3/4 to 2 inches in length and 1/2 to 3/4 inch in width. Young seedlings have leaflets that are often densely covered with short hairs.**

Stems: **Seedlings have stipules that develop at the base of the leaf petioles and the stems. These stipules develop into woody spines that may reach as much as 1 inch in length with age.**

Roots: Underground stems that are capable of regenerating new plants and a fibrous root system.

Flowers: A drooping raceme, 4 to 8 inches in length, containing many fragrant flowers. Individual flowers are white and yellow in color.

Fruit: A pod (legume) that is twisted, 12 to 18 inches in length and 1/2 to 3/4 inches in width. A narrow wing occurs along the upper surface of the legume.

Identifying Characteristics: The alternately arranged leaves that consist of many leaflets, stipules that develop into spines, and underground stems that can produce new plants are all characteristics that help in the identification of black locust. Several other locust species occur and are primarily differentiated from black locust by their flower color and type of fruit.

Virginia Tech Weed Identification Guide

Select a Resource...

Black Nightshade: *Solanum nigrum*

Weed Description: **An annual or short-lived perennial ranging from 1 1/2 to 3 1/3 feet in height. Black nightshade is primarily a weed of agronomic crops, forages, and gardens that is found along the West Coast of the United States only.**

Seedling: **Cotyledons are covered with short hairs along the margins, midribs evident on lower surface, and petioles are also covered with hairs. Stems below the cotyledons (hypocotyls) are hairy and green in color.**

Roots: **Fibrous with shallow taproot.**

Leaves: **Alternate, petioled, egg-shaped in outline, margins variable either without teeth or shallowly round-toothed. Leaf pubescence is highly variable.**

Stems: **Slender and becoming woody with age, may be round, ridged, ridged with small teeth, with or without hairs.**

Flowers: **Star-shaped,**

in umbel-like clusters, 4-9 per cluster, white.

Fruit: **A berry, round, 5-10 mm in diameter, green early, turning black or dark green at maturity. Berries do not contain sclerotic granules.**

Identifying Characteristics: **Nightshade with berries that do not contain sclerotic granules, as those in Eastern Black Nightshade (*Solanum ptycanthum*) do. This species is not found in the eastern United States.**

Virginia Tech Weed Identification Guide

Select a Resource...

Black Medic: *Medicago lupulina*

Weed Description: **A low-trailing summer annual, with yellow flowers. Found throughout the United States, primarily a weed of turfgrass.**

Seedling: **Cotyledons oblong (4-9 mm long). First true leaf is borne on a single stalk, followed by leaves that consist of 3 leaflets and arise from a common point (palmately compound).**

Mature Plant: **Stems prostrate, 4-angled, hairy, radiating out from the taproot. Compound leaves are alternate, with wedge- to oval-shaped leaflets. Leaflets have toothed margins, are widest at the apex, and have a projecting tip in the center of the leaf. The central leaflet is borne on a short stalk, while the lateral leaflets arise from the central petiole. Stipules are present at the base of the petioles.**

Fruit: **A kidney-shaped, 1-seeded black pod, 2-3 mm long and hairy.**

Roots: **Taproot.**

Flowers: **Small and yellow, in clusters, approximately 1/2 to 3/4 inches long.**

Identifying Characteristics: **This weed may easily be confused with other weedy trifoliate legumes such as hop clover, large hop clover, yellow woodsorrel, etc. However, the longer stalk of the central leaflet compared to lateral leaflets, small projecting tip at the leaflet apex, and toothed margins are important characteristics that help to distinguish black medic from other trifoliate legumes.**

Virginia Tech Weed Identification Guide

Select a Resource...

Blackseed Plantain: *Plantago rugelii*

Weed Description:
Perennial from a basal rosette with broad oval leaves. Often mistaken for the closely related broadleaf plantain (*Plantago major*). Found throughout the United States, primarily a weed of turfgrass.

Seedling:
Cotyledons are spatula-shaped and joined at the base. Young leaves oval to elliptic with leaves that encircle the stem.

Leaves: **Usually lacking hairs, oval to elliptic and tapered at the tip, with a somewhat waxy surface and veins that are parallel to the margins. Margins are usually wavy and toothed. Petiole bases are conspicuously red or purple tinged.**

Roots: **Taproot with fibrous roots.**

Flowers: **Flowers produced on unbranched stalks (scapes) that arise from the rosette. Flowering stems are 5-15 inches long, clustered with small flowers that have whitish petals and bracts surrounding the flowers.**

Fruit: **A cylindrical, 4-6 mm long, 4-10 seeded capsule that splits below the middle.**

Identifying Characteristics: **Blackseed Plantain (*Plantago rugelii*) has petioles with red or purple colorations at their bases, a lighter green, less waxy leaf appearance, and capsules that split below the middle. These are all characteristics that help to distinguish it from the closely-related Broadleaf Plantain (*Plantago major*). Additionally, the leaves of blackseed plantain are hairless, and have toothed and wavy margins, unlike the leaves of broadleaf plantain.**

Virginia Tech Weed Identification Guide

Select a Resource...

Broadleaf Plantain: *Plantago major*

Weed Description: **Perennial from a basal rosette with broad oval leaves. Found throughout the United States, primarily a weed of turfgrass.**

Seedling: **Cotyledons are spatula-shaped and joined at the base. Young leaves oval to elliptic with leaves that encircle the stem.**

Roots: **Taproot with fibrous roots.**

Leaves: **Smooth or slightly hairy, oval to elliptic, with a waxy surface and veins that are parallel to the margins. Margins are untoothed and sometimes wavy.**

Fruit: **A 2-celled oval capsule, 3-5 mm long, that opens by a lid around the middle.**

Flowers: **Flowers produced on unbranched stalks (scapes) that arise from the rosette. Flowering stems are 5-15 inches long, clustered with small flowers that have whitish petals and bracts surrounding the flowers.**

Identifying Characteristics: **This weed may be confused with Blackseed Plantain (*Plantago rugelli*) that is also found in the eastern United States. Blackseed plantain has a red or purple coloration at the base of the petioles that is less often found in broadleaf plantain. Additionally, the capsules of blackseed plantain are cylindrical and split below the middle, while the capsules of**

broadleaf plantain are egg-shaped and open by splitting around the middle.

Bladderworts: *Utricularia* spp.

Weed Description:
Submersed aquatic plants that float freely throughout the water and have no true roots. Bladderworts can be found in ponds, lakes, ditches, and bogs. Most bladderworts are free-floating aquatics, however some species may occur in marshes or along the edges of ponds, lakes, or bogs. The bladderworts are carnivorous plants that capture aquatic invertebrates in their bladders and then break these organisms down to nitrogen and other nutrients.

Leaves: **No distinct leaves occur. However, the stem-like segments of this species are actually the leaves. Many distinctive bladders are attached to these segments. When removed from the water, the bladders are almost clear and have a pinkish-red color.**

Stems:
Stems may be creeping, floating, or submersed, depending on the species. Stems are typically branching with

bladders attached throughout.

Roots: No true roots are present on the aquatic bladderwort species.

Flowers: Most bladderwort species have yellow flowers, however there are a few with either white (*Utricularia olivacea*) or purple (*Utricularia purpurea*) flowers. Flowers occur on an erect, leafless stems (scapes) that may reach up to 6 inches in length and

are usually completely emerged above the water surface. Flowers reach up to 3/4 inch in width.

Identifying Characteristics: **The bladders that occur on the stems and leaves of all the *Utricularia* species helps to distinguish these weeds from any other floating or submerged aquatic weeds.**

Virginia Tech Weed Identification Guide

Select a Resource...

Bloodroot: *Sanguinaria canadensis*

Virginia Tech Weed Identification Guide

Select a Resource...

Starch Grapehyacinth or Blue-Bottles: *Muscari racemosum*

Weed Description:
A bulbous perennial with leaves that resemble an onion or garlic, and are sometimes confused as a grass. Starch grapehyacinth has attractive clusters of purple flowers and has escaped cultivation to become a weed of landscapes and some winter cereals in Virginia.

Roots:
Plants have a conspicuous bulbs, usually larger than those of wild garlic or wild onion.

Stems:
Leafless flowering stems (scapes) occur that range from

4 to 8 inches in height.

Leaves: **Leaves are linear in outline, from 5 to 16 inches in length and 2 to 5 mm in width. All leaves are hollow and resemble those of wild garlic, but have no distinct onion like odor.**

Flowers: **Plants usually bloom from May to early June in Virginia. Many bottle-shaped purple flowers occur in clusters at the ends of the leafless stems. Individual flowers are 4 to 7 mm long, 2 1/2 to 4 mm wide, bottle-shapes and drooping downward.**

Fruit: **A capsule that is 7 to 8 mm long.**

Identifying Characteristics: **Plants with onion-like leaves and conspicuous clusters of purple, bottle-shaped flowers. Starch grapehyacinth may be confused with Wild Garlic (*Allium canadense*) or wild onion, but does not have a conspicuous onion smell like these species. Additionally, Star-of-Bethlehem (*Ornithogalum umbellatum*) is very similar in appearance and growth habit, however this weed has a conspicuous white midvein along the leaves unlike those of starch grapehyacinth.**

Wild Garlic: *Allium vineale*

Weed Description: **A perennial from bulblets that emits a strong garlic or onion smell when crushed. Primarily a weed of small grains, turfgrass and pastures. Wild garlic imparts a garlic-like flavor and odor on dairy and beef products when grazed. Additionally, small grains may become tainted with a garlic-like odor and/or flavor due to the presence of aerial bulblets at the time of harvest. Wild garlic is found throughout the eastern and central United States.**

Seedlings:
Resemble those of a grass, but have hollow, round

leaves.

Leaves: Leaves are round, hollow, arising from a bulb, 6-24 inches long, 2-10 mm wide. All leaves have a garlic-like or onion scent.

Stems: Flowering stems are the only stems that occur. These are slender, solid, waxy, unbranched, and 1-3 feet tall.

Flowers: **Flowers are produced at the top of the flowering stems. Flowers are greenish-white, small, and on short stems above the globe of aerial bulblets. Aerial bulblets are ovoid, often wholly or partially replace the flowers, and are usually tipped by a long, fragile slender green leaf.**

Fruit: **The fruit is an egg-shaped 3-parted capsule.**

Roots: **Round to egg-shaped bulbs with a papery outer covering. Smaller bulblets may form at the base of the bulbs, and fibrous roots are also attached at the bases of the bulbs.**

Identifying Characteristics: **Round hollow leaves and garlic-like odor. Wild garlic is often confused with wild onion (*Allium canadense*), but the two may be easily distinguished after a closer examination of the leaf cross section. The leaves of wild garlic are hollow and round, while those of wild onion are more flat and 'solid'. Wild garlic is also similar to Star-of-Bethlehem (*Ornithogalum umbellatum*), however this weed lacks the garlic-like odor of wild garlic and also has distinctive white midveins that run the length of the leaf when mature. Starch Grapehyacinth (*Muscari racemosum*) is also similar in appearance and growth habit, but lacks the garlic-like odor as well.**

Virginia Tech Weed Identification Guide

Select a Resource...

Star-of-Bethlehem: *Ornithogalum umbellatum*

Weed Description: A perennial from a bulb that is often misidentified as a grass or as wild garlic or wild onion. Star-of-Bethlehem has been sold as an ornamental and has escaped to become a weed of landscapes, pastures, hayfields, turfgrass, and lawns. Primarily distributed throughout the northern United States.

Seedlings: Rarely occur. Most plants develop from bulbs.

Roots: Bulbs that are

oval-shaped. Smaller bulblets occur around the parent bulb, and these bulblets are responsible for the spread of star-of-Bethlehem from one year to the next.

Leaves: The leaves are shiny, dark green, and have a distinct white midrib. Leaves are approximately 4 to 12 inches long, 2 to 6 mm wide, and are hollow in cross section. The leaves of this weed are commonly confused for a grass, but more closely resemble those of wild garlic. Leaves lack any garlic or onion-like smell.

Stems: Leafless flowering stems (scapes) occur that reach up to 12 inches in height.

Flowers: **Flowers consist of 6 white petals that collectively resemble a star. Flowers occur at the ends of leafless flowering stems (scapes).**

Fruit: **A capsule that is 3-lobed and contains several oval black seed.**

Identifying Characteristics: **A bulbous perennial with leaves that resemble wild garlic and have small, white, star-shaped flowers. Star-of-Bethlehem is similar to Wild Garlic (*Allium vineale*), however star-of-Bethlehem lacks the characteristic garlic smell and also has distinctive white midveins along the leaves unlike wild garlic. Starch Grapehyacinth (*Muscari racemosum*) is also similar in appearance, however this weed also lacks the distinctive white midveins that run the length of the leaves as in star-of-Bethlehem.**

Virginia Tech Weed Identification Guide

Select a Resource...

Roughstalk Bluegrass: *Poa trivialis*

Weed Description: **A perennial bluegrass with stolons that may reach 1-3 feet in height. These plants go dormant throughout the summer and carry out their life cycle during the winter months. Found throughout the southeastern United States.**

Stems: **Covered with many small hairs, with brown to purple bands surrounding the nodes.**

Leaves: **Folded in the bud and have the boat-shaped tip typical of most bluegrass species. Leaf blades are 2-7 inches long, 2-5 mm wide, covered with many small**

hairs, with a relatively large (4-6 mm) membranous ligule.

Flowers: The seedhead is a panicle very similar to other bluegrass turf species.

Roots: Fibrous roots with a stoloniferous root system (aboveground creeping roots) that contributes significantly to the spread of this weed.

Identifying Characteristics: As an agronomic weed, this weed should be relatively easy to distinguish from other grasses. The distinctive boat-shaped leaf tip, seedhead, growing season, and presence of stolons are all characteristics that help in the

identification of this weed.

Virginia Tech Weed Identification Guide

Select a Resource...

Blue Phlox: *Phlox divaricata*

Weed Description: **A perennial with rhizomes that produces many attractive blue flowers during the spring. Blue phlox primarily grows in moist, shaded areas such as the edges of woods. It is primarily viewed as an attractive wildflower rather than a detrimental weed.**

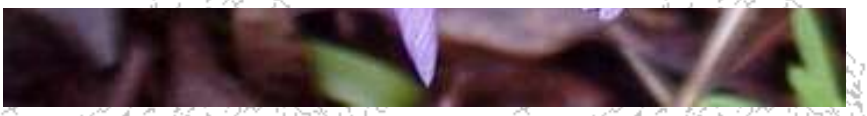
Leaves: **Leaves are elliptic to lanceolate in outline, reaching 3/4 to 1 1/2 inches in length and 5 to 12 mm in width. Leaves are arranged oppositely along the stem and 4 pairs of leaves typically occur on the flowering stems. All leaves are hairy.**

Stems: **Hairy, erect, reaching 15 inches in height.**

Roots: **Rhizomes and fibrous roots occur.**

Flowers: **Many flowers occur on each plant clustered at the ends of the flowering stems. Individual flowers are tube- or funnel-shaped with 5 blue to lavender**

petals that are notched.



Identifying Characteristics:
The elliptic to lanceolate oppositely-arranged leaves, attractive blue to lavender flowers, and tendency of this plant to grow in moist, shady areas are all characteristics that help in the identification of blue phlox.

Viper's Bugloss or Blueweed: *Echium vulgare*

Weed Description: **A biennial that takes on a rosette growth habit during the first year of growth and produces a flowering stem during the second year. Plants are covered with long hairs and produce many bright blue flowers. Viper's Bugloss is primarily a weed of pastures, roadsides, and noncrop areas.**

Leaves: **Rosette leaves are oblong to linear- lanceolate in outline, 2 to 6 inches long and reaching 1 1/4 inches in width. Rosette leaves narrow to a short petiole. Leaves that occur on the flowering stem are also oblong to linear-lanceolate in outline but do not**

have petioles. Flowering stem leaves also become progressively smaller up the stem. All leaves have white 'speckles' that give the leaves a dimpled appearance and also have relatively long white hairs.

Stems: **Erect, branching, reaching 2 1/2 feet in height. Stems also have relatively long, bristly hairs.**

Flowers: **Bright blue to purple in color, approximately 8 to 12 mm long. Flowers somewhat resemble a funnel and also have external hairs.**

Roots: **Taproot.**

Identifying Characteristics: **The 'dimpled' appearance of the leaves and bright blue to purple flowers of viper's bugloss helps to distinguish this weed from most other weed species. When in the rosette stage, this weed might be confused with Curly Dock (*Rumex crispus*), but curly dock does not have white-speckled and 'dimpled' leaves like viper's**

bugloss.

Virginia Tech Weed Identification Guide

Select a Resource...

Curly Dock: *Rumex crispus*

Weed Description: **Taprooted perennial, developing a basal rosette of wavy-margined leaves and an unbranched stem that may reach 5 feet in height. Found throughout the United States primarily as a weed of pastures, hay fields, forages, landscapes, and some agronomic crops.**

Stems: **Unbranched, thick, without hairs, ridged, often reddish in color.**

Seedling: **Stems below the cotyledons may be tinted maroon at the base. Cotyledons are rounded at the apex and narrowed to the base (spatulate-shaped). Cotyledons are without hairs and occur on petioles. Young leaves may have reddish patches on them and form a basal rosette.**

Leaves: **Lower rosette leaves are petioled, without hairs, alternately arranged on the stem, dark green with wavy margins. Stem leaves are arranged alternately along the stem, have a membranous sheath that encircles the stem (ocrea), and become progressively smaller up the flowering stalk. Leaves become more reddish-purple with age.**

Roots: **Large, fleshy tap-root, yellowish orange in color.**

Flowers: **Occur in clusters on the upper portion of the elongating stem, consisting of greenish sepals that become reddish-brown with age.**

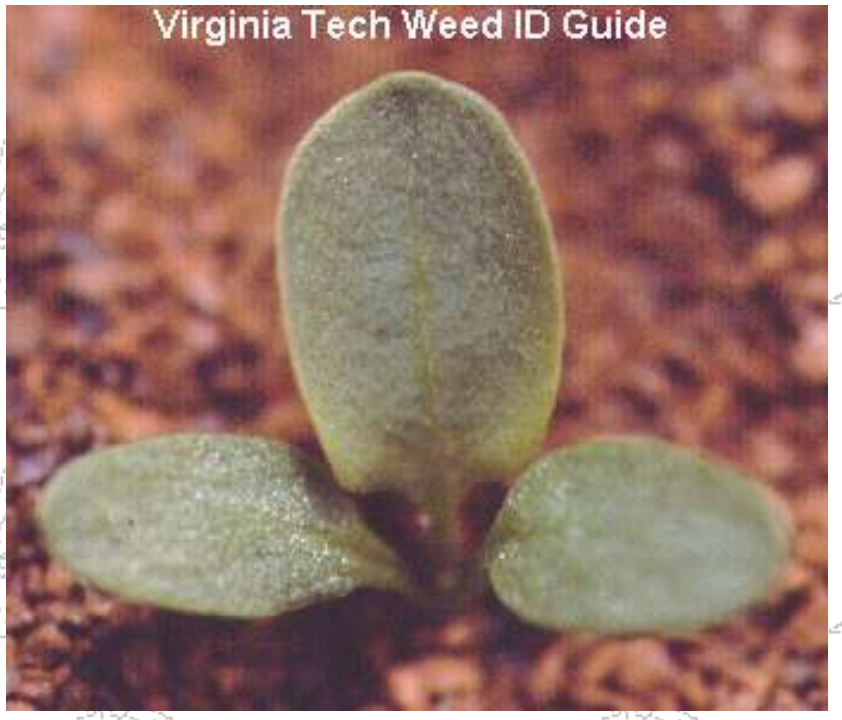
Fruit: **An achene (2 mm long) that is triangular, glossy, and brown to reddish-brown. A papery 3-valved or 3-winged structure surrounds the achene.**

Identifying Characteristics: **Leaves with markedly wavy-margins. This weed may be confused with Broadleaf Dock (*Rumex obtusifolius*). However, the much wider and less wavy leaves of broadleaf dock help to distinguish the two species.**

Virginia Tech Weed Identification Guide

Select a Resource...

Broadleaf Dock: *Rumex obtusifolius*



Weed Description: **A taprooted perennial from a basal rosette,developing a single stem that may reach 3 1/3 feet in height. Broadleaf dock is found throughout the eastern United States, the Midwest, and Arizona.**

Seedling: **Cotyledons are egg-shaped, with a 'mealy' cast on both surfaces. Petioles are as long as the blade. First true leaf is spatula-shaped**

Leaves: **Lower leaves are petioled, may be reddish-veined, flat with a heart-shaped base and very broad, up to 6 inches wide and 12 inches long. Stem leaves have an ocrea and progressively become smaller up the flowering stalk. Leaves become more reddish-purple with age. All leaves are**

slightly wavy on edges.

Stems: **A singe flowering stem that is erect, reddish- brown, and ribbed.**

Roots: **Large, fleshy tap-root, yellowish orange in color.**

Flowers: **Arranged in clusters of racemes on the upper portion of the elongating stem, consisting of greenish sepals that become reddish-brown with age.**

Fruit: **An achene, with 1-3 spines on the 3-winged triangular structure that surrounds the achene.**

Identifying Characteristics: **The large, broad leaves that form a basal rosette and the single, erect flowering stalk are both characteristics that help in thee identification of broadleaf dock. Curly Dock (*Rumex crispus*) is similar in appearance, but it's leaves are narrower and more wavy than those of broadleaf dock.**

Virginia Tech Weed Identification Guide

Select a Resource...

Bouncingbet or Soapwort: *Saponaria officinalis*

Weed Description:

A perennial that primarily occurs in pastures and hay fields of Virginia. Often called soapwort because it produces a soapy lather when crushed, this weed was grown by early settlers for use as a cleaning detergent and soap. Bouncingbet was also cultivated during the Industrial Revolution when cloth was first manufactured on a large scale. Bouncingbet was introduced from Europe and is now

distributed throughout North America. Bouncing-bet is perhaps most noticeable when it produces it's showy flowers in September to October.

Leaves: Elliptic, ovate, or lanceolate in outline, with 3 distinct veins or nerves running the length of the leaf. Leaves range from 1 1/4 to 4 inches in length and from 1/2 to 2 inches in width. Leaves are without petioles (sessile).

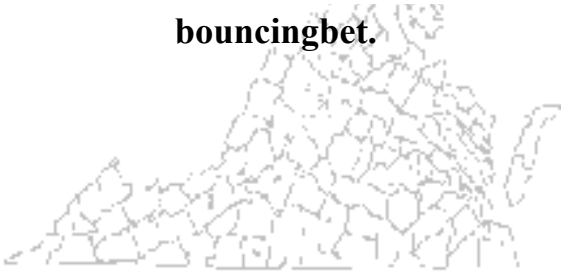
Stems: Erect, 2 to 6 inches tall, usually without hairs. Stems often produce a soapy lather when crushed.

Flowers: Occur in clusters at the ends of stems. Flowers consist of 5 white to pink petals.

Fruit: A long (10-12 mm), elliptical capsule.

Identifying Characteristics: Plants usually occur in colonies. Additionally, the 3-nerved leaves and stems that produce a soapy lather are characteristics that help in the identification of bouncingbet prior to flowering. This weed might be confused with White Campion (*Silene alba*), which also can form dense colonies in pastures and hay fields, but white campion is covered with hairs unlike

bouncingbet.





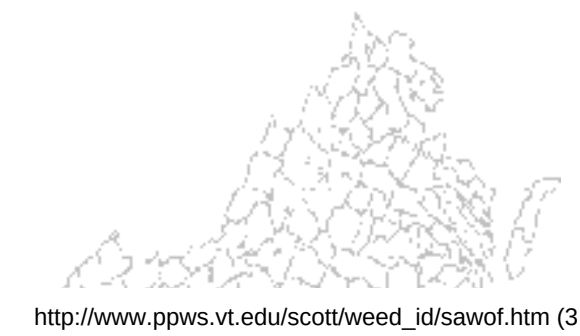
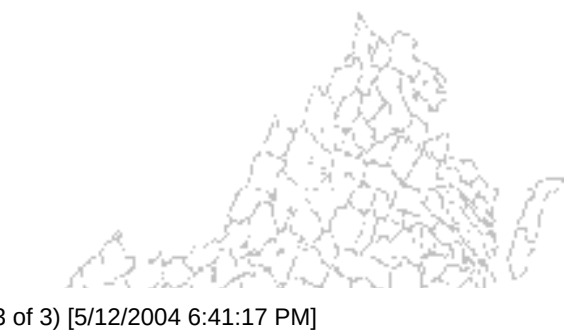











Virginia Tech Weed Identification Guide

Select a Resource...

Brambles: *Rubus* spp.

Weed Description:
Erect, prostrate, or climbing perennials with prickly stems and red or black berries. Members of the brambles include the raspberries, blackberries, dewberries, etc. Brambles are primarily weeds of fence rows, roadsides, landscapes, and occasionally pastures and hay fields. Several different species occur in Virginia and throughout the southeastern United States.

Stems: Erect to eventually arching and climbing on other vegetation or also running prostrate along the ground. All species have prickles along the stem, some are more densely covered with prickles than others.

Roots: **Rhizomes, root sprouts, a fibrous root system, and some stems are capable of forming roots where they come into contact with the ground.**

Leaves: **Leaves are arranged alternately along the stem, occur on petioles, and are divided into 3 to 7 leaflets. Each leaflet has toothed margins.**

Flowers: **Usually consist of 5 green, hairy sepals and 5 white or pinkish petals.**

Fruit: **Many drupelets that compose a berry which we commonly refer to as the fruit. Berries are usually either red or dark purple to black in color when mature and very juicy.**

Identifying Characteristics: **The leaves that are divided into 3 to 7 leaflets, distinctive berries, and rhizomes are all characteristics that help to identify members of the *Rubus* genus. Many different brambles are common in Virginia, perhaps the most common are the blackberries, raspberries, and the dewberries.**

Brazilian Elodea or Egeria: *Egeria densa*

Weed Description: **Submersed aquatic weed that can be found throughout the southeastern United States in ponds, lakes, streams, and rivers.**

Stems: **May reach 6 feet in length and are freely branching. Roots can be formed in the areas where the branching occurs. Stems can be either rooted below or free-floating.**

Leaves: **May occur in whorls of 3 to 6 but are most commonly found in whorls of 4. Individual leaves are linear to oblong in outline, approximately 1 to 1 1/4 inches long and 5 mm wide. Leaves have leaf margins that are finely toothed, but these are hardly noticeable without a magnifying glass. The undersides of the leaf midribs are smooth and without teeth unlike those of hydrilla.**

Flowers: **Consist of 3 white petals and 3 green sepals. Individual flowers are relatively large and showy, with petals that are approximately 1/3 inch long. Flowers usually appear just at the water surface due to long (1 to 4**

inches) flower stalks (pedicels) that arise from the areas between the leaves and the stems (leaf axils).

Identifying Characteristics:

Submersed aquatic weed with leaves arranged in whorls of 3 to 6 and showy flowers with 3 white petals. Brazilian elodea may be easily mistaken for Hydrilla. However, hydrilla has leaves with teeth on the undersides of the leaf midribs and also has much smaller flowers.

Hydrilla also produces tubers unlike Brazilian elodea.

Virginia Tech Weed Identification Guide

Select a Resource...

Brittleleaf or Slender Naiad: *Najas minor*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Broadleaf Signalgrass: *Brachiaria platyphylla*

Weed Description:

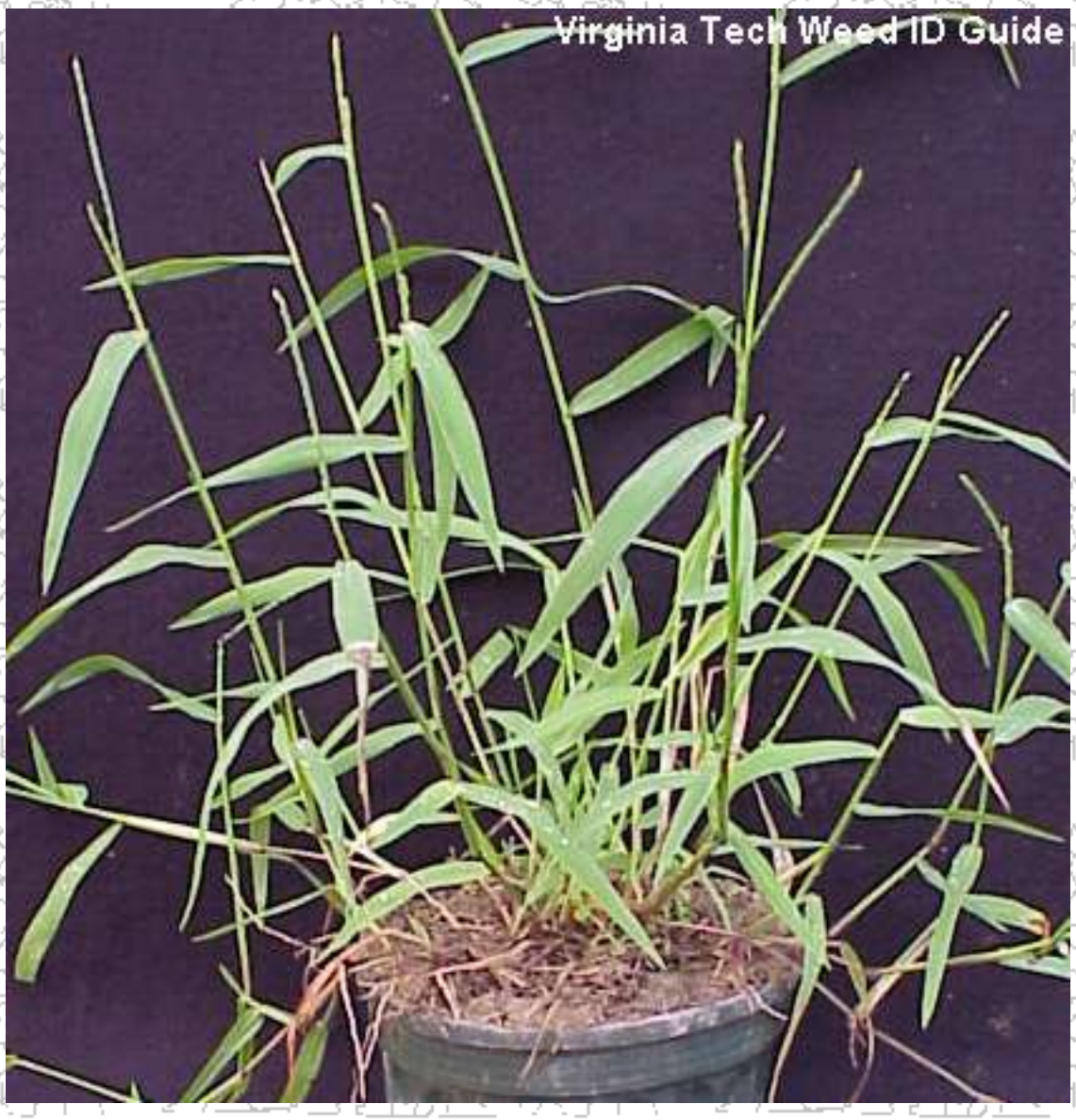
A spreading summer annual that commonly is found growing along the ground but with tips ascending (decumbent growth habit). Broadleaf signalgrass may reach as much as 3 feet in height and is found most commonly as a weed of agronomic crops of the southeastern United States.

Seedling: **Leaf sheaths are often maroon-tinged and hairy throughout. Leaf blades are without hairs, except for those that occur on the margins. Leaf blades may also be maroon-tinged, with a fringed membranous ligule.**

Stems: **Prostrate, branching and bent at the nodes, to approximately 3 ft tall. These plants often root at the lower stem nodes, and therefore are most commonly seen growing along the ground with some tips ascending (decumbent).**

Leaves: **Leaf blades are overall short and wide in appearance, approximately 1 1/2 to 6 inches long and 6-15 mm wide. Leaf blades are widest near the base and taper to the apex. Leaves are rolled in the bud and without hairs on either leaf surface except on margins and in the collar region. The ligule is a narrow membrane fringed with hairs, 1/2 to 1 mm long. Leaf sheaths are hairy.**

Roots: **Roots are fibrous and capable of rooting at the lower stem nodes.**



Flowers: **Seedhead a raceme, approximately 12 inches long and 4 inches wide. Each seedhead has 2 to 6 'branches', approximately 1 to 3 1/2 inches long. Spikelets on the seedhead are somewhat flattened in appearance.**

Identifying Characteristics: **The relatively broad and short leaves of this grass weed make it easily distinguishable from other grasses. Additionally, the lack of hairs on the leaf blades, rooting stem nodes, and flattened spikelets help to identify broadleaf signalgrass from most**

other grasses found in similar environments. Broadleaf signalgrass is similar to Texas panicum (*Panicum texanum*) in growth habit and appearance. However, the leaves of broadleaf signalgrass are not covered with short, soft hairs like those of Texas panicum.

Virginia Tech Weed Identification Guide

Select a Resource...

Texas Panicum: *Panicum texanum*

Weed Description: **A spreading summer annual that may have an erect growth habit or grows close to the ground with tips ascending (decumbent growth habit). Texas panicum may reach as much as 32 inches tall and can root at the lower nodes. Texas panicum is found throughout the southeastern United States and has developed into a significant weed of agronomic crops.**

Seedlings: **Leaf sheaths and blades are covered with soft hairs on both surfaces. First leaves are relatively broad compared to most annual grasses. The fairly large seed from which seedlings arise also helps in the identification of this species.**

Leaves: **Leaf blades range from 3 to 11 inches in length and may reach as much as 20 mm in width. Leaves are covered with short, soft hairs on both surfaces. Auricles are not present and the ligule is membranous and fringed with hairs, from 1 to 1.8 mm long.**

Stems: **May be erect to as much as 32 inches in height or may grow close to the ground with tips ascending (decumbent growth habit). Stems may reach as much as 4 1/2 feet in length and plants can root at the lower nodes. Stem nodes are distinctive and are also covered in soft hairs.**

Flowers: **Seedhead a simple, narrow panicle that ranges from 2 3/4 to10 inches in length. Each 'spike' has 2 rows of spikelets that are each approximately 3 mm long.**

Roots:
Roots are fibrous and plants may root at the lower stem nodes.

Identifying Characteristics: **A summer annual with relatively wide leaves that are covered with soft minute hairs on both surfaces. Texas panicum is very similar in appearance and growth habit to Broadleaf Signalgrass (*Brachiaria platyphylla*). However, broadleaf signalgrass has hairs only along the leaf margins unlike Texas panicum. Additionally, the two can be distinguished in the seedling stage by the lack of hairs on the leaves of broadleaf signalgrass compared to the small velvety hairs on both leaf surfaces of Texas panicum. Texas panicum seedlings also very closely resemble Large Crabgrass (*Digitaria sanguinalis*) in appearance. Once ligules become noticeable, however, the two can be readily distinguished from one another. Large crabgrass has a relatively tall membranous ligule with jagged edges while Texas panicum has a ligule that is membranous at the base but fringed with hairs on the top.**

Virginia Tech Weed Identification Guide

Select a Resource...

Large Crabgrass: *Digitaria sanguinalis*

Weed Description: **Summer annual, having a prostrate or ascending growth habit with stems that root at the nodes. Major distribution in North America from Canada south to Virginia, Kentucky, and Texas, west to California. Usually not found in the lower south.**

Stems: **Prostrate, spreading, branched, and rooting at the nodes.**

Seedling: **Sheaths and blades usually densely hairy, with a jagged membranous ligule. Hairs on the blade and sheath are at a 90° angle to the plant surface. Seedlings are upright, leaves are rolled in the bud, and the first leaf blade is lanceolate to linear.**

Roots: **Fibrous root system.**

Leaves: **Blades 1 1/4 to 8 inches long, 3-10 mm wide, with hairs on both surfaces. Sheaths hairy and closed. Ligules are 1-2 mm long, membranous and appearing as if cut off straight across the end, with uneven teeth or margin. Leaves and sheaths may turn dark red or maroon with age.**

Flowers: **Seed head composed of 4-6 branches (spikes) at the top of stems, each approximately 1 1/2 to 7 inches long. Spikelets are elliptic and in two rows along the spike.**

Seed: **Shiny, yellowish-brown, 2-3 mm long.**

Identifying Characteristics:
Densely hairy leaf and sheath and relatively large membranous ligule. Similar in appearance to Smooth Crabgrass (*Digitaria ishaemum*), but smooth crabgrass does not have hairs on leaves and sheaths, only a few hairs may be found in the collar region. Additionally, large crabgrass roots at the stem nodes while smooth crabgrass does not.

Virginia Tech Weed Identification Guide

Select a Resource...

Smooth Crabgrass: *Digitaria ischaemum*

Weed Description:
Summer annual, having a prostrate or ascending growth habit, with leaves and sheaths that do not have hairs and stems that do not root at the nodes. Found throughout the United States.

Seedling:
Sheaths and blades not hairy, few hairs at mouth only, with a jagged membranous ligule. Seedlings are upright, leaves are rolled in the bud, and the first leaf blade is lanceolate to linear.

Stems: Prostrate or lying on the ground with tips ascending (decumbent) up to 60 cm long, branching at lower nodes but not rooting.

Flowers: Seedhead composed of 2-6 branches (spikes) at the top of stems, each 10 cm long. Spikelets 1.8-2.1 mm long, 0.8-0.9 mm wide, in two rows along the spike, with short mushroom-like hairs.

Leaves: Blades 5-14 cm long, 2-7 mm wide, without hairs. Sheaths are without hairs and closed, with hairs in the collar region only. Ligules are 1-2 mm long, membranous with even margins. Leaves and sheaths may turn dark red or maroon with age.

Roots: Fibrous root system.

Identifying Characteristics: Sheath and leaves without hairs, mushroom-like hairs on spikelet. May be distinguished from Large Crabgrass (*Digitaria sanguinalis*) by the absence of hairs on the leaves and sheath, and only a few hairs found in the collar region. Additionally, smooth crabgrass does not root at the nodes like large crabgrass.

Virginia Tech Weed Identification Guide

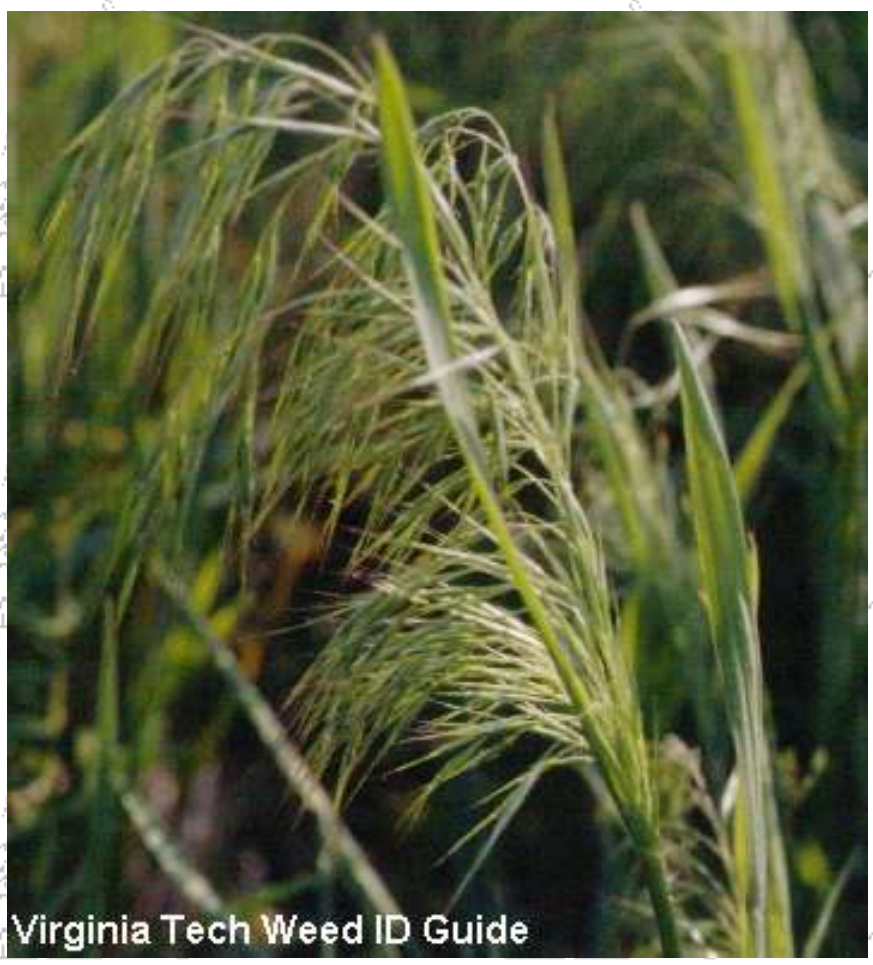
Select a Resource...

Downy Brome: *Bromus tectorum*

Weed Description:
A summer or winter annual with densely hairy leaves and sheaths and drooping seedheads when mature. Downy brome is primarily a weed of landscapes, fencerows, pastures, hay fields, and occasionally winter small grain crops. Downy brome is found throughout the United States except in the extreme southeast.

Leaves: **The leaves are rolled in the shoot and are densely soft hairy on both surfaces. Leaves lack auricles and have a membranous ligule that is approximately 1 1/2 to 3 mm long and may be toothed or fringed with hairs near the top. Leaf blades are approximately 5 to 10 mm wide.**

Roots: **A fibrous root system.**



Stems: **Sheaths are round and also densely hairy.**

Flowers: **The seedhead is a soft drooping panicle that is often purple-tinged. Individual spikelets are approximately 10 to 18 mm long.**

Identifying Characteristics:

The densely hairy leaves and sheaths and drooping seedheads are all characteristics that help to distinguish downy brome from most other weeds. Cheat is very similar in appearance and growth habit, however cheat has mostly smooth leaves unlike those of downy brome.

Virginia Tech Weed Identification Guide

Select a Resource...

Broomsedge: *Andropogon virginicus*

Weed Description:
A perennial grass that forms clumps in many pastures, hay fields, and abondoned fields, and often goes unnoticed until it matures into a reddish-brown clump of broom-like leaves. Found in the eastern half of the United States and in California.

Seedling:
Young leaves are folded in the shoot, to the point that plants take on a compressed appearance. Sheaths are also flat. Leaves have hairs at the base of the

leaf blade and also have a membranous ligule.

Leaves: Leaves are folded in the shoot and are without auricles. A membranous ligule occurs that is approximately 1 to 2 mm long and rounded (sometimes with hairs along the top). Leaf blades are distinctly keeled and approximately 4 to 6 mm wide and from 4 to 24 inches in length. Leaves are usually hairy near the leaf base. Leaves and sheaths turn reddish-brown with maturity and were once used in early times as brooms.

Stems: **Sheaths are distinctly flattened and often have long hairs along the overlapping margins.**

Flowers: **A thin panicle that is produced in the upper half of the stems. The panicle is almost inconspicuous until the hairy spikelets start to emerge and disperse.**

Roots: **Fibrous root system and short, almost unnoticeable, rhizomes.**

Identifying Characteristics: **Plants with distinctly flattened leaves and sheaths that turn reddish-brown with maturity.**

Broomsedge

Browntop Millet: *Brachiaria ramosa*

Weed Description:
A summer annual with relatively wide leaves and open panicles. Browntop millet may grow erect or prostrate along the ground with tips ascending. This grass is primarily a weed of agronomic crops, hay fields, and abandoned fields.

Flowers:
Seedhead an open panicle, 1 1/2 to 7 inches long, 3/4 to 2 1/2 inches wide. Individual grains are tan in color, ellipsoid, and approximately 2 mm long.

Stems: Plants go erect or prostrate along the ground with tips ascending. Stems may reach 3 1/2 feet in height. Nodes along the stem are minutely to shortly hairy, and sheaths between the nodal sections are without hairs. Sheath margins may be hairy.

Roots: A fibrous root system.

Leaves: Leaf blades may reach 7 inches in length and 15 mm in width and are without hairs on both surfaces. However, minute hairs may occur on the upper leaf surfaces near the leaf bases, but these are rarely visible to the naked eye. Leaves are without auricles and have a ligule that is a fringe of hairs approximately 1/2 to 1 1/2 mm long.

Identifying Characteristics: A summer annual grass with

relatively large leaves that have a small ligule that is a fringe of hairs and is otherwise essentially hairless throughout. Wild-proso millet (*Panicum miliaceum*) is very similar to browntop millet, however wild-proso millet has sheaths that are densely covered with conspicuous hairs. Wild-proso millet also appears to be more common in Virginia than browntop millet.

Virginia Tech Weed Identification Guide

Select a Resource...

Buckhorn Plantain: *Plantago lanceolata*

Weed Description:
Perennial weed primarily of turfgrass found throughout the continental United States.

Seedling: **Cotyledons resemble a grass emerging, are linear and smooth.**

Flowers: **A spike that is unbranched and leafless to 10 cm long and contains many inconspicuous flowers.**

Fruit: **A 2-seeded capsule, 3-4 mm long.**

Roots: **Fibrous roots from a short taproot.**

Mature Plant: **All leaves are in a basal rosette. Leaves are linear to lanceolate (5-25 cm long by 1-2.5 cm wide) with veins running the length of the leaf, may be sparsely hairy or without hairs.**

Identifying Characteristics: **Narrow, linear leaves from a basal rosette with characteristic flowering spikes typical of a plantain.**

Virginia Tech Weed Identification Guide

Select a Resource...

Bulbous Oatgrass or Bulbous Tall Oatgrass:

Arrhenatherum elatius var. *bulbosa*

Weed Description: **Perennial, clump-forming grass that goes dormant during the summer and carries out it's life cycle during the winter months. Found throughout the southeastern United States primarily as a weed of winter small grains, landscapes, and turfgrass.**

Leaves: **Leaves are rolled in the bud, without auricles, and have a membranous ligule approximately 1/2 to 1 mm long. Leaf blades are approximately 10 mm wide and may reach 1 foot in length. Leaf blades may be sparsely hairy above or without hairs (glabrous), but lower surfaces are**

usually completely glabrous.

Stems: **Round, without hairs or only sparsely hairy with split, overlapping margins.**

Roots: **Fibrous root system and bulbous fragments (pictured above) that are actually called corms. These fragments allow for the vegetative reproduction and spread of this species.**

Flowers: **Seedhead a narrow, shiny, erect or nodding, green or purplish panicle.**

Identifying Characteristics:

Perennial, clump-forming grass that carries out it's life cycle during the winter. Characteristic seedhead and bulbous roots (corms) also help to distinguish this weed from most other grass species.

Virginia Tech Weed Identification Guide

Select a Resource...

Bull Thistle: *Cirsium vulgare*

Weed Description: **An erect biennial with spines on the leaves and stems. Found throughout the United States, primarily a weed of pastures.**

Seedling: **Cotyledons egg-shaped, young leaves develop as a rosette. Leaves are oblong with small spines along the margins. Second true leaf and subsequent young leaves contain many hairs on the upper surface.**

Flowers: **Clustered or solitary at the ends of branches. Flowers are 1.5-2 inches wide, rose to reddish-purple, and surrounded by spiny-tipped bracts.**

Fruit: **An achene (3-4 mm long).**

Leaves: **Arranged alternately on the flowering stem, lanceolate with deeply cut margins and stiff spines on the lobes. Leaves are coarsely hairy on the upper side and contain softer whitish hairs below. Leaf bases continue down the flowering stem.**

Stems: **2 to 5 feet tall, branching, hairy, green or brown with age, and with the leaf margins extending down the stem (spiny "wings").**

Roots: **Taproot.**

Identifying Characteristics:
Spiny-winged stems and leaves with rough hairs on the upper surface and softer whitish hairs below. This weed is often confused with Musk Thistle (*Carduus nutans*), but the leaves of mature musk thistle plants usually lack hairs. Additionally, Canada Thistle (*Cirsium arvense*) is a perennial from rhizomes, and young plants do not develop as a rosette, unlike bull thistle.

Virginia Tech Weed Identification Guide

Select a Resource...

Musk Thistle, or Nodding Thistle: *Carduus nutans*

Weed Description: **An erect biennial with spiny leaves and stems that may reach 6 ½ feet in height. Primarily a weed of pastures, hayfields, roadsides, and noncrop areas that can be found throughout the United States.**

Seedling: **Cotyledons are rectangular to oblong in outline, approximately 7 ½ to 15 mm long and 2 ½ to 6 mm wide. Cotyledons occur with little to no petioles (sessile) and have distinctive white veins on their upper surface. Young leaves are essentially without hairs and immediately take on a rosette growth habit.**

Stems: **Erect, branched, with spines extending down the stem from the leaf bases.**

Roots: **Large, thick taproot that is hollow near the soil surface.**

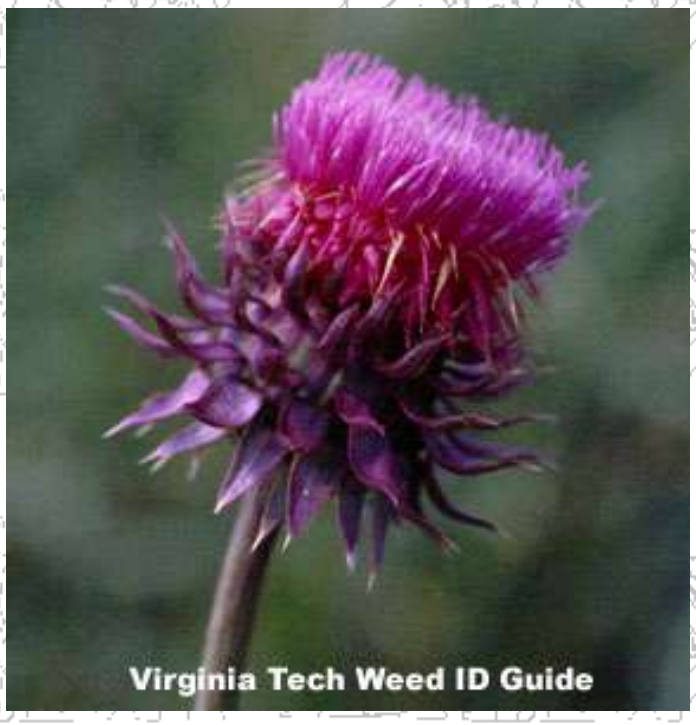
Leaves: **During the first year of growth a basal rosette of leaves form with the first 2 true leaves being opposite and all subsequent leaves alternate. During the second year of growth, the rosettes elongate and flowering stems are produced. All leaves that occur on the flowering stems are also alternate. All leaves are dark green in color with light green to white midribs and veins. Leaves are lanceolate in outline, deeply lobed and approximately 10 inches long by 4 inches wide. Three to five spines occur along the margins of each lobe, and these white or yellow spines are approximately 2 to 5 mm long. The leaf bases extend down to the stem, and the leaves become progressively smaller up the stem.**

Fruit: **An achene that is tan to brown in color and approximately 4 mm long. Achenes are oblong in outline and have a white pappus that resembles white hairs.**

Flowers: **Solitary flower heads are produced at the end of branches. Individual flowers are 1 ¼ to 2 inches wide and are pink to violet or purple in color. Spiny bracts occur below the flower heads and these are often tinted purple in color.**

Identifying Characteristics:

Erect, spiny biennial with deeply lobed leaves and relatively large flowers that are pink to violet or purple in color. Musk thistle is similar in growth habit and appearance to Bull Thistle (*Cirsium vulgare*), however bull thistle has many hairs on the upper surface of the leaf blades unlike musk thistle which mostly lacks hairs. Additionally, the flower heads and bracts of bull thistle gradually taper to a point when compared to those of musk thistle. Musk thistle may also be confused with Canada Thistle (*Cirsium arvense*), but Canada thistle has rhizomes and rarely takes on a rosette growth habit unlike either bull or musk thistle.



Virginia Tech Weed Identification Guide

Select a Resource...

Canada Thistle: *Cirsium arvense*

Weed Description: **Perennial by rhizomes, 2 to 6 feet in height. Often a persistent spreading weed of many pastures.**

Seedling: **Cotyledons are club shaped, dull green in color and relatively thick. Young leaves covered with short hairs. Leaf margins are wavy with spines. Shoots that emerge from rhizomes lack cotyledons.**

Roots:
An extensive rhizome system that can extend up to 3 1/2 feet into the soil in a creeping horizontal growth pattern.

Stems:
Grooved, branching

at top, glabrous early but becoming pubescent with maturity.

Leaves: **Alternate, sessile, simple, oblong to lanceolate. Leaves are irregularly lobed, developing into triangular indentations with age, with spiny margins. Upper surface of mature leaves is dark green and hairless, while the lower surface is light green in color and may be with or without hairs.**

Flowers: **Heads are numerous, 3/4 to 1 1/4 inches in diameter, and are composed of pink, purple, or rarely white disk flowers surrounded by spineless bracts. Flowers are present from June through August.**

Fruit: **A flattened, brownish achene 2 1/2 to 4 mm long which encloses the seed.**

Identifying Characteristics:

Plants in patches due to horizontal rhizome growth. Young leaves are covered with short hairs (illustrated above). The flowers of Canada thistle do not have

spines or prickles unlike bull or musk thistle. Stems are also spineless unlike Bull Thistle (*Cirsium vulgare*) or Musk Thistle (*Carduus nutans*).

Virginia Tech Weed Identification Guide

Select a Resource...

Buffalobur: *Solanum rostratum*

Weed Description: **An annual with deeply lobed leaves and spines. May grow to 2 feet in height. Buffalobur is found throughout the United States, but is relatively rare in Virginia.**

Seedling: **Cotyledons often purple-tinged beneath, without hairs or often with gland-tipped hairs on the margin and midvein beneath. Stems below the cotyledons (hypocotyls) are also often purple-tinged, succulent, and hairy.**

Roots: **Fibrous tap root system.**

Leaves: Alternate, egg-shaped in outline and widest at the apex (obovate), deeply lobed, 2 to 5 inches long, petiolate, with stiff straight hairs on the upper surface and dense star-shaped hairs on the lower surface. Leaf venation is also very prominent.

Stems: Erect or spreading, up to 2 ft tall, with star-shaped hairs and many yellow spines.

Flowers: Bright yellow in color, 5-parted, and approximately 1 inch wide.

Fruit: A berry, 8-12 mm in diameter that is enclosed by a spiny calyx.

Identifying Characteristics: The deeply lobed leaves with prominent white veins, bright yellow flowers, and foliage and fruit that are covered with spines are all characteristics that help to distinguish buffalobur from most other weeds.

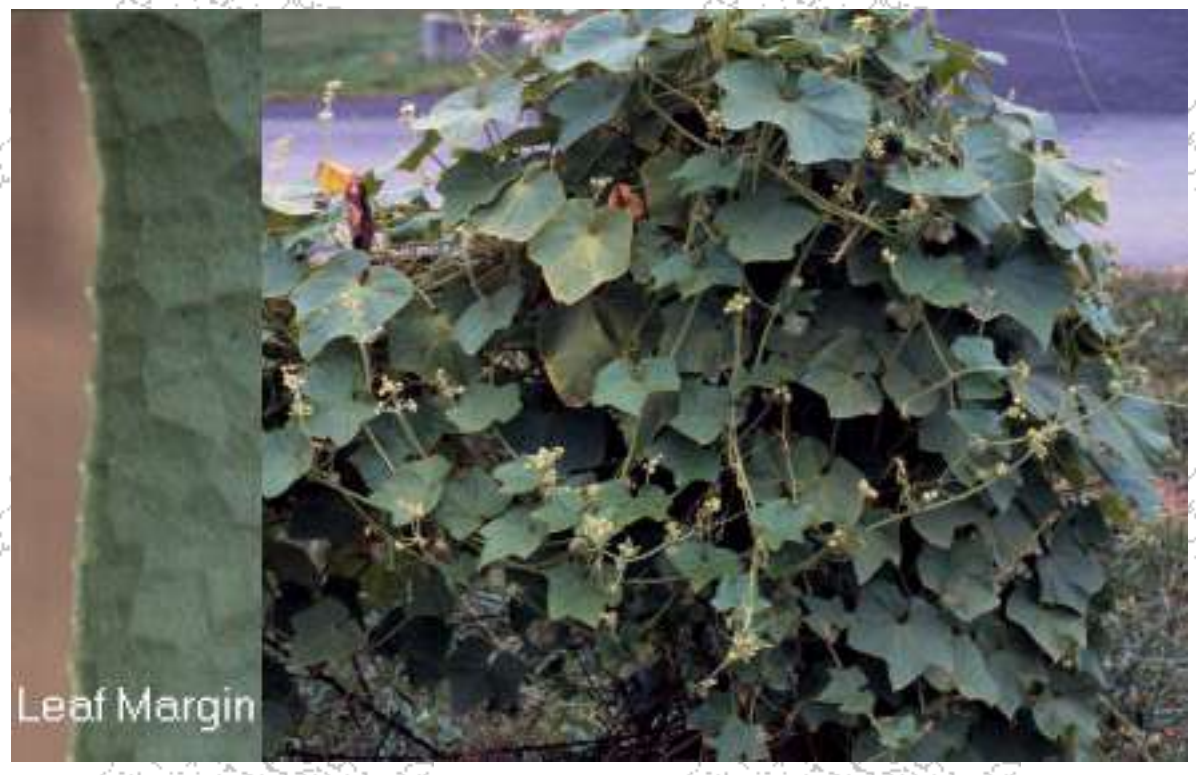
Burcucumber: *Sicyos angulatus*

Weed Description: **A summer annual climbing vine that closely resembles cucumber plants, especially during the early stages of growth. Vining stems often climb by way of tendrils. Found from the east coast to Florida and west to Minnesota, Kansas and Texas.**

Roots: **Fibrous.**

Seedling: **Cotyledons very closely resemble those of ordinary cucumber cotyledons, are thick and oblong, with many spreading hairs on the top and bottom. The stem below the cotyledons (hypocotyl) is also covered with many short hairs that typically point downward.**

Stems: **Stems are hairy especially at the leaf nodes, longitudinally ridged, and climb by way of branched tendrils.**



Leaves: **Alternate, 2-8 inches long, 2-8 inches wide, hairy, broadly heart shaped with 5 pointed lobes and a toothed margin.**

Flowers: **Whitish to green, with 5 sepals and 5 petals.**

Fruit: **Produced in clusters of 3-20, and resemble very small cucumbers covered with long bristles.**

Identifying Characteristics:

Vining plant with 5-lobed leaves and small, spiny fruit that resemble cucumbers. This plant may very easily be confused with wild cucumber (*Echinocystis lobata*). However, wild cucumber has more deeply lobed leaves that are almost star-shaped, stems that are rarely hairy, and flowers that have 6 sepals and 6 petals. Burcucumber might also be confused with Japanese Hops (*Humulus japonicus*), however this weed does not have tendrils and has downward-pointing prickles on the stems.

Virginia Tech Weed Identification Guide

Select a Resource...

Japanese Hops: *Humulus japonicus*

Weed Description: **Annual climbing or trailing vine with 5-lobed leaves and stems with prickles. Japanese Hops is primarily a weed of pastures, hayfields, and other noncrop areas that is found throughout Virginia, Tennessee, North Carolina, and West Virginia.**

Leaves: **Leaves are approximately 2 to 4 inches long and are divided into 5 distinct lobes. Leaves are rough to the touch and occur on petioles that may reach 8 inches in length. Bracts occur at the base of the leaf petioles.**

Stems: **Climbing or trailing along**

the ground and are covered with small prickles that are turned downward. Bracts occur where the leaf petioles attach to the stem.

Flowers: **Individual flowers are relatively inconspicuous, without petals, and green in color. Flowers occur in clusters that may reach 2 1/2 inches in length.**

Fruit: **An achene.**

Identifying Characteristics:

The climbing or trailing growth habit, conspicuously 5-lobed leaves, and stems with downward pointed prickles are all characteristics that help in the identification of Japanese hops. Wild cucumber (*Echinocystis lobata*) also has 5-lobed leaves and a similar growth habit, however this weed has tendrils and does not have the downward pointing prickles along the stem like Japanese hops.

Virginia Tech Weed Identification Guide

Select a Resource...

Common Burdock: *Arctium minus*

Weed Description: **A biennial that produces a rosette of very large leaves in the first year and a branched stem with many burs during the second year. Found across the upper half of the United States and is most commonly found as a weed of pastures, hay fields, and fence rows.**

Seedling: **Cotyledons are egg-shaped and widest near the apex (obovate) with a waxy surface. Young leaves are also egg-shaped, except at the truncated base.**

Roots: **Large taproot.**

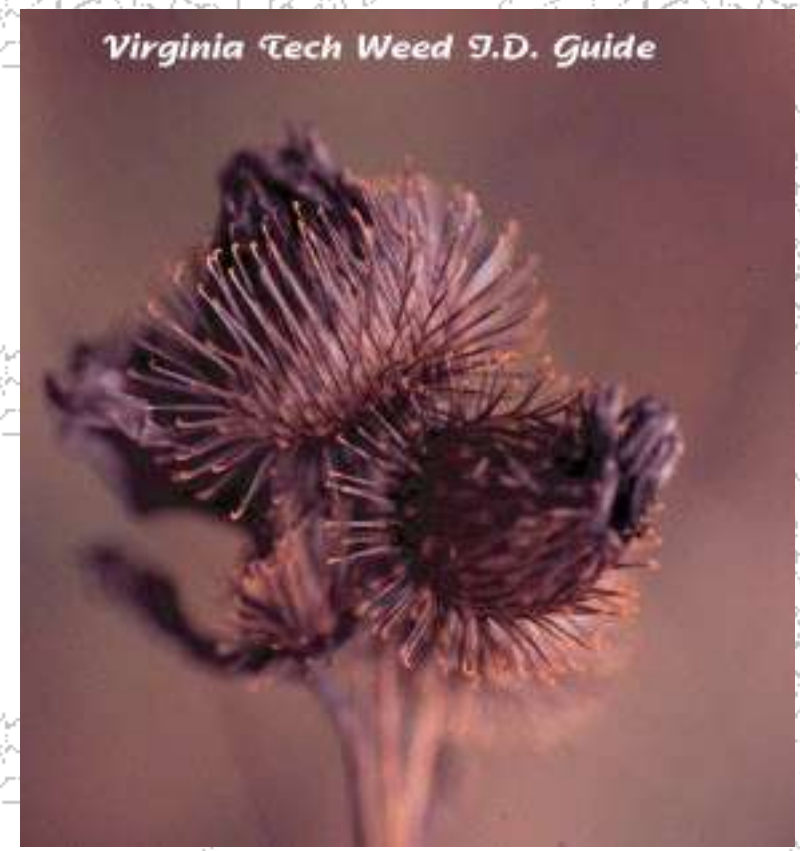
Leaves: **Rosette leaves are broadly heart-shaped, 6-18 inches long, 4-14 inches wide, with hollow petioles and wavy and toothed margins. The undersides of these leaves are loosely hairy and light green. Stem leaves are much smaller, alternate, and egg-shaped.**

Flowers: **Occur in clusters at the ends of branches (terminal racemes) or in clusters that arise from the region between the stem and leaves (axillary racemes). Flowers are purple to lavender, occasionally white, with outer bracts that are "hooked." Flowers dry to a bur, and the hooked bracts are often confused with a thistle.**

Fruit: **An achene, mottled dark-gray to black, 4-7 mm long, with a pappus of short bristles.**

Stems: **Produced during the second year of growth. Stems are erect, branched, hollow, hairy, and ridged. Stems may reach 5 ft in height.**

Identifying Characteristics:
Large basal rosette of leaves with hollow lower petioles, and flowers with hooked bracts. After senescence, the remaining burs on the stems of common burdock may resemble a thistle. However, the dried flowers of thistle plants do not have hooked bracts like common burdock.



Virginia Tech Weed Identification Guide

Select a Resource...

Lawn Burweed: *Soliva pterosperma*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Bulbous Buttercup: *Ranunculus bulbosus*

Weed Description: **A low-growing perennial with divided leaves and distinctive yellow flowers. The buttercups are common weeds of turfgrass, lawns, pastures, hay fields, and occasionally landscapes. Bulbous buttercup is found throughout the eastern and western United States.**

Seedlings: **Cotyledons occur on petioles and are oval to elliptic in outline. The first true leaves are hairy and divided into 3 lobes. True leaves also occur on petioles.**

Roots: **The base of the plant is**

thickened into a structure known as a corm, which resembles a bulb. Corms aren't always as evident as that pictured below. In younger plants, a thickened base may be all that occurs.

Leaves:
Basal leaves occur on long petioles and are divided into 3 lobes. As the leaves become more mature, the central lobe occurs on it's own stalk while the lateral lobes are attached directly to the main leaf petiole. Stem leaves

are generally smaller than the basal leaves and arranged alternately along the stem. Stem leaves are also less distinctively lobed than the basal leaves.

Stems: Erect, from 8 to 24 inches in height but generally more prostrate in turfgrass and lawns. Stems are occasionally hairy near the base and end in a typical buttercup flower.

Flowers: **Single flowers occur on flower stalks at the ends of stems. Flowers range from 1/2 to 1 1/4 inches wide and consist of 5 to 7 bright yellow petals.**

Fruit: **An achene.**

Identifying Characteristics: **The distinctive buttercup flowers, leaves that are divided into 3 parts, and thickened 'bulbous' base are all characteristics that help to distinguish bulbous buttercup from other similar species. Several other buttercup species are common, such as Corn Buttercup (*Ranunculus*

arvensis), however none of the other buttercups have the corms like bulbous buttercup. Additionally, the stem leaves of corn buttercup are essentially linear in outline unlike bulbous buttercup.

Bird's-foot Violet (_Viola pedata_) also resembles the buttercup species prior to flowering, however this plant has leaves that are divided into 3 lobes with each lobe being divided further.

Virginia Tech Weed Identification Guide

Select a Resource...

Corn Buttercup: *Ranunculus arvensis*

Weed Description: **Erect winter annual, 6 to 24 inches tall with yellow flowers. Found primarily in the piedmonts of Virginia, Georgia, Florida, Mississippi, Tennessee, and Kentucky.**

Seedling: **Cotyledons have petioles. Leaves egg-shaped in outline, with the broadest end occurring at the apex, and having toothed margins.**

Stems: **Erect, branching.**

Fruit: **An achene, 6-8 mm long, 4-5 mm wide, covered with up to 3 mm long spines.**

Flowers: **Yellow in color, 5 sepals 3-5 mm long, and 5 petals 4-6.5 mm long.**

Leaves: **Leaves consist of both basal and stem leaves (cauline). Basal leaves are on long petioles, spatulate in outline with toothed margins. Stem leaves are dissected into 3-parted linear segments that are approximately 1 1/4 inches in length and 5 mm in width, without petioles, without hairs to sparsely roughly hairy.**

Identifying Characteristics: **The distinctive buttercup flowers and spatulate basal leaves with linear stem leaves are all characteristics that help to distinguish corn buttercup from most other similar weeds. Several different buttercup species are common, like Bulbous Buttercup (*Ranunculus bulbosus*), but this weed has a thickened 'bulbous' base and does not have linear stem leaves like those of corn buttercup.**

Virginia Tech Weed Identification Guide

Select a Resource...

Bird's-foot or Crowfoot Violet: *Viola pedata*

Weed Description: **A perennial with short rhizomes that is often misidentified as one of the buttercup species prior to flowering. Bird's-foot violet is usually found along the edges of woods in the mountainous and piedmont areas of Virginia, Georgia, Alabama, Mississippi, Tennessee, Kentucky, and West Virginia. It is rarely viewed as a weed but often admired as a wildflower.**

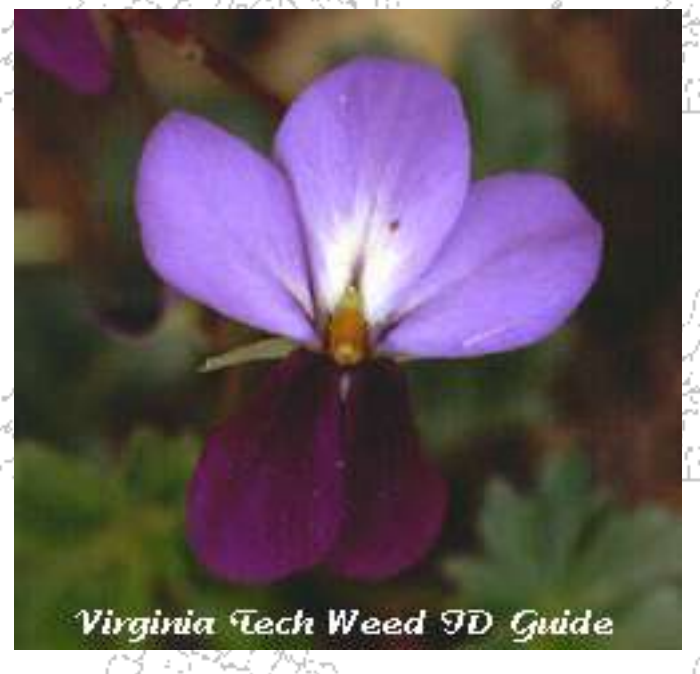
Stems: **Plants grow prostrate along the ground with no real stems present. Flowers occur on long flower stalks (peduncles).**

Roots: **Short rhizomes.**

Fruit: **A capsule that ranges from 7 to 9 mm in length.**

Leaves: **Leaves are without hairs and dissected or lobed into 3 main parts, with each lobe arising from the same central point. The lateral lobes are lobed or dissected again into 3 parts. The central lobe is also lobed or dissected into at least 3 parts. Overall, the leaves are approximately 1 to 2 inches long and occur on petioles that are approximately 6 inches long.**

Flowers: **Approximately 1 1/4 to 1 3/4 inches wide, purple to light blue in color. Flowers consist of 2 upper petals that are deep purple in color and three lower petals that are light purple to lavender in color. Flowers occur on long flower stalks (peduncles).**



Identifying Characteristics: **The leaves that are lobed or dissected into 3 parts, with each lobe then divided further and the distinctive flowers are both characteristics that help to distinguish this plant from most other species. Prior to flowering, bird's-foot violet may be mistaken with any of the buttercup species, including Bulbous Buttercup (*Ranunculus bulbosus*). However, most of the buttercups have leaves with a central lobe that eventually occurs on its own stalk, unlike bird's-foot violet. Additionally, the lateral lobes of most buttercup leaves are not divided further as in bird's-foot violet.**

Virginia Tech Weed Identification Guide

Select a Resource...

Smallflower Buttercup or Small-flowered Crowfoot: *Ranunculus abortivus*


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Butterfly Milkweed or Butterfly Weed:

Asclepias tuberosa


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Poorjoe or Common Buttonweed: *Diodia teres*

Weed Description: **Erect or spreading annual with opposite, linear leaves and small white flowers. Found throughout the southeastern United States.**

Leaves: **Linear or elliptic, 3/4-1 1/2 inches long, 2-6 mm wide, opposite, without petioles, with a prominent midvein on both surfaces. Leaves are connected across the stem by a membrane that has several long (3-5 mm) hairs connected to it.**

Stems: **Hairy, and most often occur prostrate and spreading along the ground.**

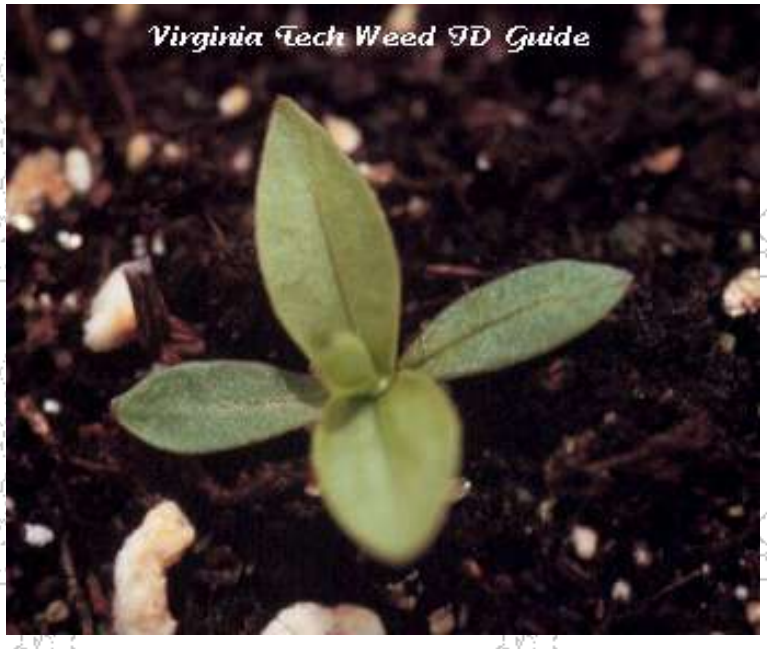
Flowers: **Arise from a region between the stem and leaf (axillary), usually solitary, star-shaped, and consist of 4 small white sepals.**

Identifying Characteristics:
Prostrate growth habit, small, white, 4-parted flowers, and membrane connecting each pair of opposite leaves helps to distinguish this plant from most other weeds. However, Virginia Buttonweed (*Diodia virginiana*) is very similar in growth habit and appearance but is a perennial with much wider leaves and stems that root at the nodes.

Virginia Tech Weed Identification Guide

Select a Resource...

Virginia Buttonweed: *Diodia virginiana*



Weed Description: **A spreading perennial weed with opposite leaves that often have a yellowish mottling due to the presence of a virus that grows in close association with this weed. Virginia buttonweed seems to proliferate in moist or wet areas, tolerates close mowing and is a very troublesome weed of lawns and turfgrass throughout the southeastern United States.**

Roots: **Flesh roots allow vegetative reproduction to occur.**

Stems: **Usually trail along the ground but sometimes are ascending. Stems root at the nodes and are occasionally hairy.**

Leaves: **Opposite, elliptic to lance-shaped, without petioles (sessile), and approximately 1 ¼ to 2 ½ inches long by ½ to 1 inch wide. Leaves often have a yellow mottling due to the presence of a virus and the leaves are joined across the stem by a membrane that has 1 to 3 stipules that resemble long bristly hairs.**

Seedling: **Cotyledons are thick and oblong, dark green on the upper surface and lighter green below. First true leaves are elliptic to lance-shaped, without petioles (sessile), and are joined across the stem by a membrane that has 1 to 3 stipules that resemble long bristly hairs.**

Flowers: **Occur in the position between the leaf and the stem (leaf axils). Individual flowers are star-shaped with four white petals and are approximately ½ inch wide and 9 mm long.**

Fruit: **A small, hairy capsule (5 to 9 mm) that contains 2 seeds.**

Identifying Characteristics: **A prostrate perennial weed of turfgrass with opposite leaves and small white flowers that occur in the leaf axils. The yellow mottling that is often associated with this weed is also a characteristic that helps to distinguish Virginia buttonweed from other similar weeds. Poorjoe or Common Buttonweed (*Diodia teres*) is similar in appearance to Virginia buttonweed but this weed grows**

more upright, has much narrower leaves, and has stems that are much more hairy than those of Virginia Buttonweed. Additionally, Florida pusley (*Richardia scabra*) has opposite leaves and a similar growth habit, but Florida pusley has leaves and stems that are much more hairy and flowers with 6 petals unlike Virginia buttonweed.

Common Weed Names: C

Common Name	Scientific Name
Calamint	*Calamintha nepeta*
Calepina	*Calepina irregularis*
Campion, Bladder	*Silene vulgaris*
Campion, White	*Silene alba*
Canada Goldenrod	*Solidago canadensis*
Canada Thistle	*Cirsium arvense*
Cancer-root	*Conopholis americana*
Caper Spurge	*Euphorbia lathyris*
Carolina Geranium	*Geranium carolinianum*
Carpetweed	*Mollugo verticillata*
Carrot, Wild	*Daucus carota*
Catnip	*Nepeta cataria*
Catsear, Common	*Hypochoeris radicata*
Cattails	*Typha spp.*
Centipedegrass	*Eremochloa ophiuroides*
Chara	*Chara* spp.
Chickweed, common	*Stellaria media*
Chickweed, mouse-ear	*Cerastium vulgatum*
Chicory	*Cichorium intybus*
Chinese Yam	*Dioscorea batatas*
Cinnamon Vine	*Dioscorea batatas*

Cinquefoil, Sulfur	*Potentilla recta*
Clammy Groundcherry	*Physalis heterophylla*
Clover, Japanese	*Lespedeza striata*
Clover, Rabbitfoot	*Trifolium arvense*
Clover, Red	*Trifolium pratense*
Clover, White	*Trifolium repens*
Clover, White Sweet	*Melilotus alba*
Cocklebur, Common	*Xanthium strumarium*
Cocklebur, Spiny	*Xanthium spinosum*
Coffee Senna	*Senna occidentalis*
Common Blue Violet	*Viola papilionacea*
Common Burdock	*Arctium minus*
Common Buttonweed	*Diodia teres*
Common Catsear	*Hypochoeris radicata*
Common Cocklebur	*Xanthium strumarium*
Common Dayflower	*Commelina communis*
Common Eveningprimrose	*Oenothera biennis*
Common Groundsel	*Senecio vulgaris*
Common Lambsquarters	*Chenopodium album*
Common Lespedeza	*Lespedeza striata*
Common Mallow	*Malva neglecta*
Common Milkweed	*Asclepias syriaca*
Common Mullein	*Verbascum thapsus*
Common Pokeweed	*Phytolacca americana*

Common Purslane	*Portulaca oleracea*
Common Ragweed	*Ambrosia artemisiifolia*
Common Reed	*Phragmites australis*
Common Teasel	*Dipsacus fullonum*
Common Toadflax	*Linaria canadensis*
Common Venus' Looking-glass	*Triodanis perfoliata*
Common Vetch	*Vicia sativa*
Common Yarrow	*Achillea millefolium*
Coontail	*Ceratophyllum demersum*
Copperleaf, Hophornbeam	*Acalypha ostryifolia*
Copperleaf, Virginia	*Acalypha virginica*
Coral-Berry	*Smphoricarpos orbiculatus*
Coreopsis Beggarticks	*Bidens polylepis*
Corn Buttercup	*Ranunculus arvensis*
Cornflower	*Centaurea cyanus*
Corn Salad	*Valerianella radiata*
Corn Spurry	*Spergula arvensis*
Cotton Morningglory	*Ipomoea cordatotriloba**
Cow-itch	*Campsis radicans*
Crabgrass, Large	*Digitaria sanguinalis*
Crabgrass, Smooth	*Digitaria ischaemum*
Creeping Phlox	*Phlox subulata*
Creeping Primrose	*Ludwigia palustris*
Creeping Rush	*Juncus repens*

Creeping Woodsorrel	*Oxalis corniculata*
Cress, Mouse-ear	*Arabidopsis thaliana*
Crossvine	*Bignonia capreolata*
Croton, Tropic	*Croton glandulosus*
Crowfootgrass	*Dactyloctenium aegyptium*
Crowfoot, Small-flowered	*Ranunculus abortivus*
Crownbeard, Yellow	*Verbesina occidentalis*
Crownvetch	*Coronilla varia*
Cudweed, Purple	*Gnaphalium purpureum*
Curly Dock	*Rumex crispus*
Curlyleaf Pondweed	*Potamogeton crispus*
Cutleaf Eveningprimrose	*Oenothera laciniata*
Cutleaf Geranium	*Geranium dissectum*
Cypress Spurge	*Euphorbia cyparissias*
Cypressvine Morningglory	*Ipomoea quamoclit*

The full scientific name is *Ipomoea cordatotriloba* var. *torreyana

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Canada or Common Goldenrod: *Solidago canadensis*


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Squaw-root or Cancer-root: *Conopholis americana*

Virginia Tech Weed Identification Guide

Select a Resource...

Caper Spurge or Mole Plant: *Euphorbia lathyris*

Weed Description: **An annual with opposite, lanceolate leaves that is often grown as an ornamental. All parts of these plants emit a milky sap when broken. Caper spurge occasionally occurs as a weed of landscapes, roadsides, and pastures, but is not very common. Caper spurge is found throughout Virginia, North Carolina, Georgia, and West Virginia.**

Leaves: **Lanceolate in outline, without hairs, approximately 2 1/2 to 6 inches long, 1/4 to 1 inch wide. Leaves are arranged oppositely and are without petioles (sessile). Leaves also have conspicuous white midveins. Leaves near the upper flowers are much shorter and triangular in outline. Leaves emit a milky sap when broken.**

Flowers: **Flowers are relatively inconspicuous and occur in the upper portions of the plant. Flowers are green to greenish yellow in color.**

Fruit: **A smooth capsule that is 8 to 10 mm long.**

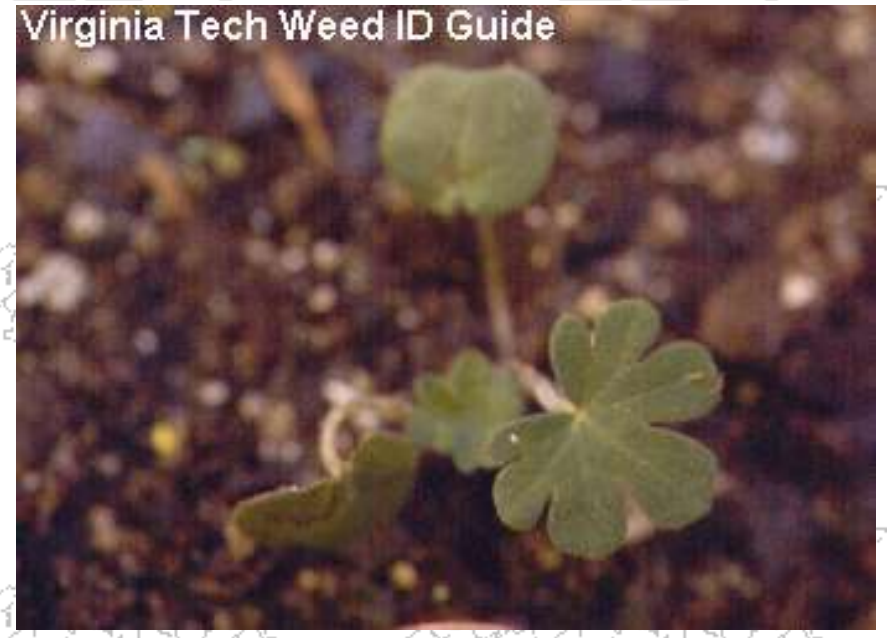
Stems: **Erect, without hairs, emits a milky sap when cut.**

Identifying Characteristics: Erect plants with lanceolate leaves with a conspicuous white midvein. Additionally, the fact that these plants emit a milky sap when cut readily identifies them as a *Euphorbia* species. Caper spurge is often confused with leafy spurge, however leafy spurge is a perennial with lateral root buds and does not have the conspicuous white midveins like those of caper spurge.

Virginia Tech Weed Identification Guide

Select a Resource...

Carolina Geranium: *Geranium carolinianum*



Weed Description: **Most often a biennial, forming a basal rosette initially with subsequent stem elongation and branching as the plant matures. May also occur as a winter or summer annual. Found throughout the United States.**

Roots: **Fibrous with shallow taproot.**

Stems: **Erect, freely branching near base to 28 inches tall. Stems are usually pink to red in color and densely hairy.**

Leaves: **Alternate near base, opposite above, and hairy on both surfaces. Leaves (3/4 to 2 1/2 inches wide) are**

rounded in appearance, and deeply (palmately) divided into 5-9 segments, with each segment also lobed or toothed.

Fruit: **Less than 3 mm long with an elongated beak that gives this structure the appearance of a crane's bill, which is also another common name of this weed.**

Seedling: **Cotyledons are hairy, broad (6 mm wide), kidney-shaped, green above and pink below. Young leaves are hairy on both surfaces, alternate, and have leaf veins arising from a common point (palmately veined). Petioles of young plants are pink and covered with hairs that point downward.**

Margins of leaves are deeply lobed.

Flowers: **Two or more in clusters at tips of stems and branches. Petals are whitish-pink to pale purple in color, 4-6 mm long.**

Identifying Characteristics: **Divided leaves and distinctive 'crane's bill' fruit. Also, the whitish-pink to purple flower color of Carolina geranium helps to distinguish it from similar geranium species (dovefoot and smallflower geraniums).**

Carpetweed: *Mollugo verticillata*

Weed Description: **A late-germinating, much-branched summer annual forming circular patches several feet in diameter.**

Seedling: **Hypocotyl is short, green early turning brown with time. Cotyledons are oblong, thickened, smooth and 1.5 to 3.0 mm long.**

Leaves: **Smooth, in whorls of 3-8 at each node. Leaves are sessile, 1 to 3 cm long, widest above the middle and tapering to the base (oblanceolate).**

Roots: **Small, branched taproot.**

Stems: **Smooth and much-branched, lying on the ground with tips ascending (decumbent). Stems are green and 5 to 30 cm long.**

Flowers: **In clusters of 2 to 5 with slender 5-15 mm long stalks. Each flower is small (4-5 mm wide), and white in color.**

Fruit: **A small (1.5-4 mm long) three-parted, egg-shaped capsule containing small orange to red seeds.**

Identifying Characteristics: **Whorls of leaves at each stem node in addition to the circular, light green, mat-like growth.**

Wild Carrot or Queen Anne's Lace: *Daucus carota*

Weed Description: **A biennial that closely resembles a typical garden carrot during the first year of growth. During the second year of growth, the plants produce stalks with white, flat-topped flowers. Found throughout the United States.**

Seedling: **Cotyledons are linear, and may be mistaken for an emerging grass seedling. Cotyledons are without hairs, do not have petioles, and taper at both the base and the apex.**

Leaves: **A rosette of lobed, deeply dissected leaves are produced during the first year of growth. Leaves have long petioles, are without hairs on the upper surface, and may have hairs on the veins and margins of the lower surface. Leaves on the flowering stems produced during the second year of growth are alternate,**

oblong in outline, with lobed segments.

Flowers: **Many white flowers occur in a cluster where the stalks of each flower (pedicels) all arise from a common point (an umbel). However, this gives the appearance of a single, flat-topped white flower. A solitary**

purple flower often occurs in the center of the umbel. These umbels may curve inward at maturity producing a 'bird's nest' effect.

Stems: **Produced during the second year of growth, hollow, with hairs.**

Roots: **Slightly thickened taproot.**

Identifying Characteristics: **Plants resemble a typical garden carrot during the first year of growth and produce white, flat-topped flowers with a central purple flower during the second year of growth. Wild carrot seedlings are similar to Common Yarrow (*Achillea millefolium*) seedlings, however the cotyledons of common yarrow are egg-shaped unlike the linear cotyledons of wild carrot. Additionally, mature Poison Hemlock (*Conium maculatum*) plants closely resemble this weed but have purple spotted stems without hairs, unlike the stems of wild carrot which are hairy and lack the purple spots.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Yarrow: *Achillea millefolium*

Weed Description: **A perennial from rhizomes with finely dissected leaves and white, flat-topped flowers. Found throughout the United States except on the Florida peninsula.**

Roots: **Fibrous roots with a rhizome system.**

Seedling: **Cotyledons oblong, young leaves finely dissected with pointed lobes or teeth. Seedlings develop into a rosette and have hairs that mostly lay flat against the leaf surface. Young plants are almost fern-like.**

Stems: **May have white hairs or without hairs, usually unbranched, reaching 2 1/3 ft in height.**

Leaves:
Lower basal leaves have petioles. Upper leaves are alternate and without petioles, often smaller than the lower leaves. All leaves are finely dissected, 1-6 inches long, up to 1 inch wide, with many short inconspicuous hairs.

Flowers:
Many white or sometimes pinkish flowers form a single, flat-topped rounded cluster of flowers that are often confused as a single flower. Many of these flat-topped clusters of flowers occur on a single plant

at the ends of branches. Individual flowers are 3-5 mm in diameter.

Fruit: An achene.

Identifying Characteristics: The rhizomes of common yarrow help to distinguish this weed from others with a similar flower such as Wild Carrot (*Daucus carota*) or Poison Hemlock (*Conium maculatum*). This weed may also be confused with Mayweed Chamomile (*Anthemis cotula*), especially when in the seedling stage. However, the leaves of mayweed chamomile are much less hairy than those of common yarrow. Additionally, when mayweed chamomile plants are mature, they develop white flowers with a yellow center and have a taproot, unlike the larger white flowers and rhizome system that occurs in common yarrow.

Virginia Tech Weed Identification Guide

Select a Resource...

Poison Hemlock: *Conium maculatum*

Weed Description: **An erect biennial reaching 10 feet in height. Primarily a weed of pastures and roadsides found throughout the U.S., but less common in the northern Great Plains. This weed is poisonous to cattle, swine, poultry, horses, goats, and sheep that consume it, but it is rarely eaten.**

Seedling: **Cotyledons are narrow, lanceolate, and on long petioles. First true leaves have two or more leaflets along an axis (pinnately compound), and are without**

hair (glabrous).

Leaves: Alternate, triangular in outline, 8-16 inches long, petioled, and often dark glossy green in color. Leaves are 3-4 times pinnately compound, and the individual leaflets are lanceolate in outline and 4-10 mm long.

Fruit: A schizocarp that splits into two parts when mature.

Stems: Plants produce a basal rosette the first year and then produce erect flowering stems during the second year of growth. Stems are erect, branching, without hairs, ridged, hollow except at the nodes, and distinctly purple-spotted.

Flowers: Large (1.5-2.5 inches), white flowers (compound umbels) are each composed of a cluster of smaller flowers in which the stalks of the individual flowers arise from a common point.

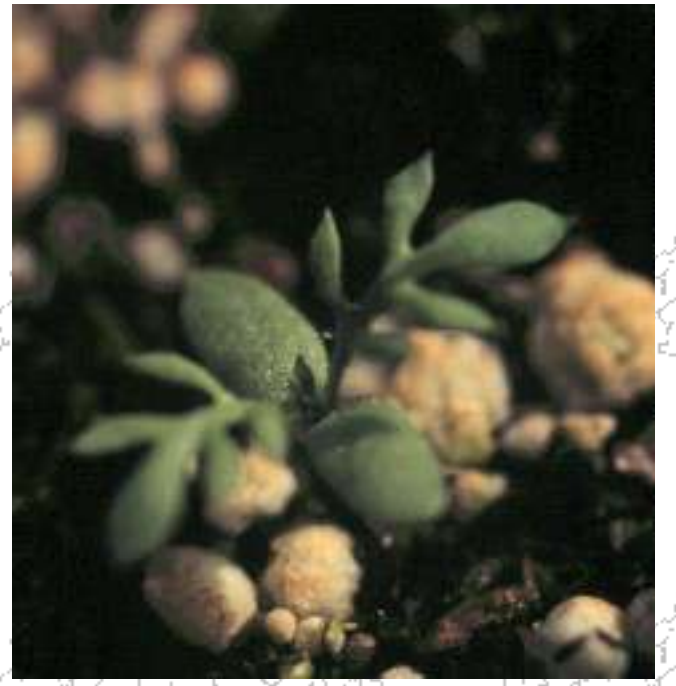
Roots: **Solid, thick, white taproot.**

Identifying Characteristics: **Purple-spotted stems with leaves and flowers that resemble Wild Carrot (*Daucus carota*). However, this weed may be distinguished from Wild Carrot primarily by the lack of hairs and purple spots along the stems. Additionally, the flowers of wild carrot are generally larger and more 'flat-topped' than those of poison hemlock.**

Virginia Tech Weed Identification Guide

Select a Resource...

Mayweed Chamomile: *Anthemis cotula*



Weed Description: **Winter or summer annual with finely dissected leaves that may reach 2 feet in height. Primarily a weed of landscapes, nursery, and some agronomic crops that is found throughout the United States.**

Seedling: **Stems below the cotyledons (hypocotyls) are green and become maroon with age. Cotyledons are thick and smooth, approximately 7 to 8 mm long. The first true leaves are opposite, but all subsequent leaves are alternate. All true leaves are thick and finely dissected with some short hairs.**

Leaves: **Alternate, finely dissected,**

approximately 3/4 to 2 1/2 inches long and 1 inch wide. Leaves emit an unpleasant odor and may have some short hairs.

Stems: **Erect, branching, usually without hairs.**

Roots: **Taproot and fibrous root system.**

Fruit: **An achene that is approximately 1.2 to 1.8 mm long.**

Flowers: **Occur in solitary heads at the ends of branches. Flowers are approximately 2/3 to 1 1/3 inches in diameter and are white (ray flowers) with yellow centers (disk flowers). White ray flowers have 3 distinct teeth.**

Identifying Characteristics: **Plants with finely dissected leaves that emit an unpleasant odor and have white flowers with a yellow center. Mayweed chamomile may resemble Dogfennel (*Eupatorium capillifolium*) when in the seedling stage, however dogfennel seedlings have petiolated cotyledons and hairy stems. Pineapple-weed (*Matricaria matricarioides*) also has similar characteristics, but has green flowers and emits a pineapple-like odor when crushed.**

Virginia Tech Weed Identification Guide

Select a Resource...

Dogfennel: *Eupatorium capillifolium*

Weed Description: **A perennial with finely dissected leaves that may reach 6 1/2 feet in height. Dogfennel is primarily a weed of agronomic crops, pastures, hay fields, nurseries and landscapes. It is found throughout the southeastern United States from Massachusetts to Texas.**

Seedlings:
Cotyledons occur on petioles, are oval, and are without hairs. The first true leaves are opposite and subsequent leaves become

finely divided like those of the mature plant.

Leaves: **Leaves are finely divided into linear segments. Lower leaves may sometimes be opposite, but upper leaves are always alternate.**

Roots: **A**

fibrous root system.

Stems: **Erect, reaching 6 1/2 feet in height, hairy above, sometimes without hairs below. Stems are branched only in the upper 1/3 to 1/2 of the plant. Stems have a somewhat woody base and are often dark red or purple in this area.**

Flowers: **Flowers are inconspicuous and are produced in the upper branching portions of the plant. Individual flower heads are 2 to 3 mm long and greenish white in color.**

Fruit: **An achene that is 1 to 1 1/2 mm long.**

Identifying Characteristics: **Erect plants that branch in the upper portions only with finely dissected leaves. Additionally, the leaves and flowers of this weed often emit an unpleasant odor when crushed. Dogfennel is sometimes confused with Horseweed (*Conyza canadensis*), but horseweed leaves are much wider and not finely dissected like those of dogfennel. Dogfennel may also be confused with Mayweed Chamomile (*Anthemis cotula*) and Pineapple-weed (*Matricaria matricarioides*) when in the seedling stage of growth. However, mayweed chamomile seedlings emit a strong pungent odor when crushed and pineapple-weed seedlings emit a sweet pineapple-like odor when**

crushed. Dogfennel seedlings also have stems that are very hairy unlike the sparsely hairy or glabrous stems of mayweed chamomile and pineapple-weed.

Virginia Tech Weed Identification Guide

Select a Resource...

Horseweed or Marestail: *Conyza canadensis*

Weed Description:
An erect winter or summer annual reaching 6 1/2 ft in height. Seedlings develop a basal rosette and mature plants have leaves that are entirely without petioles. Found throughout the United States in agronomic crops, pastures, orchards, fallow fields, waste areas, and roadsides.

Seedling: Cotyledons oval, 2-3 mm long. Young leaves egg-shaped with toothed margins and becoming hairy.

Stems: Erect, solid, hairy, reaching 6 1/2 ft in height.

Leaves: The mature plant has leaves that are entirely without petioles (sessile). Leaves are 4 inches long, 10 mm wide, alternate, linear, entire or more often toothed, crowded along the stem, and hairy. Leaves become progressively smaller up the stem.

Roots: A short taproot with a secondary fibrous root system.

Flowers: Many small inconspicuous flower heads occur at the top of the central stem. Individual flowers are 5 mm in diameter with white or slightly pink ray

flowers and yellow disk flowers.

Fruit: **A 1 mm long achene, tapered from the base to the apex with many small white bristles that help in wind dispersal.**

Identifying Characteristics: Erect plants with mature leaves that are entirely without petioles. When mature, this weed is easily identifiable. However, in the rosette stage of growth, horseweed might resemble other weeds that have this rosette habit, such as Shepherd's-Purse or Virginia Pepperweed (*Lepidium virginicum*).

Virginia Tech Weed Identification Guide

Select a Resource...

Virginia Pepperweed: *Lepidium virginicum*

Weed Description:
An annual weed that develops as a basal rosette initially, eventually producing flowering stems that have a bottle-brush appearance. Virginia pepperweed is a weed of agronomic, vegetable, orchard, and nursery crops, and is distributed throughout the United States.

Seedlings:
Cotyledons are hairless, oval and occur on long petioles. Plants initially develop a basal rosette of leaves.

Leaves: **Rosette leaves are without hairs, are oval in outline, and are lobed along both sides of the leaf. Rosette leaves do not usually persist once flowering stems are produced. Leaves that occur along the flowering stem are lanceolate or linear in outline and**

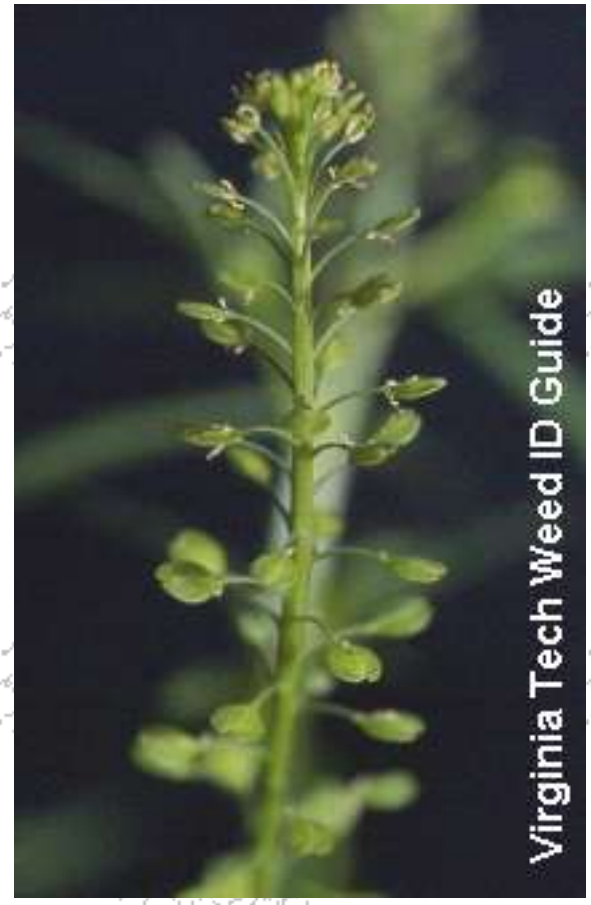
do not have petioles (sessile).

Stems: **Erect, branched, reaching 20 inches in height.**

Roots: **Taproot.**

Flowers: **Flowers are produced at the ends of the stems in a dense inflorescence that gives a 'bottle-brush' appearance. Individual flowers are relatively inconspicuous and no more than 1 mm long. Individual flowers consist of 4 white or greenish white petals.**

Fruit: **A rounded silicle that is approximately 4 mm wide and has a small notch at the apex. The fruit are flattened and also have a winged structure around the exterior.**



Identifying Characteristics: **The bottle-brush appearance of mature plants and rosette leaves that are lobed are both characteristics that help in the identification of Virginia pepperweed. Field Pepperweed (*Lepidium campestre*) is similar in appearance and growth habit, however this weed has**

leaves that clasp the flowering stem and has fruit that are generally larger and more robust than those of Virginia pepperweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Field Pepperweed: *Lepidium campestre*

Weed Description: **A winter annual that overwinters as a rosette and produces flowering stems in the spring. Found throughout the United States.**

Seedling: **Cotyledons occur on petioles, are hairless, 12-15 mm long, and oval. Young leaves are alternate on long petioles and circular in outline.**

Roots: **Taproot.**

Leaves: **Rosette leaves and lower stem leaves are rounded but taper to the base. Margins may be either lobed, toothed, or entire. Upper stem leaves do not have petioles (sessile) and are clasping at the base. All leaves covered with**

short hairs.

Stems: **Flowering stems may reach 2 feet in height and are covered with short hairs.**

Fruit: **Many silicles that are ovate in outline, 5-6 mm long, 4 mm wide, with a 'winged' structure at the apex.**

Flowers:
Occur collectively in racemes that may reach 6 inches in length. Individual flowers are 2 mm long, have 4 white or greenish-white petals, are inconspicuous, and occur on 4-8 mm long stalks (pedicels).

Distinguishing Characteristics:
Unique seedhead and clasping stem leaves. Virginia Pepperweed (*Lepidium virginicum*) is similar in appearance but does not have clasping stem leaves and has fruit that are flat and round, unlike the oval and more robust fruit of field pepperweed. Field Pennycress (*Thlaspi arvense*) is also similar but has leaves that are hairless and has fruit

that are more flattened than those of field pepperweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Field Pennycress: *Thlaspi arvense*

Weed Description: **A winter annual (or very seldom a summer annual) that resembles some of the pepperweeds when mature. Field pennycress is primarily a weed of winter small grains, nurseries, and horticultural crops that is found throughout the United States.**

Seedlings: **Cotyledons are oval to oblong in outline and occur on long (5-7 mm) petioles. First true leaves also occur on distinct petioles and develop into a basal rosette. Young leaves are without hairs, round to oval in outline, with a distinct white midvein and wavy margin.**

Flowers: **Individual flowers are very small (4-6 mm) and occur in clusters at the ends of the 'bottle-brush' stems. Flowers consist of 4 white petals and 4 green sepals.**

Leaves: **Leaves initially develop into a basal rosette and are without hairs, oval in outline, with a wavy margin. Leaves along the flowering stem are generally much different than those of the basal rosette. Leaves along the flowering stem are more lanceolate in outline, without petioles (sessile), usually have toothed margins, and have pointed lobes that clasp the stem at the base of the leaf.**

Roots: **A taproot and smaller fibrous root system.**

Stems: **Erect, ranging from 4 to 24 inches in height, usually branching in the upper portions only. Stems are without hairs and the leaves usually fall off the stems as the plants reach maturity.**

Fruit: **Many winged silicles give mature plants the distinctive 'bottle-brush' appearance, similar to many of the pepperweeds. Each silicle is circular in outline, approximately 1/2 inch in diameter, relatively flat, and distinctly winged along the outer margins. Silicles divide in half and may contain as many as 16 seed per silicle.**

Identifying Characteristics: **The oval, hairless leaves of the basal rosette and leaves with pointed lobes that clasp the flowering stem are both characteristics that help in the identification of field pennycress. Additionally, the bottle-brush appearance of the seedhead helps to distinguish this weed from many other winter annuals. Thoroughwort or Perfoliate Pennycress (*Thlaspi perfoliatum*) is similar but has fruit that are more distinctly notched and heart-shaped in appearance. Field Pepperweed (*Lepidium campestre*) is also similar to field pennycress but has leaves with short hairs and more rounded fruit than those of field pennycress.**

Virginia Tech Weed Identification Guide

Select a Resource...

Thoroughwort Pennycress or Perfoliate Pennycress: *Thlaspi perfoliatum*

Virginia Tech Weed Identification Guide

Select a Resource...

Pineapple-weed: *Matricaria matricarioides*

Weed Description: **A summer or winter annual with finely dissected leaves that emit a sweet "pineapple-like" odor when crushed. Pineapple-weed is primarily a weed of landscapes, nurseries, and turfgrass, but also occurs in compacted areas like gravel roads or walkways. Pineapple-weed is found throughout the United States.**

Leaves: **Individual leaves are arranged alternately along the stem and are from 1/2 to 2 inches long. Each leaf is hairless and divided into many narrow segments (1 to 2 mm wide) that give off a "pineapple-like" smell when crushed.**

Stems: **Smooth, hairless, branched, reaching a maximum of 16 inches in height.**

Roots: **A taproot with secondary fibrous roots.**

Flowers: **One or several**

flowers are produced at the ends of the stems on short flower stalks (peduncles). Individual flowers are cone-shaped, from 1/4 to 1/2 inch in diameter. Flowers are greenish yellow in color.

Fruit: **An achene.**

Identifying Characteristics: **Low-growing plants with finely divided foliage that gives off a pineapple smell when crushed. Pineapple-weed may be confused with young Mayweed Chamomile (*Anthemis cotula*) or Dogfennel (*Eupatorium capillifolium*) seedlings, however neither of these species emits a pineapple-like odor when**

crushed. Additionally, both mayweed chamomile and dogfennel grow much taller than pineapple-weed

Virginia Tech Weed Identification Guide

Select a Resource...

Catnip: *Nepeta cataria*

Common Catsear or False Dandelion: *Hypochoeris radicata*

Weed Description: **Perennial weed primarily of turfgrass and lawns that resembles dandelion. Found in the eastern United States as far north as New Jersey and as far west as Mississippi.**

Leaves: **Leaves are arranged in a basal rosette and are densely hairy with toothed or irregularly lobed margins. Leaves emit a milky sap when broken.**

Stems: **Typical stems do not occur, however leafless flower stalks (scapes) are present with 2 to 7 flowers on each**

stalk. Flower stalks also emit a milky sap when broken.

Flowers: Consist of bright yellow ray flowers that have teeth at the tip. From 2 to 7 flowers are produced on each flower stalk.

Identifying Characteristics: The rosette growth habit, irregularly lobed leaves, and bright yellow flowers are all characteristics that help with the identification of common catsear.

However, Mouseear Hawkweed (*Hieracium pilosella*) is similar in appearance and growth habit, but does not have irregularly lobed or toothed margins and has flower stalks that are covered with stiff dark hairs. Dandelion (*Taraxacum officinale*) also resembles common catsear but has much more divided leaves and does not have hairs like either common catsear or mouseear hawkweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Mouseear Hawkweed: *Hieracium pilosella*

Weed Description:
A perennial weed from stolons that has a basal rosette of hairy leaves and yellow flowers that resemble dandelion. Mouseear hawkweed is primarily a weed of turfgrass, lawns, pastures, hayfields, and roadsides that is found throughout the northeastern United States and as far south as North Carolina.

Leaves: **Elliptic in outline, approximately 1 1/4 to 4 inches long, reaching 3/4 inches in width. All leaves have a distinctive white midveing and are covered with long white hairs.**

Roots: **Stolons and a fibrous root system.**

Flowers: **Produced on a long, leafless flower stalk (scape) that are covered with stiff dark hairs. Flowers occur in clusters of at least 2 on the top of the flower stalks and are bright yellow in color. Flowers resemble those of dandelion.**

Fruit: **An achene.**

Identifying Characteristics: **The rosette of hairy leaves and bright yellow flowers that occur on the ends of the leafless flower stalks are both characteristics that help in the identification of mouseear hawkweed. Common Catsear (*Hypochoeris radicata*) is also similar in appearance and growth habit, however this weed has leaves that are slightly lobed and only slightly hairy unlike those of mouseear hawkweed.**

Virginia Tech Weed Identification Guide

Select a Resource...

Dandelion: *Taraxacum officinale*

Weed Description: **A perennial from a basal rosette with yellow flowers and a 'puff-ball' seedhead. Dandelion is one of the most common and problematic weeds of turfgrass and lawns throughout the United States. Dandelion also occurs as a weed of container ornamentals, landscapes, nurseries, orchards, and occasionally agronomic crops.**

Roots: **Deep taproot up to 1/2 inch in diameter.**

Seedlings: **Cotyledons are light-green, smooth, and oval to spatulate in shape. Young leaves form a basal rosette and are also oval to spatulate in shape, 2 to 6 inches in length.**

Flowers: **Large, bright yellow in color,**

approximately 1 1/4 to 2 inches in diameter. Flowers are solitary on the end of unbranched, leafless, hollow stalks (scape) that are 2 to 6 inches tall.

Leaves: **Margins are noticeably wavy, especially on older leaves. All leaves are basal, ranging from 2 to 16 inches in length depending on the environment. Usually, leaves are more in the range of 2 to 8 inches in length. Leaves are oblong in outline, sometimes sparsely hairy, deeply indented with lobes that point toward the center of the rosette.**

Stems: **Erect, hollow flowering stems (scapes) occur that are approximately 2 to 6 inches in height.**

Fruit: **An achene that is brown, 3-5 mm long, with a feathery pappus attached that aids in wind dispersal of seed. Collectively, the achenes form a white seedhead that resembles a puff-ball.**

Identifying Characteristics: **The rosette growth habit, lobed leaves, yellow flowers, and characteristic 'puff-ball' seedheads are all features that help in the identification of dandelion. When in the rosette stage, Chicory (*Cichorium intybus*) and dandelion resemble one another. However, the lobes of chicory may point either toward the center of the rosette or away from the center of the rosette. Additionally, chicory has blue flowers and a flowering stem with alternately arranged leaves. White Flowered Mazus (*Mazus japonicus*) also resembles dandelion in the rosette stage of growth, however the leaves of this weed are not as severely lobed as those of dandelion.**

Virginia Tech Weed Identification Guide

Select a Resource...

Chicory: *Cichorium intybus*

Weed Description: **A perennial that resembles dandelion but produces an attractive blue or purple flower. Chicory is primarily a weed of pastures, hayfields, and turfgrass and is found throughout the United States.**

Seedling: **Cotyledons are oval and have an indented apex. Cotyledons are widest at the apex and taper down to a short petiole.**

Stems: **Stems are branched and produced during the latter part of the growing season.**

Roots: **A taproot that is relatively large and brown in color.**

Flowers: **Produced in clusters of 1 to 3 on the flowering stems. Individual flowers are approximately 1 ½ inches in diameter and are blue, purple, or white in**

color.

Fruit: An achene that is approximately 2 to 3 mm long and angled.

Leaves: Plants initially produce a basal rosette of leaves that resembles dandelion. Leaves are also produced on flowering stems during the same season. All leaves are alternate and lanceolate in outline and usually have rough hairs on both

surfaces. All of the leaves are also slightly dissected or lobed and usually have toothed margins. The lobes that occur are not always opposite one another unlike those of dandelion. Rosette leaves are approximately 3 to 10 inches long by ½ to 3 inches wide. Leaves that occur on the flowering stalks are much smaller than the rosette leaves and also have leaf bases that surround or clasp the stem.

Identifying Characteristics:

Plant that resembles dandelion when in the rosette stage but produces flowering stems with attractive blue, purple or white flowers. This weed is often confused with Dandelion (*Taraxacum officinale*) when in the rosette stage, however the rosette leaves of dandelion generally have lobes that are opposite from one another and these lobes are generally pointing in the direction of the rosette unlike those of chicory.

Virginia Tech Weed Identification Guide

Select a Resource...

White Flowered Mazus: *Mazus japonicus*

Weed Description: **An annual from a basal rosette of leaves that are often confused with those of dandelion. Primarily a weed of turfgrass, lawns, and landscapes.**

Leaves: **Leaves develop in a basal rosette. Leaves are broadest near the apex and taper to the base. Leaves often have conspicuously serrated margins. Leaves sometimes take on a purplish cast beneath.**

Flowers: **Several small, 2-lipped white and blue or light purple flowers occur along the flowering stem.**

Identifying Characteristics: **A somewhat rare plant with leaves that develop in a basal rosette and 2-lipped white and blue or light purple flowers. White flowered mazus may be confused with Dandelion (*Taraxacum officinale*), however the margins of dandelion are deeply serrated and lobed unlike those of white flowered mazus.**

Virginia Tech Weed Identification Guide

Select a Resource...

Cattails: *Nympha spp.*

Weed Description: **Erect perennials from rhizomes with distinctive cylindrical, brown spikes. The cattail species primarily grow in marshes, ditches, and shallow water of lakes, ponds, and rivers. There are four species of *Nympha* that are found throughout the United States.**

Leaves: **Leaves may reach as much as 10 feet in length but are more commonly about 5 feet long and 1 inch wide. Leaves are slightly twisted from the base to the tip.**

Stems: **Erect, jointless, reaching up to 7 feet in height.**

Flowers: **Cylindrical brown spikes that may reach as much as 6 inches in length and are typically 1 inch in diameter. The fruit are somewhat cigar-shaped and have an upper, much narrower pointed portion which is the staminated portion of the spike. It is this portion that helps to distinguish between the different cattail species.**

Fruit: **A cluster of nutlets that are collectively oblong in shape.**

Roots: **A fibrous root system and rhizomes, which often lead to the formation of dense cattail colonies.**

Identifying Characteristics: **The dense, cylindrical brown spikes, large leaves, and growth environment are all characteristics that help in the identification of the cattail species.**

Centipedegrass: *Eremochloa ophiuroides*

Weed Description: **A creeping perennial with stolons and distinctly compressed sheaths. Centipedegrass forms a dense turf where established and for this reason is often planted as a lawn grass. It is most commonly planted as a lawn grass in the southeastern United States from Virginia to Florida and west to Texas.**

Leaves: **Approximately 15 to 30 mm long, 2 to 4 mm wide, and distinctly flat with a white midvein. Leaves are without hairs except in the collar regions. Leaf apexes are rounded.**

Leaves are without auricles, and have a short membranous ligule that also has short hairs.

Stems: **Sheaths are distinctly compressed, to the point that considerable effort is required to pull them apart.**

Roots: **Creeping stolons that are slender and branching.**

Flowers: **The inflorescence is a single spikelike raceme that range from 3 to 5 inches in length. The racemes are purplish in color, somewhat flattened, and have spikelets arranged in two rows.**

Identifying Characteristics: **The strongly compressed sheaths, flat leaves with rounded apexes, and creeping stolons are all characteristics that help in the identification of centipedegrass. Additionally, centipedegrass has a relatively slow growth habit and requires less mowing than many other turfgrass species.**

Virginia Tech Weed Identification Guide

Select a Resource...

Chara, Musk-grass, or Stonewort: *Chara* spp.

Virginia Tech Weed Identification Guide

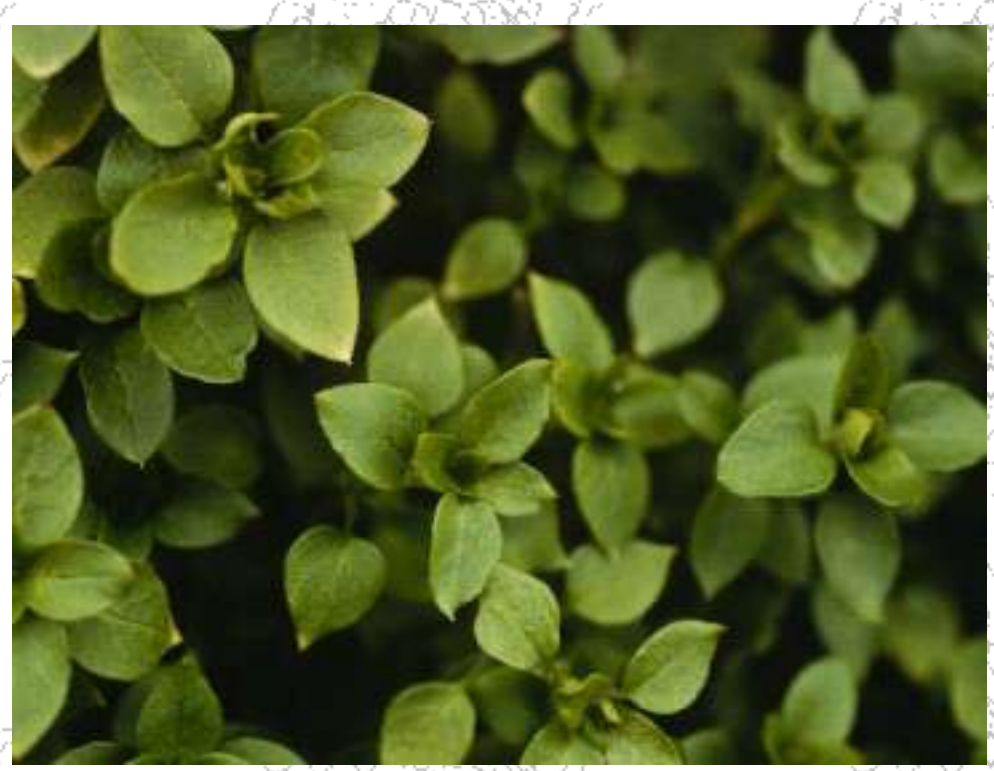
Select a Resource...

Common Chickweed: *Stellaria media*

Weed Description: **Prostrate, winter annual that is found throughout North America except for in the far west. Common chickweed is primarily a weed of turfgrass, lawns and winter small grains.**

Seedling: **Cotyledons are ovate, 1-12 mm long by 0.25-2 mm wide, with a slender reddish hypocotyl that is sparsely hairy.**

Leaves: **Arranged oppositely, oval or elliptic in outline. Leaves range from 1/2 to 1 1/4 inches in length, are light green in color and smooth or possibly hairy toward base and on the petioles. Upper leaves are without petioles (sessile), while lower leaves are long petiolated.**



Roots: **A shallow, fibrous root system.**

Stems: Usually running prostrate along the ground, rooting at the nodes, with the upper portion erect or ascending and freely branching. Stems are light green in color and with hairs in vertical rows.

Fruit: An oval, one-celled capsule, whitish in color, containing numerous seeds.

Flowers: Alone or in small clusters at the ends of stems. Flowers are small (3-6 mm wide) and consist of 5 white petals that

are deeply lobed, giving the appearance of 10 petals.

Identifying Characteristics:
The oppositely arranged small oval or elliptic leaves and stems with rows of hairs are both characteristics that help in the identification of common chickweed.
Mouseear Chickweed (*Cerastium vulgatum*) is very similar in appearance and growth habit, however this

species is densely covered with hairs unlike common chickweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Mouseear Chickweed: *Cerastium vulgatum*

Weed Description: A spreading, mat-forming perennial with prominently hairy prostrate stems and leaves, resembling common chickweed. Found throughout the United States except extreme portions from Texas to California.

Seedling: Cotyledons rounded to ovate, green, 2-7 mm long, 0.5-2 mm wide, bearing a few hairs at base of stalk.

Leaves: Opposite, dull-green, 1-2 cm long, 3-12 mm wide, oval to elliptic, lacking a petiole (sessile), with prominent hairs on upper surface and the veins beneath.

Roots: Fibrous and shallow.

Stems: **Slender, 1.5 to 5 cm long, with 2 rows of dense hairs, and root at the nodes when in contact with the soil.**

Flowers: **Usually in clusters of three at the end of stems. Flowers consist of 5 white petals that are deeply lobed, giving the appearance of 10 petals. Flowers are produced from May through October.**

Fruit: **Capsule that is cylindrical to slightly curved, membranous, 7-11 mm long, 2-3 mm wide, producing many seeds.**

Identifying Characteristics:
Perennial growth habit with curved seed capsule. Very similar to Common Chickweed (*Stellaria media*), however, mouseear chickweed is densely pubescent and roots at the stem nodes.

Virginia Tech Weed Identification Guide

Select a Resource...

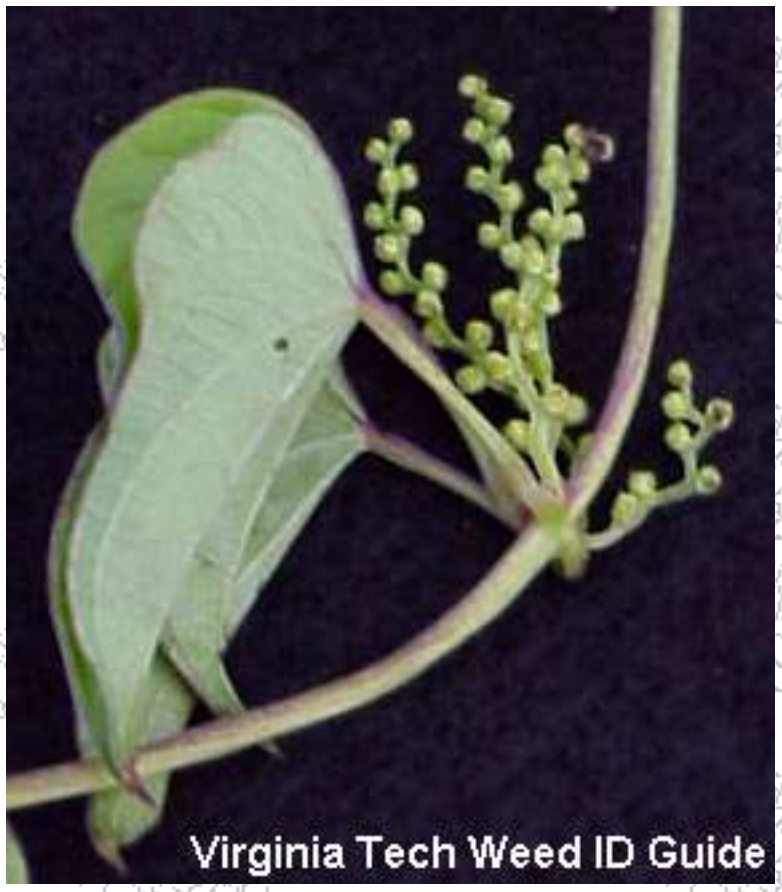
Cinnamon Vine, Chinese Yam or Potato Vine: *Dioscorea batatas*

Weed Description:
Herbaceous or slightly woody twining vines with fleshy or woody rootstocks, winding upward from left to right to approximately 13 feet in length. Found especially throughout the piedmont and mountainous areas of the southeastern United States.

Leaves: **Alternate or lower leaves opposite and ovate with a long tapering point, concave sides, and heart-shaped base (cordate). Leaves have 9 to 13 distinct veins. Leaves are thin and without hairs (glabrous) or nearly so above, pubescent or sometimes glabrous beneath. Petioles often longer than the blades. New leaves often have a bronze 'tint'.**

Stems: **Herbaceous or slightly woody vine that twines upward from left to right.**

Flowers: **Greenish-yellow, nearly sessile, in spikes or panicles at the ends of branches, from June-August.**



Roots: **Slender or stout, simple or branched, horizontal and woody.**

Fruit: **Membranous, 3-angled capsule, approximately 3/4 to 1 1/4 inches long and 3/4 inch in diameter.**

Identifying Characteristics: **This weed is often confused with wild yam, however the vines of wild yam twine upwards from the right to the left, while those of cinnamon vine twine from the left to the right. Cinnamon vine is also commonly confused with the morningglory species. However, the distinct leaf veination and bronze 'tint' of newer leaves help to distinguish this weed from most morningglories.**

Sulfur Cinquefoil: *Potentilla recta*

Weed Description: **A perennial with many ascending stems from a crown that may reach 1-2 1/2 ft in height. Primarily found in disturbed areas and along roadsides or railroads throughout N.C., S.C., Va., Tenn., Ky., W. Va.**

Stems: **Erect, unbranched, ascending from a central crown, hairy, reaching 1 to 2 1/2 ft tall.**

Fruit: **An achene.**

Leaves: **Divided into 7 (sometimes 5, rarely 9) leaflets that arise from a common point on the stem. Lower leaves alternate, petioled. All leaves much longer than wide, widest at the middle and tapering to the base, sparsely hairy, with coarsely toothed margins.**

Flowers: **Light yellow (sulfur) with a darker yellow center, 1/2-1**

inch wide, with 5 deeply notched petals.

Identifying Characteristics: **The 7 leaflets that most often occur in this species helps to distinguish it from other similar cinquefoils. Oldfield cinquefoil (*Potentilla simplex*) and common cinquefoil (*Potentilla canadensis*) both have 5 leaflets, darker yellow flowers, and rhizomes and/or stolons. Additionally, the light yellow flower with 5 petals is a good identifying characteristic of this cinquefoil.**

Clammy Groundcherry: *Physallis heterophylla*

Weed Description: **A perennial from rhizomes, 8 inches to several feet in height. Mature plants develop a papery case over the berry. Found throughout the eastern United states, west to Utah and Texas, also found in Washington.**

Seedling:
Stem below the cotyledon (hypocotyl) smooth or with short hairs toward the top. Cotyledons 1-4 mm wide, 4-9 mm long, without hairs, or with a row of hairs on margins and on the midvein below. Plants emerging

from rhizomes lack cotyledons.

Leaves: **Alternate, ovate, 1-3 inches long, margins are either continuous and untoothed or shallowly indented. Hairs are short and dense along the margins and on the lower leaf surface, but few and scattered on the upper surface.**

Roots: **Deeply buried thick rhizomes.**

Stems: **Erect, highly branched, with hairs.**

Flowers: **Occur singularly on flower stalks (pedicels) in the region between the stem and leaf, or the region between the stem and branch (axils of the branches and leaves). Petals are yellow with a purple center.**

Fruit: **A round berry, surrounded by a papery case (the calyx). The berry is yellow when mature.**

Identifying Characteristics: **Perennial from rhizomes, yellow and purple flowers, stems and leaves hairy, papery case surrounding the berry. Smooth groundcherry (*Physalis subglabrata*) is similar but does not have the dense (clammy) hairs that are typical of clammy groundcherry. Additionally, the berries of smooth groundcherry are orange, red, or purple when mature, unlike the yellow berries of clammy groundcherry.**

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Virginia Tech Weed Identification Guide

Select a Resource...

Common Lespedeza or Japanese Clover: *Lespedeza striata*

Weed Description: **Prostrate, freely-branched summer annual with inconspicuous purplish flowers forming mats 15 to 18 inches in diameter. Found throughout the southeast.**

Roots: **Taproot**

Leaves: **Consist of 3 oblong leaflets (trifoliolate), 1/2 to 3/4 inch long and 1/3 to 1/2 as wide, obtuse at apex, narrowed at the base. Leaflets without hairs except for appressed hairs along the margins and midvein beneath. Lance-shaped stipules are present, 3-6 mm long, becoming brownish with age. Petioles are 1-2 mm long, much shorter than the leaves.**

Stems: **Freely-branched stems with sparsely to densely appressed hairs that are bent or turned downward (retrorse).**

Flowers: **Solitary or 2-5 in spike-like axillary racems, pink to purple.**

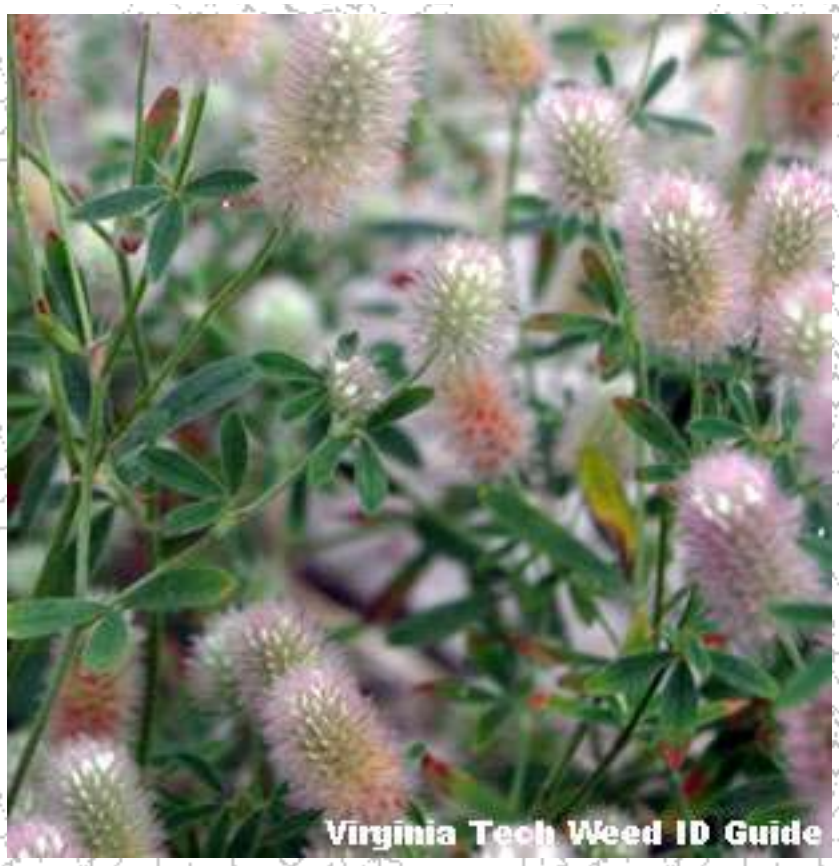
Fruit: **A legume that is 3-4 mm long, tapering to a pointed apex.**

Identifying Characteristics: **Trifoliolate leaves with lance-shaped stipules, hairs along leaf margins, and pink to purple flowers. Common lespedeza is often confused with Black Medic (*Medicago lupulina*), however the small spur at the tip of each leaflet and yellow flowers or black medic help to distinguish the two weeds.**

Virginia Tech Weed Identification Guide

Select a Resource...

Rabbitfoot Clover: *Trifolium arvense*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Red Clover: *Trifolium pratense*

Weed Description: **A perennial with trifoliate leaves and pink to red flowers. Red clover is often planted as a component of pasture and forage mixes, but sometimes escapes to become a weed of turfgrass, lawns, landscapes, and orchards. Red clover is distributed throughout the United States.**

Seedlings: **Cotyledons are spatula-shaped, 6-7 mm long, without hairs. The first true leaf is solitary, oval in shape, and cut off squarely at the base (truncate). All subsequent leaves consist of 3 leaflets (trifoliate).**

Roots: A fibrous root system and stems that root at the nodes.

Leaves: Consist of 3 leaflets (trifoliate). Each leaflet is elliptic in outline, approximately 1/2 to 1 1/4 inches long and about half as wide. Leaves are usually hairy on both surfaces or sometimes without hairs above and hairy beneath. Each leaf usually has a light green or white 'V-shaped' marking.

Stems: Growing somewhat prostrate but ranging from 8 to 20 inches in height. Stems are sometimes without hairs but can be slightly hairy, and root at the nodes.

Flowers: **Occur in round to oval heads usually on flower stalks (peduncles) less than 5 mm long, but also without flower stalks (sessile). Individual flower heads are pink to red in color, 1/2 to 1 1/4 inches in length.**

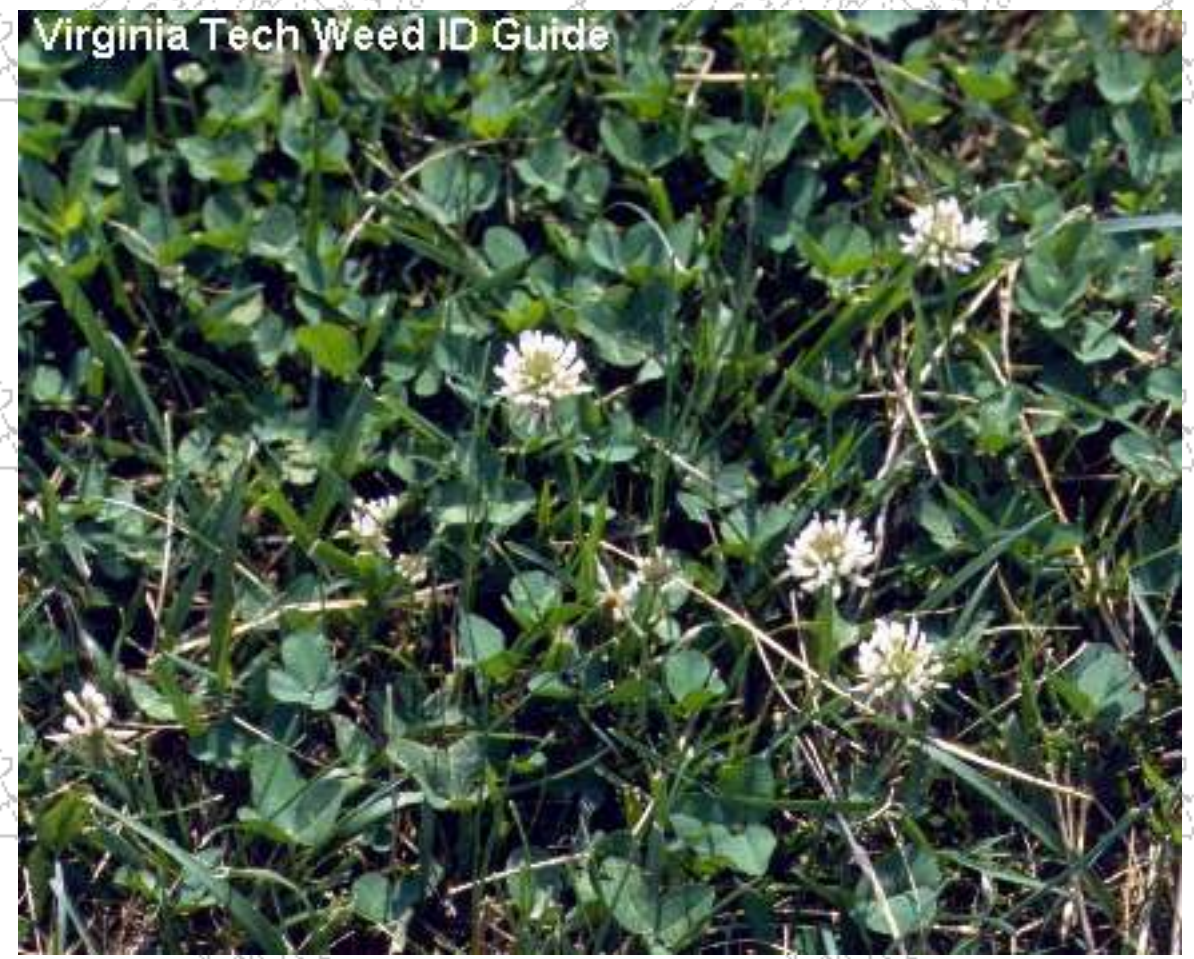
Fruit: **A pod known as a legume, 4 to 5 mm long.**

Identifying Characteristics: The trifoliate leaves and pink to red flowers are both key features that help in the identification of red clover. There are many other clover species that are both planted in forages and occur as weeds. White Clover (*Trifolium repens*) is similar but is generally more prostrate, has smaller leaflets, and much smaller, white flowers.

Virginia Tech Weed Identification Guide

Select a Resource...

White Clover: *Trifolium repens*



Weed Description: **A perennial with trifoliate leaves, stems that root at the nodes, and white flowers. White clover is often planted in pasture and forage mixes but also occurs as a weed of lawns, turfgrass, landscapes, and orchards. White clover is found throughout the United States.**

Roots: **A fibrous root system with stems that root at the nodes.**

Seedlings: Cotyledons are spatula-shaped, 6 to 7 mm long, without hairs. The first true leaf is solitary, oval in shape, and cut off squarely at the base (truncate). Subsequent leaves consist of three leaflets (trifoliate).

Stems: Stems are low-growing, prostrate, usually without hairs but sometimes with short hairs, ranging from 4 to 16 inches in height. Stems root at the nodes.

Leaves: Leaves are composed of 3 leaflets (trifoliate). Each leaflet is egg-shaped, widest at the apex, 1/2 to 1 1/4 inches long, and has an indentation at the apex. Leaflets usually have a lighter green or white 'V-shaped' marking close to their base and a slightly toothed margin. Each trifoliate leaf occurs on a 1-3 inch petiole.

Flowers: Occur on flower stalks (peduncles) that arise from the leaf axils. Each flower head is round or globular in outline, approximately 1/2 to 1 1/4 inches long, and consists of 20-40 individual white flowers.

Fruit: **A pod known as a legume that is 4 to 5 mm long.**

Identifying Characteristics: **The trifoliate leaves and white flowers are both key features that help in the identification of white clover. There are many other clover species that are planted in forages and occur as weeds. Red Clover (*Trifolium pratense*) is similar but is generally more upright and taller, has larger leaflets, and generally larger, pink to red flowers. Alsike clover (*Trifolium hybridum*), also has white flowers, but may be distinguished from white clover by the more upright, clump-forming habit and larger, more elongated leaflets.**

Virginia Tech Weed Identification Guide

Select a Resource...

White Sweet Clover: *Melilotus alba*

Weed Description:
Biennial legume with compound leaves consisting of 3-leaflets (trifoliolate). Found throughout the Southern states in fields, roadsides, and waste places.

Leaves:
Trifoliolate leaflets oblong or oblanceolate, 1-2.5 cm long, 8-12 mm wide. Leaflets without hair above and having appressed hairs below. Leaflet margins serrated halfway or more back from the apex.

Fruit: **Legume, dark brown to black at maturity, ovoid, 2.5-4 mm long, without hairs, and cross-ribbed.**

Flower: **Small, white, arranged in many-flowered terminal and axillary racemes.**

Stems: **Short-pubescent above, without hairs below.**

Identifying Characteristics: **Trifoliate leaves with serrated margins halfway or often more back from the apex. White sweet clover is similar in appearance to yellow sweet clover, but has white flowers and net-veined pods.**

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Select a Resource...

Coffee Senna: *Cassia occidentalis*

Weed Description: **Erect, much-branched summer annual that may reach as much as 10 feet in height. Coffee senna is primarily a weed of agronomic crops that is found from Pennsylvania to Iowa and south to Texas and Florida.**

Leaves: **Arranged alternately along the stem, ranging from 8 to 12 inches in length. Leaves are divided into 8 to 12 leaflets per leaf which are arranged oppositely from one another. Each leaflet ranges from 1 1/4 to 3 inches in length and from 3/4 to 1 1/4 inches in width. Leaflets are ovate to ovate-lanceolate in outline with a long, tapering point. Leaves have petioles that are from 1 1/4 to 2 inches in length. Leaves also have a distinct spherical gland that is 3-5 mm from the base of each petiole.**

Stems: **Erect, without hairs (glabrous).**

Seedlings: **Cotyledons are broad and round, without hairs (glabrous), and have distinctive veins.**

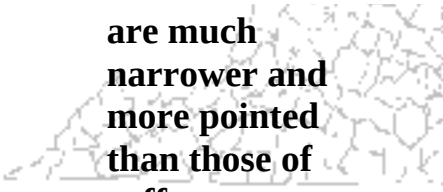
Roots: **A taproot and fibrous root system.**

Fruit: **A long pod (legume), straight to slightly curved, from 3 to 5 inches in length, without hairs (glabrous) or minutely pubescent.**

Flowers: **Occur in the axils of the upper leaves or borne in few-flowered racemes. The flower petals are yellow, 1/2 to 3/4 inches long.**

Identifying Characteristics: **The leaves that are divided into many ovate leaflets and the spherical glands near the base of the leaf petioles are both characteristics that help in the identification of coffee senna. This weed is similar to Sicklepod (*Cassia obtusifolius*) in growth habit and appearance, especially during the seedling stage. However, the leaflets of coffee senna are more numerous and pointed when compared to those of sicklepod. The seedlings of Partridgepea (*Cassia fasciculata*) are also similar to those of coffee senna and sicklepod. However, with maturity the leaflets of partridgepea**





are much narrower and more pointed than those of coffee senna.















Sicklepod: *Cassia obtusifolius*

Weed Description: **An invasive summer annual, reaching 1-6 ft in height. Found throughout the southeastern United states and north to east Kansas, Illinois, and Michigan.**

Seedling: **Cotyledons are rounded, much more so than the subsequent egg-shaped leaflets. Distinctive veins (3-5) also occur on the cotyledons.**

Stems: **Erect, branched, and without hairs (glabrous).**

Fruit: Brownish, angular seed are produced in a long (4-8 inches long, 3-5 mm wide), slender, curved seed pod (a legume).

Roots: Taproot.

Leaves: Arranged alternately up the stem, and consist of 4-6 leaflets that are arranged oppositely from one another (pinnately compound). The basal pair of leaflets smallest, terminal pair largest. Individual leaflets are egg-shaped, with the broadest end above the middle (obovate), 1 to 3 1/2 inches long, 1/2 to 1 inch wide.

Flowers: Contain yellow petals on stalks that arise between stems and leaves (axillary flowers).

Identifying Characteristics: **Plants with yellow flowers, long narrow seed pod, and pinnately compound leaves with the terminal pair of leaflets the largest. This weed is similar to Coffee Senna (*Cassia occidentalis*) in growth habit and appearance, especially during the seedling stage. However, the leaflets of coffee senna are more numerous and pointed when compared to sicklepod.**

Virginia Tech Weed Identification Guide

Select a Resource...

Partridgepea: *Cassia fasciculata*

Weed Description: **Summer annual with divided leaves that consist of 8 to 15 pairs of oppositely arranged leaflets and relatively large yellow flowers. Partridgepea is primarily a weed of pastures, hayfields, roadsides, rights-of-way, and other noncrop areas. Partridgepea may be found throughout the eastern half of the United States.**

Seedling: **Large round cotyledons usually with three distinct white veins. Cotyledons are without hairs. First true leaf is divided into two rows of leaflets that are arranged oppositely from one another (pinnately compound).**

Leaves: **All leaves are divided into two rows of 8 to 15 leaflet pairs that are arranged oppositely from one another (pinnately compound). Each leaflet is linear to oblong in outline, approximately ½ to 1 inch long by 2 to 4 mm wide. All leaflets occur on a petiole**

and a distinctive gland occurs on the underside of the petiole below the first leaflet pair.

Stems: Branching only rarely, hairy, and can reach 3 ½ feet in height.

Roots: Taproot.

Flowers: Arise from the position between the petiole and the stem (leaf axils). Flowers consist of 5 bright yellow petals and have some red mottling. Flowers are approximately

1 inch wide and occur on long (10 to 25 mm) flower stalks (pedicels).

Fruit: **A legume that is linear in outline, approximately 1 to 3 inches long and 4 to 6 mm wide. Each legume contains 4 to 20 seed.**

Identifying Characteristics:
Showy yellow flowers and leaves that are divided into 8 to 15 pairs of oppositely arranged leaflets. Also, the gland that occurs on the petiole below the first leaflet pair helps to distinguish this weed from other weeds with pinnately compound leaves.

Virginia Tech Weed Identification Guide

Select a Resource...

Common Blue Violet: *Viola papilionacea*

Weed Description: **A perennial with heart-shaped leaves and purple flowers, most commonly 2 to 5 inches tall. Common blue violet is found throughout the eastern United States and Canada. It is primarily a weed of turfgrass and landscapes.**

Leaves: **Leaves arise from a basal crown, are heart-shaped, and occur on long petioles. Leaves are also hairless and have rounded teeth along the margins.**

Fruit: **A capsule ranging from 10 to 12 mm in length.**

Roots: **Rhizomes and a fibrous root system.**

Flowers: **Occur on stalks that do not contain leaves. Flowers consist of 5 petals that are purple or blue in color. The 2 lateral petals are bearded or hairy near the base.**

Identifying Characteristics:
The heart-shaped leaves with rounded teeth along the margins, purple flowers, and rhizomes are all features that help in the identification of common blue violet.

Virginia Tech Weed Identification Guide

Select a Resource...

Common Eveningprimrose: *Oenothera biennis*

Weed Description:

Usually a biennial or a winter annual, but may rarely occur as a summer annual. Common eveningprimrose has narrow leaves with untoothed margins and produces many showy yellow flowers. This weed is primarily a weed of landscapes, nurseries, some agronomic crops, and occasionally turfgrass and lawns. Common eveningprimrose occurs throughout the southern and eastern United States.

Seedlings: **Cotyledons are 6 to 11 mm long, and usually egg-shaped with a short petiole. The stem at the base of the cotyledons has a reddish tint. Leaves initially develop as a basal rosette. Upper leaf surfaces of young leaves may have a few hairs near the base.**

Leaves:
Leaves are elliptic to lanceolate in outline, are relatively narrow, and have untoothed margins. Leaves have a distinctive white or pink midvein and may have wavy margins. Leaves along the erect flowering stem are alternate and become

progressively smaller up the stem.

Stems: **Erect, reaching as much as 6 1/2 feet in height.**

Roots: **A taproot.**

Flowers: **Occur in the upper leaf axils and are without flower stems (sessile). Flowers consist of 4 bright yellow petals (12 to 25 mm long). Individual flowers are approximately 3/4 to 2 inches wide.**

Fruit: **An erect, hairy capsule that is approximately 1/2 to 1 1/2 inches long. Many seed are arranged in rows within the capsule.**

Identifying Characteristics: **Erect plants with lanceolate or elliptic leaves that have untoothed margins, and showy yellow flowers. Common eveningprimrose is very similar in appearance to Cutleaf Eveningprimrose (*Oenothera laciniata*), but cutleaf eveningprimrose has toothed margins and usually grows much more prostrate than common eveningprimrose.**

Virginia Tech Weed Identification Guide

Select a Resource...

Cutleaf Eveningprimrose: *Oenothera laciniata*

Weed Description: **Usually a biennial or a winter annual, but may rarely occur as a summer annual. Cutleaf eveningprimrose has leaves with deeply toothed margins and produces many showy yellow or red flowers. This weed is primarily a weed of landscapes, nurseries, some agronomic crops, and occasionally turfgrass and lawns. Cutleaf eveningprimrose occurs throughout the southern and eastern United States.**

Seedlings:
Cotyledons are egg- or arrowhead-shaped and occur on petioles. Leaves initially develop as a basal rosette. Young leaves have margins that are untoothed (entire), but subsequent leaves have toothed margins. Upper leaf surfaces of young leaves are usually

hairy and lower leaf surfaces are without hairs.

Leaves: **Mature leaves may have hairs on the upper leaf surfaces but are without hairs below. Leaves are lanceolate in outline, are relatively narrow, and have deeply toothed margins. Leaves have a distinctive white midvein.**

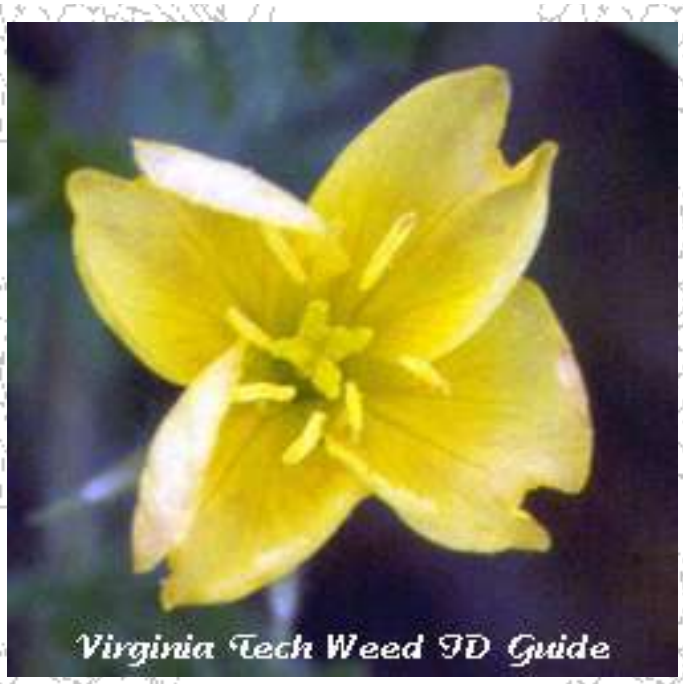
Stems: Either prostrate or erect, hairy, and usually reddish in color. When plants grow erect, stems may reach as much as 32 inches in height.

Roots: A taproot.

Flowers: Occur in the upper leaf axils and are without flower stems (sessile). Flowers occur at the end of a long (1/2 to 1 1/4 inch) tube, which is actually the fused sepals. Individual flowers are either red or yellow in color.

Fruit: A capsule that is approximately 3/4 to 1 1/2 inches long and often curved. Many seed are arranged in rows within the capsule.

Identifying Characteristics: **Erect or prostrate plants with lanceolate leaves that have toothed margins, red stems, and yellow or red flowers. Cutleaf eveningprimrose is very similar in appearance to Common Eveningprimrose (*Oenothera biennis*), but common eveningprimrose has untoothed margins and usually grows much more erect than cutleaf eveningprimrose.**



Common Groundsel: *Senecio vulgaris*

Weed Description: **A winter or summer annual with lobed leaves, yellow leaves and a white 'puff-ball' seedhead like that of dandelion. Common groundsel is primarily a weed of landscapes, nursery crops, greenhouses, and occasionally agronomic crops. It is distributed primarily in the northern United States.**

Stems: **Branched, without hairs, ranging from 4 to 20 inches in**

height. Stems are capable of rooting at the nodes.

Leaves: Arranged alternately along the stem, usually without hairs but occasionally with a few hairs. Leaves have deeply lobed margins.

Roots: A taproot and a fibrous root system.

Flowers: Occur in clusters at the ends of stems. Individual flowers are approximately 1/2 inch in diameter and are yellow in color.

Fruit: **A red to brown achene with soft white hairs that helps in wind dispersal. Fruit form a 'puff-ball' like that of dandelion.**

Identifying Characteristics: **The deeply lobed leaves, yellow flowers, and 'puff-ball' seedhead are all characteristics that help in the identification of common groundsel.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Mallow: *Malva neglecta*

Weed Description: **A winter or summer annual or biennial, freely branching at the base, with a prostrate growth habit. Found throughout the United States, more common in turfgrass, landscapes, and nursery crops.**

Seedling: **Cotyledons are heart-shaped, 5-7 mm long, 3-4 mm wide, with 3 main veins, hairy. Alternate young leaves, crinkled, circular with toothed margins, and hairy on both surfaces.**

Roots: **Short, straight-taproot.**

Leaves: Alternate, on long petioles, circular to kidney-shaped, toothed and shallowly 5-9 lobed, 2-6 cm wide. Short hairs present on upper and lower leaf surfaces, margins and petioles.

Flowers: Single or in clusters of 2-4 in leaf axils. Petals white or tinged with pink or purple.

Stems: Freely branching at the base, lying close to the soil surface, nearly erect or spreading with tips turned up (decumbent).

Fruit: Flattened, round, disc-like, composed of 12-15 small hairy, 1-seeded segments, 5 to 8 mm in diameter, resembling a button in appearance.

Identifying Characteristics:

Fruit disc-like, resembling a button. Leaves circular, toothed, and long petioled. This weed is often confused with Ground Ivy (*Glechoma hederacea*). However, ground ivy leaves are opposite, and have much more prominent rounded teeth. Ground ivy also has square stems and may emit a minty odor.

Ground Ivy: *Glechoma hederacea*

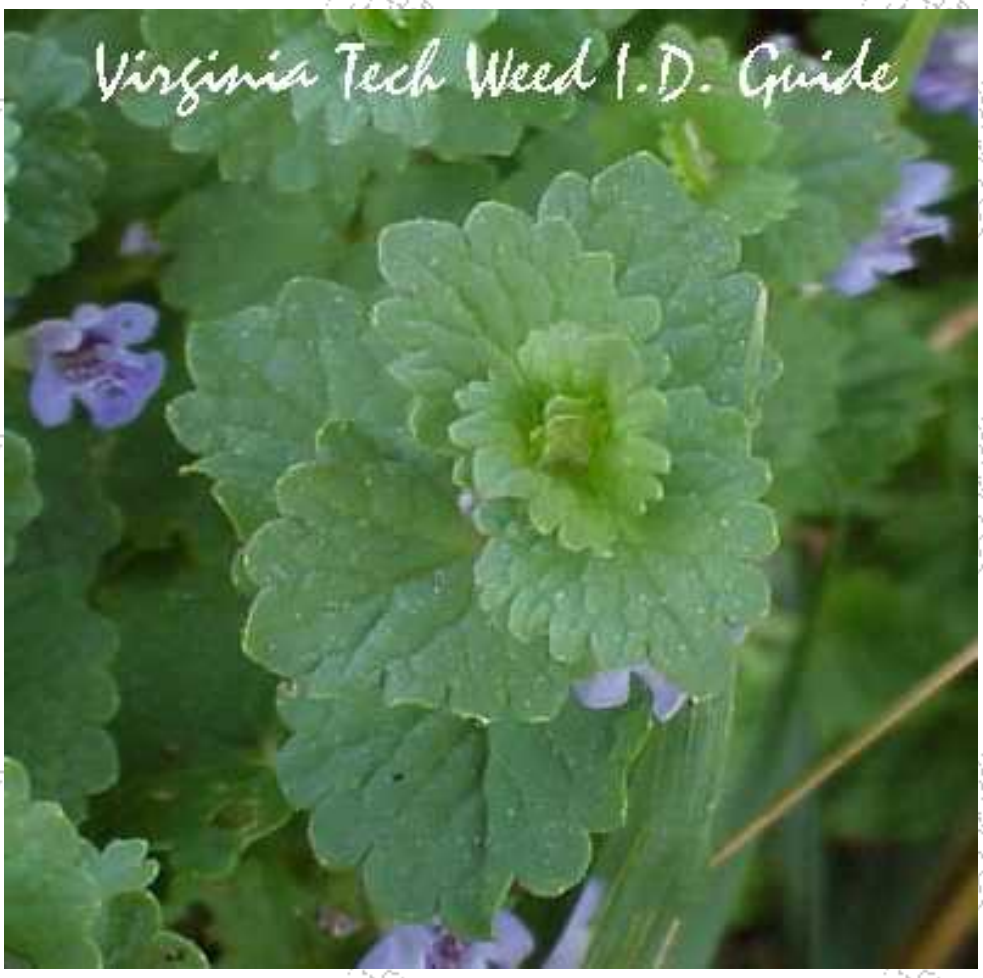
Weed Description: **Perennial with creeping stems that root at the nodes and foliage that emits a mint-like odor when mowed. Primarily a weed of turfgrass and landscapes that is found in the northeastern, north-central and southern United States.**

Seedlings: **Although seedlings rarely occur due to the creeping stems and rhizomes, cotyledons are oblong to spatula-shaped.**

Leaves: **Opposite, nearly round in outline or sometimes kidney-shaped, on long petioles. Margins have large rounded teeth and leaf veins arise from the same point.**

Stems: **Square, trailing, rooting at the nodes, mostly without hair but occasionally with short, stiff backward-pointing hairs.**

Roots: **Rhizomes occur and fibrous roots are also produced at the base at each node of the trailing stem.**



Flowers: **Typically occur in clusters of 3 in the area between the stem and petiole (leaf axils). Flowers are blue-violet, 3/8 to 5/16 inch long.**

Fruit: **Small nutlets (1 mm long) that are**

egg-shaped and brown in color.

Identifying Characteristics:
**This weed is often misidentified as one of the speedwells or sometimes as Common Mallow (*Malva neglecta*), but the square stems of ground ivy help to distinguish it from either of these weed species. Additionally, Henbit (*Lamium amplexicaule*), Purple Deadnettle (*Lamium*

***purpureum*) and Persian Speedwell (*Veronica persica*) are somewhat similar in appearance to ground ivy, but neither of these species have creeping stems that root at the nodes.**

Virginia Tech Weed Identification Guide

Select a Resource...

Henbit: *Lamium amplexicaule*

Weed Description: **Winter annual with square stems and pink-purple flowers, reaching 16 inches in height. Primarily a weed of turfgrass, landscapes and small grains. Found throughout the United States but most common in the eastern states.**

Leaves: **Opposite, reaching 5 inches in length, circular to heart-shaped, with hairs on the upper leaf surfaces and along the veins of the lower surface. Leaf margins have rounded teeth. Lower leaves occur on petioles, while the upper leaves are without petioles (sessile).**

Seedlings: **Cotyledons are oval, 3-12 mm long, 1-4 mm wide. Stems below the cotyledons become purple with age. The base of the cotyledon is notched where it joins the petiole. Young leaves occur on petioles, are circular to heart-shaped, opposite, and have distinctly 'crinkled' upper surfaces. Hairs occur on the upper leaf surfaces and along the veins of the lower surface.**

Stems: **Lie on the ground but have tips that are ascending (decumbent), green or often purple-tinged. Stems root at the lower nodes, are square in cross section and are covered with downward-pointing hairs.**

Roots: **Fibrous.**

Flowers: **Occur in whorls in the upper leaves without petioles. Flowers are pink to purple in color and are fused into a tube approximately 2/3 inch long.**

Fruit: **The fruit are egg-shaped nutlets reaching 2 mm in length and are brown with white spots.**

Identifying Characteristics: **Square stems with petioled lower leaves and sessile upper leaves. This weed is commonly confused with Purple or Red Deadnettle (*Lamium purpureum*). However, purple deadnettle has upper leaves that are triangular, occur on petioles, and are distinctly red- or purple-tinted, unlike the upper leaves of henbit.**

Purple or Red Deadnettle: *Lamium purpureum*

Weed Description: **Winter annual with square stems and purple-red flowers that closely resembles henbit (*Lamium amplexicaule*). P rimarily a weed of turfgrass, landscapes, and winter grain crops found throughout the U. S.**

Seedling: **Cotyledons oval and without hairs, while subsequent leaves are hairy, opposite, and nearly circular in outline with rounded teeth on the sides.**

Leaves: **All leaves occur on short petioles, are sparsely hairy, and are circular in outline with 'scalloped' margins. Leaves are 8-12 mm long and dark green in color, becoming more purple-red in the upper leaves. Upper leaves are also relatively triangular in outline.**

Stems: **Branched from the base of the plant, are square, and may reach 16-18 inches in height.**

Roots: **Fibrous root system.**

Flowers: **Occur in whorls of 3-6 in the upper leaves. Purple-red in color and 1-2 cm long.**

Fruit: **A berry 2 mm long.**

Identifying Characteristics: **Winter annual with purple-red flowers, square stems, and petioled leaves. The petioled leaves, triangular and sometimes purplish-red upper leaves help to distinguish this weed from Henbit (*Lamium amplexicaule*), which has upper leaves that do not occur on petioles (sessile).**

Virginia Tech Weed Identification Guide

Select a Resource...

Persian Speedwell: *Veronica persica*

Weed Description: **A winter annual with small, light blue and white flowers and oval or round hairy leaves with round teeth. Many similar speedwell species occur throughout most of the United States. They are primarily weeds of lawns, turfgrass, landscapes, nurseries, and winter small grains.**

Roots: **A fibrous root system.**

Leaves: Usually oval-shaped, 7 to 21 mm long, 5 to 14 mm wide. All leaves are hairy and have rounded leaf margins. The lower leaves are arranged oppositely and occur on petioles that range from 1 to 3 mm in length. The upper leaves that occur on the erect flowering stems are arranged alternately and do not occur on petioles (sessile).

Stems: Stems initially grow prostrate along the ground. Flowering stems grow more erect and may range from 4 to 12 inches in height.

Fruit: A capsule, 4 to 5 mm long, 5 to 8 mm wide.

Flowers: Occur singly and occur on long flower stalks. Flower stalks arise from the area between the leaf bases and stems (leaf axils). Flowers range from 7 to12 mm in width and are

usually light blue in color with darker blue lines and a pale blue to white center.

Identifying Characteristics: The oval-shaped, hairy leaves that are arranged oppositely below and alternately along the flowering stem and the small, light blue flowers are all characteristics that help in the identification of Persian speedwell. Prior to flowering, the speedwells are often misidentified as Ground Ivy (*Glechoma hederacea*), Henbit (*Lamium amplexicaule*), and Purple Deadnettle (*Lamium purpureum*). However, ground ivy does not have hairy leaves like those of Persian speedwell and both henbit and purple deadnettle have leaves that are arranged oppositely along the flowering stem. Many other *Veronica* species may be found in similar environments and habitats. These species are primarily distinguished by leaf shape, leaf hairiness, leaf and flower arrangement, and flower type.

Virginia Tech Weed Identification Guide

Select a Resource...

Common Milkweed: *Asclepias syriaca*

Weed Description: **Perennial, erect, from a deep rhizome that excretes a milky sap when broken. Found throughout the northeastern United States, south to Virginia and northern Georgia, and west to the Rocky Mountains.**

Seedling: **Cotyledons flat, dull green, oval (1.2 cm long), plants emerging from rhizomes lack cotyledons and are much more robust than seedlings.**

Roots: **Taproot with a deep rhizome.**

Stems: Rarely branched, erect, hollow, covered with fine hairs, emitting a milky sap when broken. Stems green initially but may become red with maturity.

Leaves: Opposite, with an untoothed margin (entire), oblong to oval, 10-30 cm long, 5-11 cm wide, petiolated. Lower leaf surfaces finely pubescent, while the upper surface is without hairs (glabrous).

Flowers: In clusters (umbels) of 20-130 at the end of stems and in the upper leaf axils, greenish-purple to greenish-white. Each flower is on a long, slender stalk.

Fruit: **Follicles that are large (8-13 cm long), teardrop-shaped, grayish-green and hairy. Each follicle may contain many seeds that are 6-10 mm long, flattened, brown, with a papery margin and a tuft of silky hairs.**

Identifying Characteristics: **All parts of the plant excrete a milky say when broken. Hemp Dogbane (*Apocynum cannabinum*) is often confused with common milkweed, especially at emergence. However, much smaller leaves and greater degree of branching in hemp dogbane help to distinguish this weed from common milkweed.**

Virginia Tech Weed Identification Guide

Select a Resource...

Hemp Dogbane: *Apocynum cannabinum*

Weed Description: **A perennial with opposite leaves that secretes a milky sap when broken, reaching 5-6 ft in height. Found throughout the United States.**

Leaves: **Entire, ovate or elliptic, 2-5 inches long, 0.5-1.5 inches wide, and arranged oppositely along the stem. Leaves have short petioles and are sparingly pubescent or lacking hairs beneath.**

Stems: **Lack hairs, often have a reddish tint when mature, become woody at the base, and are much-branched in the upper portions of the plant.**

Roots: **These plants may be found growing as colonies due to a long horizontal rootstock that develops from an initial taproot.**

Fruit: **Long (5 inches or more), narrow follicles produced in pairs that turn reddish brown when mature.**

Flowers: **Small, white to greenish-white, and produced in terminal clusters (cymes).**

Identifying Characteristics: **Stems and leaves secrete a milky sap when broken. Sprouts emerging from the underground horizontal rootstock may be confused with Common Milkweed (*Asclepias syriaca*) emerging shoots. However, the leaves of hemp dogbane are much smaller than those of common milkweed. When mature, these weeds may be distinguished by the branching in the upper portions of the plant that occurs in hemp dogbane, and also the smaller size of this weed compared to common milkweed.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Mullein: *Verbascum thapsus*

Weed Description:

A biennial that may reach as much as 7 feet in height with large woolly leaves and a long spike with many showy yellow flowers. Common mullein was brought to America by the Puritans, who used the plant as a medicinal herb. Teas and ointments made from the leaves of this weed continued to be used for many years as a 'cure' for lung diseases, rheumatism, burns, rashes, and earaches. Common mullein is primarily a weed of pastures, hay fields, roadsides, right-of-ways, and abandoned areas. It is found throughout the United States except for the upper great plains.

Seedlings: **Cotyledons are spatula-shaped. First true leaves have many soft hairs and are oval in outline with only slightly wavy margins. Subsequent leaves are also densely hairy and have more wavy margins.**

Leaves: **Leaves initially develop as a basal rosette during the first year of growth and then occur alternately along the flowering stem during the second year of growth. All leaves are covered in hairs, to the point that leaves are most often described as being 'woolly'. Rosette leaves are oblong in outline, ranging from 6 to18 inches in length. Leaves become progressively smaller up the flowering stem.**

Stems: **Erect, unbranched, occurring during the second year of growth. Stems may reach as much as 6 feet in height and are also densely hairy.**

Roots: **A taproot and a fibrous root system.**

Flowers: **Many flowers occur in a dense spike at the end of the flowering stem. These spikes may reach as much as 20 inches in length. Flowers are yellow in color, approximately 1 inch in diameter, and consist of five petals.**

Fruit: **An oval capsule, approximately 6 mm in diameter.**

Identifying Characteristics: **The rosette growth habit, large 'woolly' leaves and stems, and flowering stems with many yellow flowers are all characteristics that help in the identification of common mullein. Moth Mullein (*Verbascum blattaria*) is closely related to common mullein, however this weed is generally smaller and has leaves without hairs and toothed leaf margins unlike common mullein. Additionally, the flowers of common mullein are yellow and do not occur on peduncles (flower stalks), whereas those of moth mullein or yellow and purple or white and purple in color and do occur on peduncles.**

Virginia Tech Weed Identification Guide

Select a Resource...

Moth Mullein: *Verbascum blattaria*

Weed Description: **A biennial that is closely related to common mullein but lacks hairs and has leaves with toothed margins. Moth mullein is primarily a weed of pastures, hay fields, roadsides, rights-of-ways, and abandoned areas. It is distributed throughout the United States.**

Seedlings: **Cotyledons are spatula-shaped. First true leaves are oval in outline with only slightly wavy margins. Subsequent leaves have more scalloped or toothed margins. Seedlings are very similar in appearance to common mullein but lack hairs.**

Leaves: **Leaves initially develop as a basal rosette of leaves during the first year of growth and then occur alternately along the flowering stem during the second year of growth. Leaves are without hairs (glabrous), oblong in outline, tapering to a point, with distinctly toothed margins.**

Stems: **Erect, unbranched, only slightly hairy in the upper portions, reaching 3 1/2 feet in height.**

Roots: **A taproot with a fibrous root system.**

Flowers: **Occur on the ends of the erect flowering stems that are produced during the second year of growth. Individual flowers are yellow to white in color, usually with some tinge of purple within. Flowers consist of 5 petals and each flower occurs on an individual flower stalk (peduncle).**

Fruit: **A round**

capsule.

Identifying Characteristics: The rosette growth habit, hairless leaves with toothed margins, and yellow and purple or white and purple flowers are all characteristics that help in the identification of moth mullein. Common Mullein (*Verbascum thapsus*) is closely related to moth mullein but is generally much larger with woolly foliage and stems. Additionally, common mullein has a terminal cluster of yellow flowers that do not occur on peduncles, whereas moth mullein has yellow to white flowers with purple tinges that do occur on peduncles.

Common Pokeweed or Pokeberry: *Phytolacca americana*

Weed Description: **A large, 3 to 10 ft tall, perennial weed with thick, reddish-purple branched stems and dark purple to black berries. All parts of the plant are poisonous to cattle, horses, swine, and humans, especially the roots. Leaves may be cooked to eliminate the poisonous components. Swine are most often affected since they are capable of "grubbing-up" the roots. Found from Maine to Iowa, and Kansas, southward to Texas and Florida and southern Arizona.**

Seedling: **Cotyledons 7-33 mm long, 6-11 mm wide, egg-shaped but pointed at the apex. Stems below the cotyledons (hypocotyls) are without hairs, succulent, and often purple-tinged. Young leaves alternate, egg-shaped but pointed at the apex, and without hairs. Cotyledons and young leaves are pale green in**

color, with reddish tinted petioles.

Leaves: **Alternate, 3 1/2-12 inches long, 1-4 inches wide, egg-shaped, petiolated, without hairs, and are smaller in size toward the top of the plant.**

Stems: **Branch from the root crown at the base of the plant, erect, large, smooth, purple-tinged.**

Flowers: **Individual flowers small (6 mm wide) with 5 white to pink-tinged sepals.**

Roots: **Large, white tap root up to 6 inches in diameter.**

Fruit: **A berry, 7-12 mm, green when immature, dark-purple to black when mature. Contain a dark red juice.**

Identifying Characteristics: **Large, tree-like plant with egg-shaped leaves, purple-tinged stems and dark purple berries.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Purslane: *Portulaca oleracea*

Weed Description: **Prostrate, fleshy, succulent summer annual that is able to tolerate poor, compacted soils and drought. Common purslane is a common weed of gardens, horticultural and agronomic crops and is found throughout the United States.**

Roots: **Taproot with fibrous secondary roots.**

Seedling: **Cotyledons oblong, succulent and without hairs (glabrous). Young leaves opposite with each succeeding pair 90° from the preceding pair. Young leaves maroon or maroon-tinted on lower surface.**

Leaves: **Alternate or opposite, 1/4 to 1 1/4 inches long, rounded at apex and narrowed to the base (spatulate). Leaves are thick, succulent and fleshy, with smooth margins.**

Stems: **Succulent, smooth, prostrate, much-branched, purplish-red or green, 4 to 20**

inches long and without hairs.

Flowers: **Yellow in color with 5 petals, 5-10 mm wide, that open only when sunny. Flowers are found alone in the leaf axils or clustered at the ends of the branches.**

Fruit: **An oval, many-seeded capsule (4-8 mm long by 3-5 mm wide) that splits open around the middle.**

Identifying Characteristics: **Prostrate growth habit in combination with the fleshy, succulent nature of this weed helps to distinguish it from most other plants.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Reed: *Phragmites australis*

Weed Description: **An aquatic perennial grass from rhizomes that can form dense colonies along marshes, swamps, streams, and rivers.**

Leaves: **May reach as much as 1 1/2 feet in length, usually about 1/2 inches wide. Leaf blades are without hairs (glabrous) but leaf margins may have short stiff hairs and are rough to the touch. Auricles are absent. The ligule is a fringe of hairs. Long (1/4 inch), white hairs also occur at the junction between the leaf blade and the sheath.**

Stems: **Leaf sheaths may reach as much as 10 feet in height and are terminated by a large tan to brown panicle seedhead.**

Roots: **Rhizomes and a fibrous root system.**

Flowers: **Seedheads are tan to brown panicles that may reach 1 foot in length. Panicles take on a grayish or silvery cast after maturity due to the long white hairs on each spikelet.**

Identifying Characteristics: **The aquatic growth habit, rhizomes, and leaves with long white hairs at the leaf-sheath junction are all characteristics that help in the identification of common reed. Giant reed (*Arundo donax*) grows in similar environments, but has a larger, lighter-colored seedhead.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common Teasel: *Dipsacus fullonum*

Weed Description: **An erect biennial with small prickles on the stem and distinctive spiny flower heads. Common teasel may reach 6 1/2 feet in height and is primarily a weed of roadsides, pastures, hayfields, and occasionally rosettes can be found in turfgrass. This weed is found throughout the United States except in the northern great plains.**

Seedling: **Cotyledons are oval to round in shape and occur on short petioles. First true leaves are also oval to round in shape, have rounded or 'scalloped' teeth, and have an overall wrinkled appearance.**

Leaves: **Plants initially produce a basal rosette of leaves and then flowering stems are produced during the second year. Rosette leaves are oval in outline, have a wrinkled appearance, and have margins with rounded or 'scalloped' teeth. Leaves that occur on the flowering stems are opposite,**

without petioles (sessile), and are lanceolate in outline. Leaves that occur on the flowering stems are also 'clasping', with their leaf bases completely surrounding the stem. All leaf midveins have short prickles on them.

Stems: **Flowering stems are produced during the second year of growth and are erect and branching near the upper portions of the plant. Stems are angled and also have many small prickles that are turned downward on them.**

Fruit: **An achene that is angled and approximately 2 to 3 mm long.**

Flowers:

Flowers are egg-shaped in outline but cut off squarely at the base. Flowers are approximately 1 1/4 to 4 inches long and consist of many individual white to lilac flowers that bloom in a circular pattern around the seedhead. Individual flowers are from 10 to 15 mm long and occur on flower stalks (peduncles). Several long, leaf-like bracts also branch out from the base of the flower and curve upward around the head.

Identifying Characteristics:

Leaves with a 'wrinkled' appearance, stems with small prickles curving downward, and large spiny flower heads are all characteristics that help to distinguish common teasel from other weed species. When in the rosette stage of growth, however,

common teasel might be mistaken for a thistle, Common Burdock (*Arctium minus*), or Broadleaf Dock (*Rumex obtusifolius*), but neither of these weeds have leaves that are 'wrinkled' like those of common teasel.

Virginia Tech Weed Identification Guide

Select a Resource...

Common Toadflax: *Linaria canadensis*

Virginia Tech Weed Identification Guide

Select a Resource...

Common Venus' Looking-glass: *Triodanis perfoliata*

Weed Description: **An erect winter or summer annual with leaves that clasp the stem and purple flowers. Common Venus' looking-glass is primarily a weed of landscapes, lawns, turfgrass, and occasionally pastures and hay fields. This weed is found throughout the United States.**

Stems: **Erect, branched, hairy, reaching as much as 1 1 /2 feet in height.**

Leaves: **Leaves are rounded to oval in outline, distinctly clasping the stem to the point that they appear to completely enclose the stem. Leaves range from 1/4 to 1 1/2 inches in length**

and from 6 to 25 mm in width. Leaf margins are usually slightly serrated or toothed.

Roots: A fibrous root system.

Flowers: Occur in clusters of 1 to 3 in the positions between the leaves and stems. Flowers consist of 5 purple petals that are collectively approximately 3/4 inch wide. Flowers do not occur on flower stalks (peduncles).

Fruit: A long, narrow capsule containing many very small (0.5 mm long), reddish seed.

Identifying Characteristics:
The round or oval leaves that almost completely encircle the stem and the distinctive purple flowers are both characteristics that help to distinguish common Venus'

looking-glass from most other weeds.

Common Vetch: *Vicia sativa*

Weed Description: **A trailing or climing summer annual vine with leaves that are divided into many leaflets. The vetches are common weeds of roadsides, pastures, landscapes, ornamentals, and some of the winter annuals are weeds of winter small grains. Common vetch is found throughout Virginia, Georgia, North Carolina, and Alabama.**

Seedlings: **No distinct cotyledons emerge. First true leaves have 1 pair of oppositely arranged linear leaflets.**

Leaves: **Each leaf is arranged alternately along the stem and occurs on a petiole. Leaves are divided into 8 to 16 leaflets that are arranged oppositely from one another (pinnately compound leaves). Leaflets are oblong to elliptic in outline, either without hairs (glabrous) or with some short hairs, approximately 3/4 to 1 1/2 inches long. Stipules normally occur at the base of the leaf petiole. These stipules range from 2 to 10 mm in length, appear to be 'toothed,'**

and have brown to purple glandular nectaries (stipules are illustrated in the picture below). Older leaves develop tendrils that help in climbing.

Roots: A fibrous root system.

Stems: Stems climb on other vegetation or trail along the ground. Stems may reach as much as 3 1/2 feet in length. Stems may have short hairs or may be without hairs (glabrous).

Flowers: Occur in the area between the stems and leaf petioles (leaf axils). Flowers occur in pairs and on flower stalks (peduncles) that range from 2 to 6 mm in length. Flower petals are usually purple in color but may be rose or sometimes white in color. Flowers are approximately 3/4 to 1 1/4 inches long.

Fruit: **A flat pod (more correctly called a legume), from 1 1/2 to 3 inches long and 5 to 8 mm wide.**

Identifying Characteristics: **The leaves that are divided into 8 to 16 leaflets, the distinct stipule that occurs at the base of the leaf petiole, and the climbing or trailing growth habit are all characteristics that help to distinguish common vetch from most other weed species. Many other annual and perennial vetches occur in Virginia and the southeastern United States. They are primarily distinguished by leaflet shape and flower**

characteristics.


















Coontail or Hornwort: *Ceratophyllum demersum*

Weed Description:
An aquatic annual weed that is submersed and has the overall appearance of a 'coon's tail'. This weed is capable of forming large colonies in fairly deep water of lakes and ponds and is found throughout the southeastern United States.

Leaves:
All parts of the plant, including the leaves, are rough to the touch. Leaves are submersed, finely dissected, and occur

in whorls of 5 or more. Individual leaves are linear in outline, ½ to ¾ inch long, and are toothed along one margin only. Leaves become more and more crowded toward the stem tip.

Stems: Rough feeling, branched, reaching 15 feet or more in length. Stems are either floating free or attached to the substrate below via rhizoids.

Flowers: **Small, solitary, without a stalk, and occur at the leaf bases (leaf axils). Flowers are inconspicuous and have no sepals and petals. Flowers also remain submersed throughout the year.**

Fruit: **An achene.**

Identifying Characteristics:

Submersed aquatic weed that resembles a coon's tail. The toothed margin along one side of the leaves of coontail help to distinguish this from most other submersed aquatic weeds.

Virginia Tech Weed Identification Guide

Select a Resource...

Hophornbeam Copperleaf: *Acalypha ostryifolia*

Virginia Tech Weed Identification Guide

Select a Resource...

Virginia Copperleaf: *Acalypha virginica*

Weed Description: **Summer annual to 3 ft tall with leaves that often develop a copper coloration. Found from Maine south to Florida, west to South Dakota and Texas.**

Seedling: **Cotyledons round, slightly notched at the apex, without hairs. First true leaves opposite, subsequent leaves alternate.**

Leaves: **Lanceolate, 3/4-3 inches long, petiolated, upper leaves alternate, lower leaves opposite. Youngest leaves develop a distinct copper coloration.**

Stems: **Branching, hairy, 1 to 3 ft tall.**

Roots: **Taproot with a secondary fibrous root system.**

Flowers: **Green in color, produced in clusters in the areas between the stem and leaf petioles (axillary flower clusters). Certain flowers surrounded by deeply divided bracts.**

Fruit: **A 3-lobed seed pod.**

Identifying Characteristics: **Distinct copper-colored young leaves, axillary flower clusters.**

Virginia Tech Weed Identification Guide

Select a Resource...

Corn Salad: *Valerianella radiata*

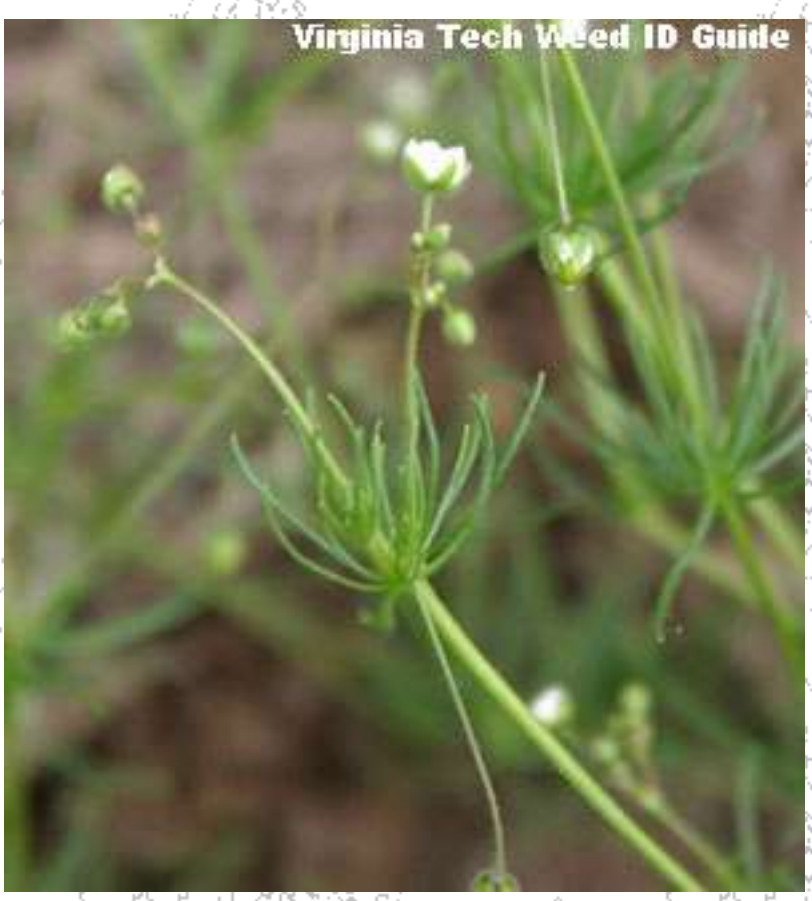

Virginia Tech Weed ID Guide

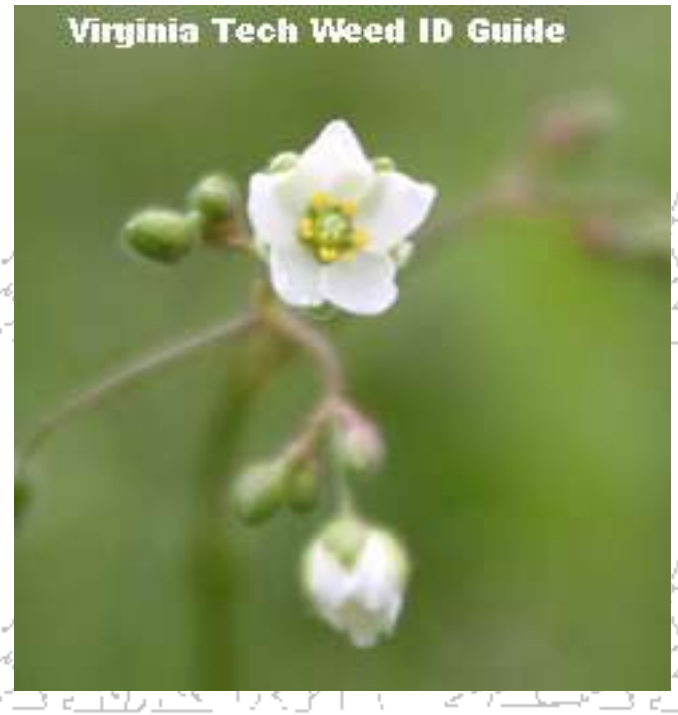
Virginia Tech Weed Identification Guide

Select a Resource...

Corn Spurry: *Spergula arvensis*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Cotton Morningglory: *Ipomoea cordatotriloba*

Weed Description: **Weak perennial, low climbing or trailing vine with lavender flowers. Found in the lower southeastern Gulf states to Texas.**

Seedling: **Cotyledons deeply indented, without hairs.**

Roots: **At first a conventional taproot, overwinters from a long-lived, branched rootstock.**

Leaves: **With a continuous, untoothed margin, either heart-shaped (cordate) or deeply 3- to 5-lobed, 1 1/2 to 3 1/2 inches long, 3/4 to 2 inches wide, with a long, tapering point and concave sides. Sepals and leaves without hairs.**

Flowers:
Rosy lavender with a dark center, approximately 1 1/4 to 2 1/4 inches long.

Fruit: **Small, brown, globoid, hairy capsule, 6-9 mm broad.**

Stems: **Twining to low-climbing vine, branched, without hairs.**

Identifying Characteristics: This weed is often confused with sharppod morningglory (*Ipomoea trichocarpa* var. *trichocarpa*). However, sharppod morningglory has sepals, leaves and stems that may be pubescent, while these areas are not pubescent in cotton morningglory.

Virginia Tech Weed Identification Guide

Select a Resource...

Trumpetcreeper or Cow-itch: *Campsis radicans*

Weed Description: **Perennial woody vine with showy red-orange trumpet shaped flowers reaching 40 ft or more in length.**

Roots: **Taproot and stems that root when they come in contact with the ground.**

Seedlings: **Rarely occur. Propagation is more commonly from root sprouts.**

Leaves: **Opposite and composed of several similar leaflets also arranged oppositely from one another (pinnately compound). A single leaf may contain 7-15 leaflets that are 1-3 inches long, 0.5-1.5 inches wide, and coarsely toothed.**

Fruit: **A long, narrow capsule containing many winged seed.**

Stems: **Become woody with age, and may be either trailing along the ground or climbing on other vegetation. Stems root where they touch the ground and also produce aerial roots that aid in climbing.**

Flowers: **Showy red-orange trumpet shaped flowers (2-3 inches long) are produced in terminal clusters.**

Identifying Characteristics:
Opposite, pinnately compound leaves and showy red-orange flowers.

Creeping Phlox or Moss Pink: *Phlox subulata*

Weed Description: **A prostrate perennial with attractive flowers. Moss pink is commonly planted as an ornamental ground cover and only rarely escapes to become a weed in certain situations.**

Leaves: **Arranged oppositely along the stem, linear in outline, usually hairy.**

Stems: **Usually creeping prostrate along the ground, hairy, often reddish in color.**

Flowers: **Consist of 5 notched petals, usually pink to rose in color but several ornamental varieties exist so it is not uncommon to see plants with white, red, pink, or purple flowers.**

Identifying Characteristics:

The prostrate growth habit, linear leaves and flowers with 5 petals are all characteristics that help in the identification of creeping phlox. Due to the overall growth habit and leaf shape, this weed might be confused with Knawel or German Moss (*Scleranthus annuus*), but the leaves and stems of this weed aren't covered in hairs like those of creeping phlox.

Virginia Tech Weed Identification Guide

Select a Resource...

Knawel or German Moss: *Scleranthus annuus*

Weed Description: **Usually a winter annual but occasionally a summer annual that forms dense, prostrate mats. Knawel is commonly mistaken as a grass and is primarily a weed of lawns, turfgrass, and small grains. Knawel is distributed throughout the eastern United States.**

Seedlings: **Cotyledons are linear in outline and less than 1 mm wide with a sharp tip. This leads to their confusion with grasses.**

Roots:

Taproot and a fibrous root system.

Leaves: **Linear in outline, less than 1 mm wide, also with a sharp tip. Leaves are arranged oppositely along the stem and joined by a thin, clear membrane.**

Stems: **Grow prostrate along the ground, branched, forming dense mats outward from a central plant.**

Flowers: **Flowers are inconspicuous, green in color, and somewhat spiny. Flowers occur in clusters that arise from the position between the leaf bases and the stem.**

Fruit: **A very small (3-4 mm) utricle.**

Identifying Characteristics: **Plants with small, linear leaves that initially resemble a grass and inconspicuous green flowers. Due to the overall growth habit and leaf shape, this weed might be confused with Creeping Phlox (*Phlox subulata*), but the leaves and stems of German moss aren't covered in hairs like**

those of creeping phlox. German moss might also be confused with some of the spurries (*Spergula* spp.) but lacks the distinctive white or red flowers of these species.

Virginia Tech Weed Identification Guide

Select a Resource...

Creeping Rush: *Juncus repens*

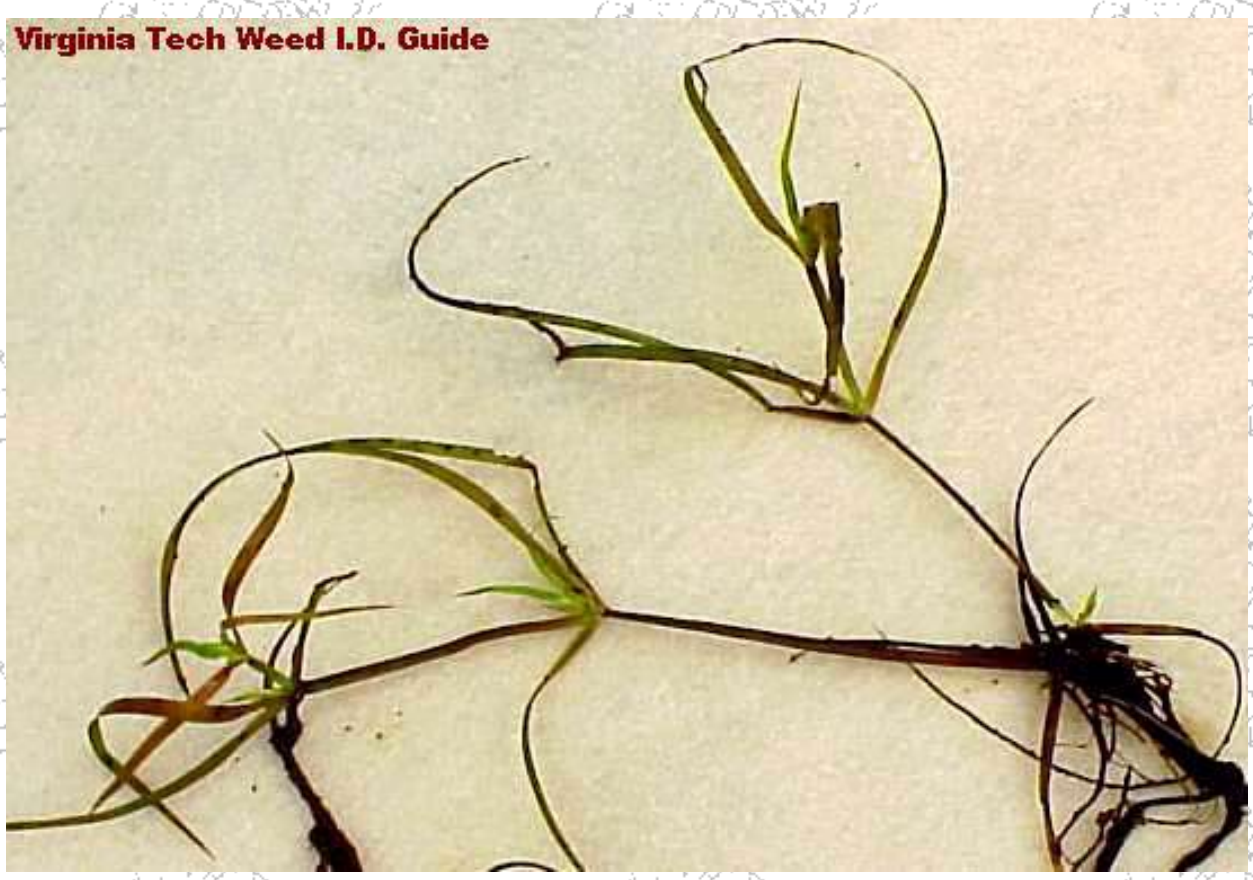
Weed Description: **A short tufted plant growing in moist soil or along shorelines or a submersed aquatic plant usually found in shallow water. Creeping rush is primarily found in ditches and along the edges of ponds and lakes.**

Leaves: **Tufted when growing out of the water, but bright green and forming whorls of leaves at the nodes in submersed plants. All leaves are linear in outline.**

Stems: **In submersed plants, stems root at the nodes. Plants growing in moist soil and out of the water may**

range from 2 to 8 inches in height.

Fruit: A capsule approximately 1/4 inch long.



Flowers: Occur in heads at the ends of stems. Flowers are green and inconspicuous, usually about 1/4 inch long.

Identifying Characteristics: **The whorled, linear leaves and submersed or tufted growth habit helps to distinguish this weed from most other aquatic weed species.**

Virginia Tech Weed Identification Guide

Select a Resource...

Creeping Woodsorrel: *Oxalis corniculata*

Weed Description: Erect, stoloniferous perennial that may mimic a summer annual in cooler climates. Found throughout the United States.

Seedling: Cotyledons smooth, oblong, green. Margins and veins on lower leaf surfaces of young seedlings are sparsely hairy.

Leaves: Alternate, long-petiolated, and divided into 3 heart-shaped leaflets. Leaf margins are fringed with hairs.

Stems: Green to pink, weak, branched at base, more prostrate than erect to 20 inches tall, varying from smooth to pubescent. Spreads by stolons, which are aboveground modified stems.

Roots: Stolons which root at the nodes.

Flowers: In clusters that arise from long stalks at the leaf axils, consisting of 5 yellow petals, 4-9 mm long.

Fruit: A capsule that is angulate with flat sides, cylindrical, pointed, and sparsely hairy. Seed disperse from capsules by explosively ejecting up to 13 feet.

Identifying Characteristics: May be distinguished from Yellow Woodsorrel (*Oxalis stricta*) by the presence of aboveground stolons vs. the underground rhizomes of yellow woodsorrel. Also, creeping woodsorrel has a more prostrate growth habit and often has more reddish-purple leaves than yellow woodsorrel. However, the presence of stolons rather than leaf color should be used to distinguish between the two species, as leaf color is variable in both.

Virginia Tech Weed Identification Guide

Select a Resource...

Yellow Woodsorrel: *Oxalis stricta*

Weed Description: **A perennial with trifoliate leaves and yellow flowers that is primarily a weed in greenhouses, container ornamentals, landscapes, turfgrass, and lawns. Yellow woodsorrel is found throughout the United States.**

Seedlings: **Cotyledons smooth, oblong, green. Margins and veins on lower leaf surfaces of young seedlings are sparsely hairy.**

Leaves: **Arranged alternately along the stem, long-petiolated, and divided into 3 heart-shaped leaflets. Leaf margins are smooth but fringed with hairs.**

Stems: **Green to pink, weak, branched at base, more prostrate than erect to 20 inches tall, varying from smooth to pubescent.**

Roots: **Long, slender rhizomes occur with a fibrous root system.**

Flowers: **Occur in clusters that arise from long stalks at the leaf axils. Individual flowers consist of 5 yellow petals that are 4 to 9 mm long.**

Fruit: **A capsule that is cylindrical and pointed with flat sides, sparsely hairy. Each capsule is approximately 3/4 inch long. Seed disperse from capsules by explosively ejecting up to 13 feet from the parent plant.**

Identifying Characteristics: **A weed of greenhouses and ornamentals with leaves that are divided into 3 heart-shaped leaflets with small yellow flowers. Yellow woodsorrel may be distinguished from Creeping Red Woodsorrel (*Oxalis corniculata*) by the presence of underground rhizomes versus the aboveground stolons of creeping red woodsorrel. Also, creeping woodsorrel has a more prostrate growth habit and often has more reddish-purple leaves than yellow woodsorrel.**

Virginia Tech Weed Identification Guide

Select a Resource...

Mouse-ear Cress: *Arabidopsis thaliana*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Crossvine: *Bignonia capreolata*

Weed Description: **A woody vine with large trumpet-shaped flowers that are dull red or orange on the outside and yellow or red inside. Crossvine may climb to a height of 20 to 40 feet or may trail along the ground where no support is present. Crossvine occurs primarily in woods, fence rows, and roadsides in the piedmont and coastal plain regions of the southeastern United States.**

Stems: **Stems become woody and are usually climbing, reaching 20 to 40 feet in height. Stems climb by way of tendrils.**

Leaves: **Leaves occur on petioles and consist of 7 to 11 leaflets that are ovate to lanceolate in outline, approximately 1 1/2 to 3 inches long. Leaflets are without hairs.**

Flowers: **Flowers occur in clusters of 2 to 5. Individual flowers are approximately 2 inches in length and are dull red to orange on the outside and yellow or red on the inside.**

Fruit: **A flattened capsule that is approximately 6 inches long and 1 inch wide. Each capsule contains several rows of 'winged' seed.**

Identifying Characteristics: **A woody vine that climbs via tendrils and has trumpet-shaped flowers that are dull-red on the outside and yellow on the inside. Trumpetcreeper (*Campsis radicans*) is somewhat similar in appearance and growth habit, but has toothed leaves and flowers that bright orange or red throughout.**





















Virginia Tech Weed Identification Guide

Select a Resource...

Tropic Croton: *Croton glandulosus* var. *septentrionalis*

Weed Description: **Summer annual weed that ranges from 4 to 20 inches in height and is a problematic weed of many agronomic crops in the southeastern United States like corn, soybeans, cotton, and peanuts. Tropic croton may be found throughout the southeastern United States.**

Seedling: **Stems below the cotyledons (hypocotyls) are covered with hairs that take on a star-shaped appearance. Cotyledons are thick, heart-shaped, 5 to 7 mm long by 7 to 10 mm wide, and have three distinct veins that originate from the same point (palmate venation). First true leaves are round to oval in outline and have margins that are toothed.**

Leaves: **Alternate, oval in outline when young, lance-shaped to elliptic in outline with maturity, approximately ½ to 2 ½ inches long, and have margins that are sharply serrated or toothed. Leaves occur on short petioles and have a white, disc-like gland on each side of the petiole where the petioles attach to the central stem. Leaves that occur below flowers appear whorled and upper and lower leaf surfaces have hairs that take on a star-shaped appearance. Leaves emit a distinctive odor when crushed.**

Stems: **Branching, becoming reddish brown with age, and covered with hairs.**

Roots: **A taproot.**

Flowers: **Terminal white flowers that are approximately ½ inch long occur at the ends of stems.**

Fruit: **A brown capsule.**

Identifying Characteristics: **Summer annual with serrated leaves and white, disc-like glands that occur above and below the petiole at the point of attachment to the stem. Tropic croton is sometimes confused with Eclipta (*Eclipta prostrata*), however the leaves of eclipta are much more linear in outline and are arranged oppositely along the stem unlike the**

alternate leaves of tropic croton. Prickly Sida or Teaweed (*Sida spinosa*) also resembles tropic croton in growth habit and appearance, however prickly sida has linear stipules at the base of the petiole but lacks the disc-like gland that occurs on tropic croton. Additionally, the stems of tropic croton are much more hairy than those of prickly sida.

Virginia Tech Weed Identification Guide

Select a Resource...

Eclipta: *Eclipta prostrata*

Weed Description: **A prostrate or erect summer annual to 2 feet in height found in the southern, lower midwest, and east coast states.**

Roots: **Shallow taproot with fibrous root system.**

Seedling: **Stems below the cotyledons (hypocotyls) are light green to light purple. Cotyledons are without hairs, slightly thickened, spatulate, with a midvein evident on the lower surface.**

Fruit: **A brown achene, 1.8-2.5 mm long, widest at the apex and tapering to the base.**

Mature Plant: **Leaves are opposite, elliptic to lanceolate either without petioles or with a short petiole, slightly thickened, approximately 1 1/4 to 5 inches long and up to 1 1/4 inches wide, with short, appressed hairs on both surfaces. Leaf margins have widely spaced teeth. Stems initially green, becoming reddish brown, freely branched, and capable of rooting at the nodes.**

Flowers: **Occur alone or in clusters of 2-3 on small stalks at the end of stems or in leaf axils. Flowers are rounded and consist of small, white**

ray flowers surrounding greennish disk flowers.

Identifying Characteristics:
Opposite, elliptic to lanceolate leaves with widely-spaced teeth. Eclipta is sometimes confused with Tropic Croton (*Croton glandulosus*), however the leaves of eclipta are much more linear in outline and are arranged oppositely along the stem unlike the alternate leaves of tropic croton. Young eclipta seedlings may also be confused with Hairy Galinsoga (*Galinsoga ciliata*) seedlings, but the two can easily be distinguished by the lack of hairs on eclipta and the presence of


hairs on hairy galinsoga.

Virginia Tech Weed Identification Guide

Select a Resource...

Hairy Galinsoga: *Galinsoga ciliata*

Weed Description: **An abundant seed-producing summer annual with hairy leaves and stems, reaching 2 feet in height. Primarily a weed of vegetable crops, however it may occur in any cultivated situation. Found throughout the eastern and midwestern United States, and also on the west coast.**

Seedling: **Cotyledons club-shaped with slightly indented tip. The stem below the cotyledon (hypocotyl) is very short, green, becoming maroon with age. Young leaves opposite, triangular with slightly toothed margins, and covered with hairs.**

Leaves: **Opposite, oval to triangular, coarsely-toothed, petiolated, and densely covered with hairs on the upper surface. Lower leaf surfaces have hairs that primarily occur on the veins.**

Stems: **Erect, reaching 2 feet in height, freely-branched, green or less often maroon-tinted, and covered with hairs.**

Roots: **Fibrous.**

Fruit: **A brown to black achene, 1 1/2 mm long, hairy, tapered from the base to the apex, with a white pappus**

that resembles a crown.

Flowers: **Many flowers are produced from terminal stems or from the areas where petioles meet the stem (leaf axils). Flowers are less than 1 cm wide and consist of 4 to 5 white (or less often pink), 3-toothed ray flowers (outer flowers) and many yellow disk flowers (inner flowers).**

Identifying Characteristics: **Hairy stems and leaves, and 3-toothed ray flowers. The densely hairy nature of this weed helps to distinguish this weed from smallflower galinsoga (*Galinsoga parviflora*), which is very similar but much less hairy than hairy galinsoga.**

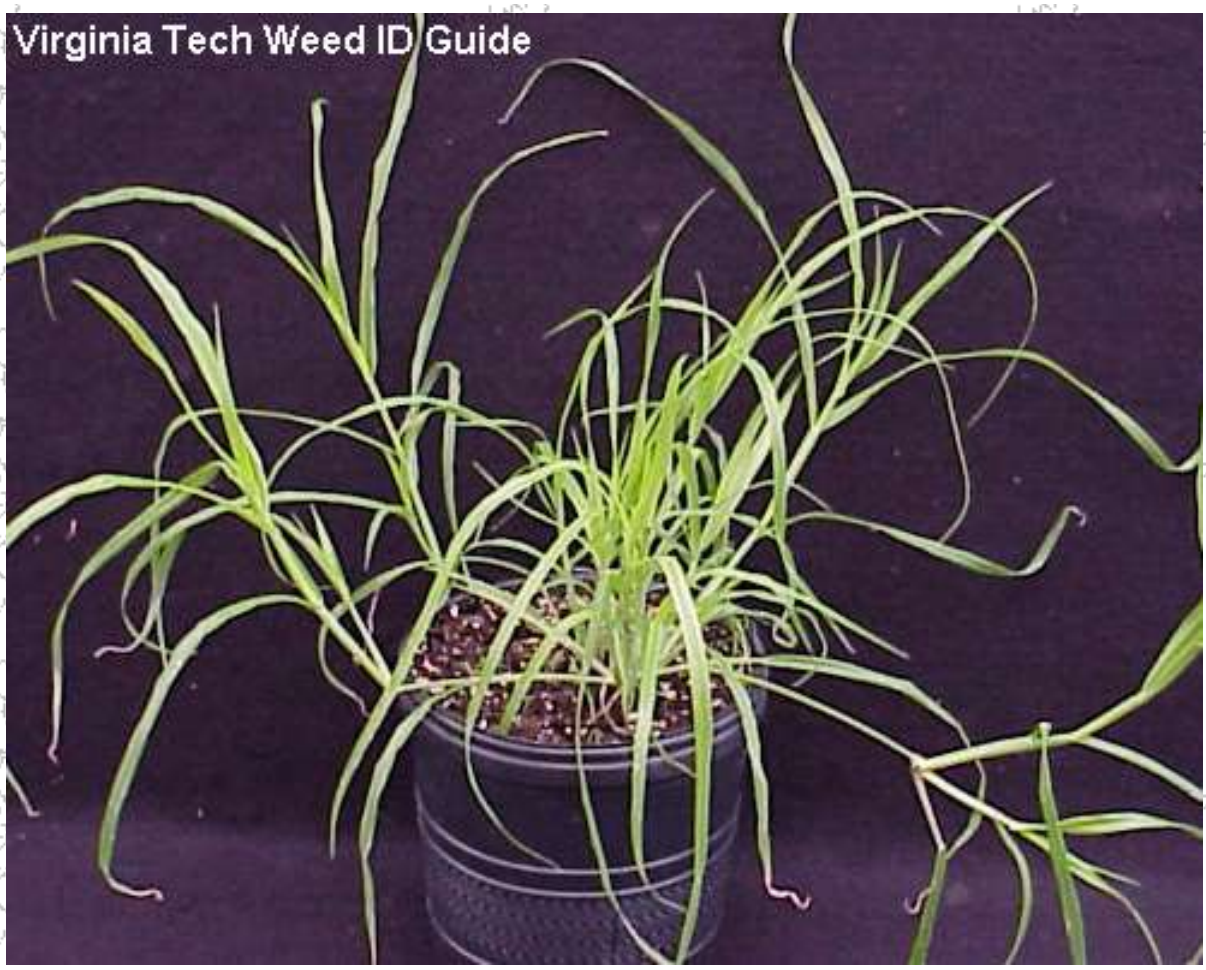
Crowfootgrass: *Dactyloctenium aegyptium*

Weed Description: An annual grass that bends and roots at the lower nodes, with tips that may rise to about 2 feet in height. Found throughout the southern states, northward to Maine, west to Illinois and southern California.

Roots: Fibrous.

Seedling: Leaf blades and sheaths are without hair. Leaf margins have long, stiff hairs. Ligule fringed,

membranous.



Stems: **Bending and rooting at the lower nodes, with tips ascending to 70 cm tall.**

Flowers: **1-7 spikes (1.0-6.2 cm long, 3-7 mm wide) at tip of stem. Seed head resembles a crow's foot.**

Leaves: **Blades are 2-30 cm long, 2-9 mm wide, without hairs or less often having long, stiff hairs. Leaf margins have hairs that point outward. The ligule is membranous to 1.0 mm long and fringed with hairs (0.8 mm long). Sheaths are without hairs.**

Identifying Characteristics: **Entire plant is most often found without hair, except for the hairs that extend outward from the margins and those found on the ligule. Seed head resembles a crow's foot.**

Virginia Tech Weed Identification Guide

Select a Resource...

Stickweed or Yellow Crownbeard: *Verbesina occidentalis*

Weed Description: A perennial that may reach as much as 13 feet in height with showy yellow flowers and conspicuous 'wings' that run along the length of the stem. Stickweed is primarily a weed of pastures, hay fields, fencerows, roadsides, and rights-of-way.

Seedlings: Cotyledons are oval and without hairs (glabrous). The first true leaves are opposite and lanceolate in outline with slightly toothed margins.

Roots: A large perennial basal crown from

which many new plants may arise.

Stems:
Erect, usually unbranced but occasionally branching, ranging from 6 1/2 to 10 feet in height. Stems are usually without hairs but occasionally have small hairs. Several 'wings' run the length of the entire stem. Stems usually persist

throughout the winter, which is more than likely where this weed gets one of its common names.

Leaves:
Leaves are lanceolate to ovate in outline, approximately 3 to 8 inches long and 2 to 4 inches wide. Leaves are without hairs (glabrous), taper to the apex and have a toothed, or serrated, margin. Leaves are arranged oppositely along the stem, unlike in wingstem.

Flowers: **Many flowers occur in clusters at the ends of the erect stems. Each flower consists of outer ray flowers and inner disc flowers, all of which are bright yellow in color. Ray flowers are approximately 1/2 to 3/4 inches long, 4 to 7 mm wide.**

Fruit: **A brown to black nutlet.**

Identifying Characteristics: **The tall growth habit, oppositely arranged lanceolate leaves, yellow flowers, and distinctive 'wings' that run the length of the stems are all characteristics that help to distinguish stickweed from most other plants. A closely related species, Wingstem (*Verbesina alternifolia*), is similar in**

appearance but has alternately arranged leaves unlike those of stickweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Wingstem: *Verbesina alternifolia*

Weed Description: **A perennial that may reach as much as 13 feet in height with showy yellow flowers and conspicuous 'wings' that run along the length of the stem. Wingstem is primarily a weed of pastures, hay fields, fencerows, roadsides, and rights-of-way. It is found throughout Virginia, Georgia, Alabama, Kentucky, and West Virginia.**

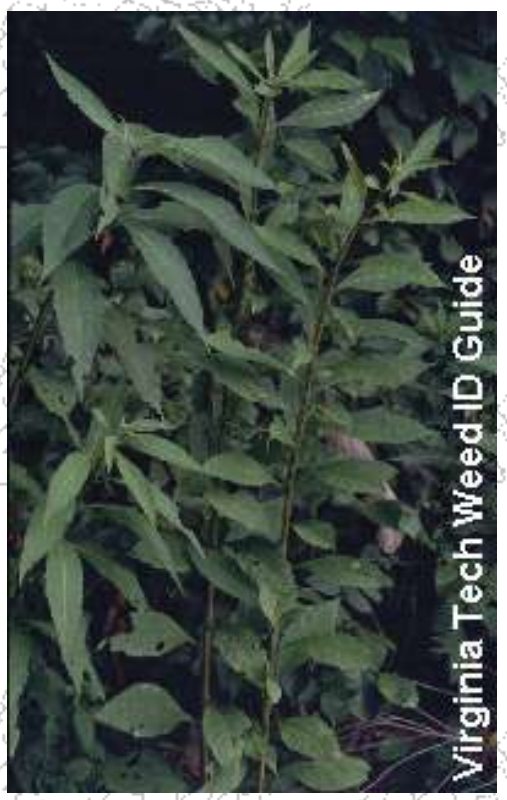
Seedlings:
Cotyledons are oval and without hairs (glabrous). The first true leaves are opposite and lanceolate

in outline with slightly toothed margins.

Roots: A large perennial basal crown from which many new plants may arise.

Leaves: Leaves are lanceolate to ovate in outline, approximately 3 to 8 inches long and 1 to 3 inches wide. Leaves are without hairs (glabrous), taper to the apex and have a toothed, or serrated, margin. Leaves are arranged alternately along the stem, unlike in stickweed.

Stems: **Erect, usually unbranced but occasionally branching, ranging from 6 1/2 to 10 feet in height. Stems are usually without hairs but occasionally have small hairs. Several 'wings' run the length of the entire stem, which is more than likely where this weed gets its common name. Stems usually persist throughout the winter.**



Flowers: **Many flowers occur in clusters at the ends of the erect stems. Each flower consists of outer ray flowers and inner disc flowers, all of which are bright yellow in color. Ray flowers are approximately 3/4 to 1 1/4 inches long, 3 to 6 mm wide.**

Fruit: **A brown to black nutlet.**

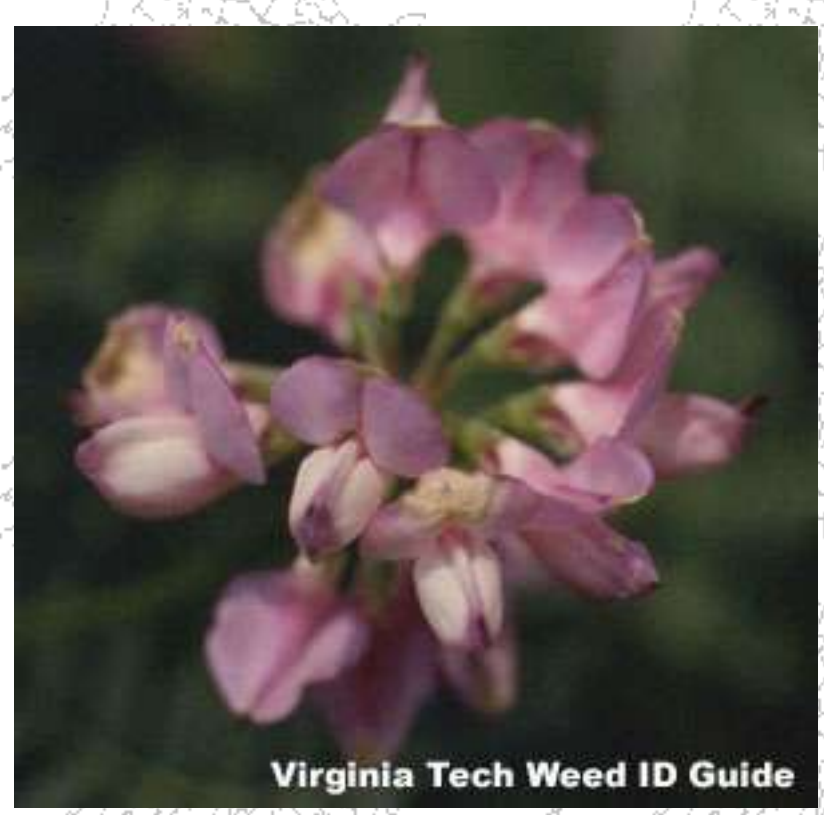
Identifying Characteristics: **The tall growth habit, alternately arranged lanceolate leaves, yellow flowers, and distinctive 'wings' that run the length of the stems are all characteristics that help to distinguish wingstem from most other plants. A closely related species, Stickweed (*Verbesina occidentalis*), is similar in appearance but has alternately arranged leaves unlike those of wingstem.**

Virginia Tech Weed Identification Guide

Select a Resource...

Crownvetch or Trailing Crownvetch: *Coronilla varia*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Purple Cudweed: *Gnaphalium purpureum*

Weed Description: **A low-growing summer or winter annual, or biennial, that forms a rosette of grayish green woolly foliage. Found throughout the United States but most common in the South.**

Stems: **Elongating stems from the rosette do not usually branch and are grayish-white and woolly in appearance.**

Seedling: **Cotyledons smooth, grayish green, without petioles, rounded to oval, 1.5-2.5 mm long, 0.75-1 mm wide. Young leaves taper from the tip to a broad petiole.**

Flowers: **Occur in clusters at the ends of the stems. Each flower is small, tannish-white with bracts that are light brown, pink or purple.**

Fruit: **An achene with an attached bristly pappus to aide in weed dispersal.**

Leaves: **Arise from the rosette or connected to the elongating stem (cauline). Rosette leaves 4 inches long, approximately 3/4 inch wide. Stem leaves alternate, grayish-white and woolly, without petioles (sessile), and progressively reduced in size moving up the stem. Leaf margins may be wavy or without teeth (entire).**

Roots: **Taproot with a secondary fibrous root system.**

Identifying Characteristics: **Stems and foliage with distinct white-woolly foliage.**

Curlyleaf Pondweed: *Potamogeton crispus*

Weed Description: **A submersed aquatic perennial with both rhizomes and stolons and distinctive "curly" leaves. Curlyleaf pondweed can form thick mats in lakes and rivers.**

Leaves: **Leaves are arranged alternately along the stem, are submersed, and do not occur on petioles (sessile). Leaves are approximately 2 to 3 inches long and 1/4 to 1/2 inch wide. The margins are distinctively wavy or 'curled', and most leaves have a prominent red-tinged midvein. Some leaves are also red-tinged**

throughout.

Roots: Both rhizomes and stolons occur.

Stems: Branching, somewhat flattened, often whitish in color.

Flowers: Occur on flower stalks (peduncles) that arise from the area between the leaf bases and the stems (axillary regions).

Identifying Characteristics: The distinctive wavy leaf margins and rhizomes and stolons of this weed make it easy to distinguish from most other submersed aquatic plants.

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Select a Resource...

Cutleaf Geranium: *Geranium dissectum*


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Cypress Spurge: *Euphorbia cyparissias*

Weed Description:
An invasive perennial that reproduces by seed and lateral root buds. Cypress spurge emits a milky sap when broken, and is very similar to leafy spurge, which is an extremely aggressive weed that more commonly occurs in the western United States. Cypress spurge is a weed of pastures, hay fields, fence rows, roadsides, and landscapes.

Leaves: **Leaves are linear, approximately 1/2 to 1 1/4 inches long and 1 to 2 mm wide. Upper stem leaves that occur near the inflorescence are yellow or yellowish green in color. All leaves emit a milky sap when broken.**

Stems: **Stems are without hairs and green to yellowish green in color, branching in the upper portions. Stems also emit a milky sap when broken.**

Flowers: **Flowers typically bloom from March to May in Virginia. Flowers are greenish yellow to yellow in color, and are clustered in bunches at the ends of stems.**

Fruit: **A capsule 2 to 3 mm long.**

Identifying Characteristics: **Plants with linear leaves with yellowish-green flowers. Additionally, the fact that all parts of these plants emit a milky sap when broken readily identifies them as a *Euphorbia* species. Leafy spurge is similar in appearance, but is much taller with wider leaves that aren't nearly as linear in outline as those of cypress spurge.**

Virginia Tech Weed Identification Guide

Select a Resource...

Cypressvine Morningglory: *Ipomoea quamoclit*

Weed Description:
Annual low-climbing or twining vine with leaves that are deeply divided into linear segments. Found throughout the southeastern United States, Virginia to Missouri and south to Texas.

Seedling:
Stems below the cotyledons (hypocotyls) are stout. Cotyledons very deeply indented and long, with an angle between the cotyledons greater than 90°.

Leaves: Egg-shaped and widest near the base in outline, approximately 1 1/4 to 3 inches long, 1 to 2 inches wide, and divided into linear segments that are 1 mm or less wide. Leaves are without hairs.

Stems: Branched, trailing or low climbing vines that may reach 6 1/2 feet in length and also without hairs.

Roots: Fibrous root system.

Flowers: Deep red to scarlet in color, approximately 1 to 1 1/2 inches long. Flower stalks as long as the subtending leaf, bearing 1-3 flowers.

Fruit: A capsule without hairs containing reddish-brown seeds.

Identifying Characteristics:

Deeply divided leaves and cotyledon leaves with very wide angles between the points is one characteristic that helps to distinguish cypressvine morningglory from all of the other morningglories.

Common Weed Names: D

Common Name	Scientific Name
Daisy Fleabane	*Erigeron annuus*
Daisy, Oxeye	*Chrysanthemum leucanthemum*
Dallisgrass	*Paspalum dilatatum*
Dame's Rocket	*Hesperis matronalis*
Dandelion	*Taraxacum officinale*
Dandelion, Dwarf	*Krigia oppositifolia*
Dandelion, False	*Hypochoeris radicata*
Dayflower, Asian	*Murdannia keisak*
Dayflower, Common	*Commelina communis*
Dayflower, Marsh	*Murdannia keisak*
Deadnettle, Purple	*Lamium purpureum*
Deer-tongue Grass	*Panicum clandestinum*
Deptford Pink	*Dianthus armeria*
Devils Beggarticks	*Bidens frondosa*
Devil's Shoestring	*Symphoricarpos orbiculatus*
Dichondra	*Dichondra repens*
Dock, Broadleaf	*Rumex obtusifolius*
Dock, Curly	*Rumex crispus*
Dodder	*Cuscuta* spp.
Dogfennel	*Eupatorium capillifolium*
Doveweed	*Murdannia nudiflora*

Downy Brome	*Bromus tectorum*
Duckweeds	*Lemna* spp.
Dwarf Dandelion	*Krigia oppositifolia*

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Virginia Tech Weed Identification Guide

Select a Resource...

Oxeye Daisy: *Chrysanthemum leucanthemum*

Weed Description: **A perennial from rhizomes with characteristic 'daisy-like' flowers. Oxeye daisy is primaily a weed of turfgrass, lawns, roadsides, and nursery crops. It is found throughout the United States.**

Leaves: **Plants initially develop as a basal rosette. Lower rosette leaves occur on petioles and are from 1 1/2 to 6 inches long. Rosette leaves have rounded teeth or lobes and are widest at the apex and taper to the base. Leaves that occur along the flowering stem are without petioles (sessile), lanceolate in outline, and have smaller rounded teeth or lobes. Leaves become progressively smaller up the flowering stem. All leaves are alternate and without hairs.**

Stems: **Erect, usually unbranched, usually around 1 foot in height, and hairless.**

Roots: **A fibrous root system with rhizomes.**

Flowers: **Occur singly at the ends of stems. Flowers normally bloom from June to July in Virginia. Individual flower heads range from 1 1/4 to 2 inches in diameter and consist of 20 to 30 white outer petals (ray flowers) that are 10 to 15 mm long and many yellow inner flowers (disk flowers) in the center.**

Fruit: **An achene that is brown or black in color.**

Identifying Characteristics: **Plants that develop initially as a basal rosette with leaves that are hairless with rounded teeth or lobes. Additionally, this plant has characteristic flowers that distinguish it from most other species. Mayweed Chamomile (*Anthemis cotula*) and White Heath**

Aster (*Aster pilosus*) have similar flowers, however both of these weeds have very finely divided foliage unlike oxeye daisy. Additionally, Annual Fleabane (*Erigeron annuus*) has similar flowers, but has leaves with toothed margins that are sparingly hairy unlike those of oxeye daisy

Dallisgrass: *Paspalum dilatatum*

Weed Description: **A clump-forming perennial with a tall membranous ligule and a seedhead with many finger-like branches. Dallisgrass is primarily a weed of turfgrass and lawns, but also occurs in pastures, roadsides, and occasionally agronomic crops.**

Seedlings: **Leaf blades may be short hairy when young, but most older plants only have hairs in the collar regions. Leaves are rolled in the bud, have a tall, membranous ligule, and are without auricles.**

Leaves: **Leaves are rolled in the bud and lack auricles. Leaf blades range from 4 to 12 inches in length and 6 to 15 mm in width. Leaves are**

without hairs except for several long silky hairs that occur in the collar region. Ligules are membranous and from 1 to 3 mm tall.

Stems: **Sheaths are compressed and mostly lack hairs. Sheaths are often tinted red with age. Plants can tolerate mowing but may also grow to a height of 5 feet when allowed to do so.**

Roots: **Fibrous roots and short rhizomes.**

Flowers: **The seedhead is produced on a terminal stalk that may reach 5 feet in height but is more commonly shorter due to close mowing. The seedhead is a raceme that has 3 to 5 finger-like spikes branching from the center. Each spike is from 2 to 4 inches long and contains 4 rows of spikelets that are each 3 to 4 mm long and covered with black silky hairs.**

Identifying Characteristics: A perennial grass with short rhizomes, a tall ligule, and leaves with hairs near the collar only. The seedhead of dallisgrass may be confused with that of Broadleaf Signalgrass (*Brachiaria platyphylla*), however broadleaf signalgrass has much shorter, wider leaves and a much shorter ligule that is a fringe of hairs.


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Dame's Rocket: *Hesperis matronalis*

Weed Description: **Erect biennial or perennial that may reach 4 to 5 feet in height. Dame's Rocket is commonly viewed as a desirable wildflower-type plant that blooms in May or June in Virginia.**

Leaves: **Lower leaves range from 3 to 8 inches in length and taper into a short petiole. Leaves become progressively smaller up the stem and are hairy on both sides. Upper leaves are also hairy but are without petioles or only have short petioles. All leaves are lanceolate in outline.**

Stems: **Erect, hairy, reaching 4 or 5 feet in height.**

Roots: **A taproot.**

Flowers: **Occur in showy clusters. Individual flowers are purple or white in color, 8 to 12 mm wide.**

Fruit: **A silique that is 2 to 4 inches long, 2 1/2 mm wide.**

Identifying Characteristics: **Erect plants with lanceolate leaves that become progressively smaller up the stem and have showy clusters of purple or white flowers. Some ironweeds like New York Ironweed (*Vernonia noveboracensis*) may resemble dame's rocket prior to flowering, however dame's rocket flowers very early in the season and has usually senesced by the time the ironweeds bloom later in the fall. Additionally, the leaves of dame's rocket are generally wider than those of New York ironweed.**

Virginia Tech Weed Identification Guide

Select a Resource...

New York Ironweed: *Vernonia noveboracensis*

Weed Description: **Ironweed is a common name often given to a many different weeds, however it is most correctly given to those members of the *Vernonia* genus. The ironweeds are perennials with showy purple flowers. They were given the name ironweeds because of their stout stems that often persist throughout the winter. The ironweeds are primarily weeds of pastures, hay fields, and roadsides and are distributed throughout most of the southeastern United States.**

Roots: **A perennial basal crown from which plants can arise year after year.**

Leaves: **All leaves occur along the erect stem unlike some ironweeds which have many basal leaves and smaller stem leaves. The leaves are elliptic to lanceolate in outline, ranging from 4 to 10 inches in length and 3/4 to 1 1/2 inches in width. Leaves are usually without hairs on the upper surface and may have many soft white hairs beneath. Many small teeth occur along the leaf margins.**

Stems: **Erect, ranging from 2 to 7 feet in height. Several stems can arise from a single crown. Stems usually persist through the winter.**

Flowers: **Occur in clusters at the ends of the erect flowering stems. Flowers are purple in color, approximately 8 to 12 mm long. Each flower occurs on a flower stalk (peduncle).**

Fruit: **A nutlet.**

Identifying Characteristics: **The elliptic to lanceolate leaves with minutely toothed margins, the clusters of purple flowers, and the stems that persist throughout the winter are all characteristics that help in the identification of New York ironweed. Several other related ironweed species may be found in similar habitats, and these are primarily distinguished by the presence or absence of basal leaves, the width of the stem leaves, and the presence or absence of toothed leaf margins. New York ironweed is sometimes confused with Stickweed (*Verbesina occidentalis*) or Wingstem (*Verbesina alternifolia*), however both of these**

weeds have yellow flowers and several 'wings' of tissue that run the entire length of the stem.

Virginia Tech Weed Identification Guide

Select a Resource...

Dwarf Dandelion: *Krigia oppositifolia* or *Krigia caespitosa*

Weed Description: **A light green to bluish-green winter annual that develops a rosette of irregularly shaped leaves and then produces a flowering stem with many yellow flowers. Plants contain a small amount of 'milky' sap which is evident when the plants are cut. Dwarf dandelion is primarily a weed of pastures, roadsides, lawns, and turfgrass. It is found in the**

southeastern United States. The scientific name of this plant has recently undergone a change from *Krigia oppositifolia* to *Krigia caespitosa*.

Leaves:
Plants initially develop a basal rosette of leaves. Leaves are lanceolate in outline, with the widest portion of the leaf at the apex and tapering down toward the

leaf base. Basal leaves range from 1 1/4 to 4 1/2 inches in length and 2 to 15 mm in width. Basal leaves have margins that are either irregularly wavy or distinctly lobed. Leaves that occur along the flowering stem are generally smaller than the basal leaves and more linear in outline.

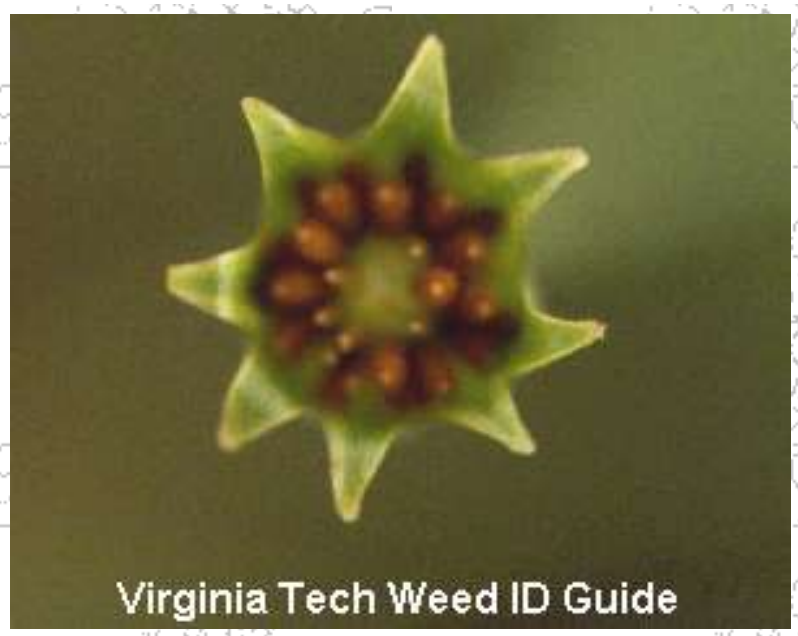
Flowers: **Many flowers occur on long flower stalks (peduncles) that arise from the area between the leaves and stems (leaf axils). Flowers consist of many yellow ray flowers that are 'toothed' and are approximately 6 to 10 mm long each.**

Stems: **Branching, ranging from 2 to 20 inches in height, depending on the environment.**

Roots: **Fibrous root system.**

Fruit: **An oval, reddish-tan nutlet.**

Identifying Characteristics: **The irregularly wavy or lobed leaves that develop as a basal rosette, yellow flowers, and winter annual growth habit are all characteristics that help in the identification of dwarf dandelion. Virginia dwarfdandelion (*Krigia virginica*) is similar in appearance, however this weed has leaves that are more**



distinctly lobes, has much longer flower stalks, and has larger yellow flowers.

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Select a Resource...

Deptford Pink: *Dianthus armeria*


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Select a Resource...

Dichondra: *Dichondra repens*

Weed Description: A creeping perennial with circular leaves, primarily a weed of lawns.

Leaves: Alternate, circular to kidney- shaped, with continuous, untoothed margins and long petioles.

Flowers: Inconspicuous, in clusters in the leaf axils.

Identifying Characteristics: **Prostrate or creeping growth habit with circular leaves and entire margins. Dichondra may be confused with Ground Ivy (*Glechoma hederacea*), however the square stems and toothed margins of ground ivy help to distinguish the two.**

Dodder: *Cuscuta* spp.

Weed Description:
A yellowish to reddish-brown parasitic vine that attaches on to host plants causing reductions in yield and/or fitness of desirable species. Dodder is primarily a weed of landscapes, nurseries, and cucurbit crops, but this weed can occasionally be found in other agronomic crops like alfalfa.

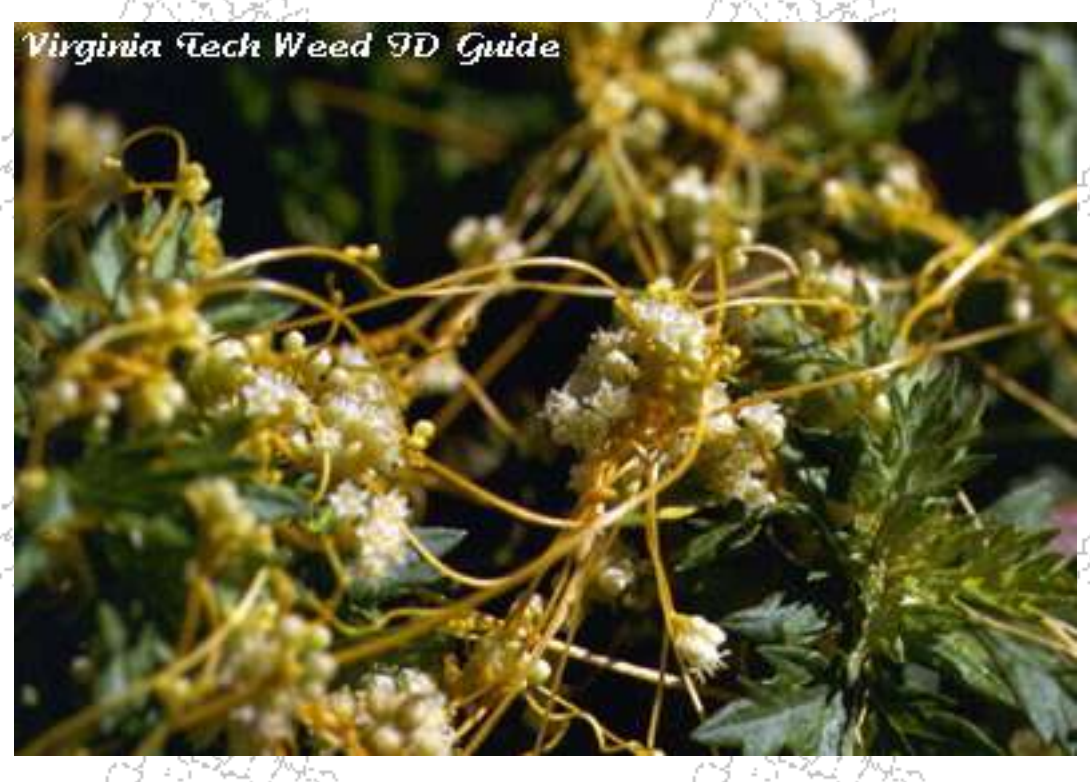
Seedlings:
Seedlings develop only for a short time until the stalks are able to attach to a host plant. Seedlings resemble mature plants and are yellowish to reddish-brown stems and no apparent leaves.

Leaves: Occur as scales that are rarely noticeable.

Stems: Twining, usually counterclockwise in direction, branching, and yellowish to reddish-brown in color.

Roots: Occur only for a short time until the plant is able to attach to a host.

Flowers: Occur in relatively inconspicuous clusters. Flowers are white or pink in color.



Fruit: A round capsule that is approximately 3 mm long and contains 4 seeds.

Identifying Characteristics: The vining nature and yellowish to reddish-brown color of dodder makes this easy to distinguish from most other weeds, however several species of dodder occur throughout the United States.

Virginia Tech Weed Identification Guide

Select a Resource...

Doveweed: *Murdannia nudiflora*

Weed Description:
An annual weed that resembles a grass but has creeping stems that root at the nodes and purple or blue flowers. Doveweed is primarily a weed of turfgrass that is now found in eastern Virginia, but is most common from North Carolina to Florida and west to Texas.

Leaves: **Leaves are fleshy and linear in outline, approximately 3/4 to 4 inches long, 2 to 5 mm wide. Leaf sheaths have soft hairs on the upper margins.**

Stems: **Stems are not readily evident, but upon closer examination, stems can be seen close to the ground and rooting at the nodes.**

Roots: **A fibrous root system.**

Flowers: **Flowers occur in small clusters on short flower stalks (peduncles). Flowers are blue to purple in color with petals that are 5 to 8 mm long.**

Fruit: **A capsule that is 3 to 5 mm wide.**

Identifying Characteristics: **Plants with fleshy, linear leaves that resemble some grasses. Also, the creeping stems and small blue or purple flowers of this weed help to identify it from most other similar weeds.**


VT Weed Identification Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Duckweeds: *Lemna* spp.

Weed Description: **Very small floating aquatic plants that often form dense mats over large areas of the water surface. The duckweeds are free-floating and do not have stems or 'typical' leaves.**

Leaves: **Flattened, round to elliptic in shape, reaching 1/8 inch long and 1/10 inch wide. Each leaf or frond has 1 root that dangles below the water**

surface.

Flowers: **Very small and inconspicuous, rarely seen.**

Identifying Characteristics:
Very small floating aquatic plants with a single small root dangling below. The giant duckweeds (*Spirodela* spp.) are similar to these species but have 2 or more roots emerging

from each frond and usually have at least one purple or red dot on the frond. Watermeal (*Wolffia* spp.) is also similar in appearance to the duckweeds but is generally much smaller and also does not have roots dangling below.

Watermeal: *Wolffia* spp.

Weed Description:

Very small, floating aquatic weeds that form large colonies and are often confused with duckweeds. There are several *Wolffia* species fount throughout the southeastern United States, all of which are typically found in lakes, ponds, streams, and rivers. The entire plants are usually about the size of a pinhead. The plants are green in color and elliptical in outline. No roots are found floating below.

Identifying Characteristics:

All though several *Wolffia* species occur throughout the southeastern United States, all can be distinguished from other aquatic weeds by their extremely small size and tendency to form dense colonies. Some mistakenly identify these colonies from afar as a type of algae, however closer examination will reveal many individual

plants that are very small and have no roots. Watermeal is often misidentified as one of the Duckweeds (*Lemna* spp.), however these weeds are much larger and have roots dangling below the water surface.

Common Weed Names: E

Common Name	Scientific Name
Eastern Black Nightshade	*Solanum ptycanthum*
Eclipta	*Eclipta prostrata*
Egeria	*Egeria densa*
Elderberry	*Sambucus canadensis*
Elodea, Brazilian	*Egeria densa*
Entireleaf Morningglory	*Ipomoea hederacea**
Eurasian Watermilfoil	*Myriophyllum spicatum*
Eveningprimrose, Common	*Oenothera biennis*
Eveningprimrose, Cutleaf	*Oenothera laciniata*
Everlasting Pea	*Lathyrus latifolius*

***The full scientific name is Ipomoea hederacea var. integriuscula**

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Select a Resource...

Entireleaf Morningglory: *Ipomoea hederacea* var. *integriuscula*

Weed Description: **A summer annual, twining or climbing vine with heart-shaped leaves found throughout the Southeast and into the north central and northeastern United States.**

Roots: **Taproot.**

Stems: **Most often found climbing, hairy, reaching 10 feet in length..**

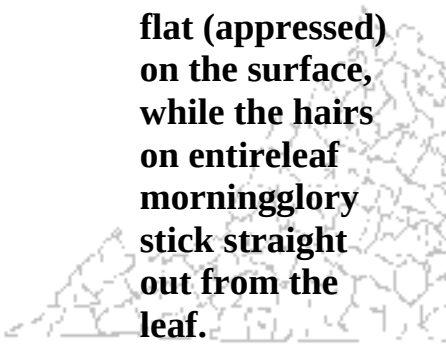
Leaves: **Alternate, heart-shaped, with hairs that stick straight out from the leaf.**

Seedling: the cotyledons (hypocotyls) are green or purple tinged, without hairs. Cotyledons have rounded points, are moderately indented and have hairs that stick straight out from the cotyledons.

Flowers: Petals are purple to pale blue or white and fused into a funnel.

Fruit: Brown capsules that separate into 3-4 parts when mature.

Identifying Characteristics: Entireleaf morningglory very closely resembles Tall Morningglory (*Ipomoea purpurea*), however the two species differ in the orientation of hairs on the cotyledon and/or leaf surfaces. Tall morningglory leaves have hairs that lie



flat (appressed) on the surface, while the hairs on entireleaf morningglory stick straight out from the leaf.

Virginia Tech Weed Identification Guide

Select a Resource...

Tall Morningglory: *Ipomoea purpurea*

Weed Description:
A trailing or climbing annual vine with heart-shaped leaves and purple to white flowers. Primarily a weed of agronomic crops, nurseries, landscapes and noncrop areas that is found throughout the eastern half of the United States except for the far northern states.

Seedling: **Cotyledons are only moderately indented as compared to either pitted, palmleaf, sharppod, or cotton morningglory. Cotyledon lobes are rounded and not pointed to any degree and cotyledons are also almost perfectly square in outline. The first true leaf is heart shaped as are all subsequent leaves, but the first true leaf often is without hairs unlike the subsequent leaves.**

Leaves: **Heart-shaped in outline, arranged alternately along the stem, and have hairs that lie flat against the leaf surface (appressed). Older leaves have rounded bases that often overlap, unlike pitted morningglory. All leaves occur on relatively long petioles.**

Stems: **Hairy, trailing or climbing, capable of reaching 6 1/2 feet in length.**

Flowers: **Occur in clusters of 3 or more and may be purple to white in color, or have some traces of both colors. Flowers range from 1 3/4 to 3 inches in length and have sepals at the base of the flower that are approximately 10 to 15 mm long.**

Fruit: **A brown capsule containing 4 to 6 dark brown to black seeds.**

Identifying Characteristics: **The distinctive heart-shaped leaves and purple to white flowers helps to distinguish tall morningglory from most of the other morningglories. When mature, the leaves of tall morningglory and Pitted Morningglory (*Ipomoea lacunosa*) are similar, however the leaf bases of tall morningglory often overlap one another and are much more heart-shaped in outline when compared to pitted morningglory. The cotyledons of tall morningglory also resemble those of Entireleaf Morningglory (*Ipomoea hederacea* var. *integriuscula*) and**

Ivyleaf Morningglory (*Ipomoea hederacea*). However, the cotyledons of tall morningglory are usually more square in outline when compared to the cotyledons of either ivyleaf or entireleaf morningglory.

Virginia Tech Weed Identification Guide

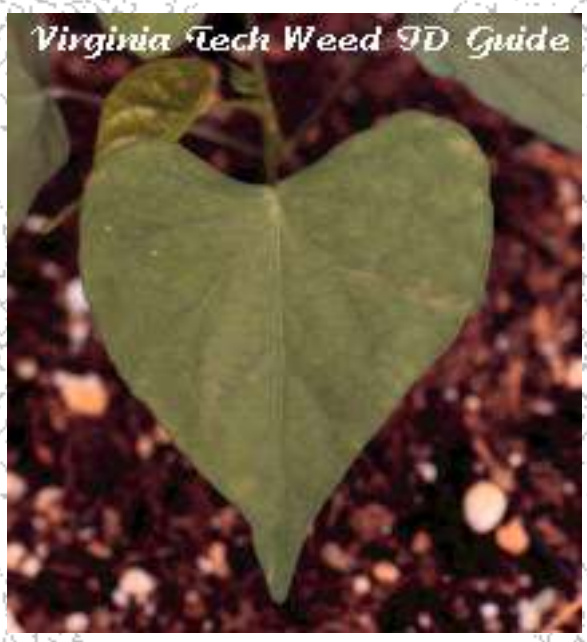
Select a Resource...

Pitted Morningglory: *Ipomoea lacunosa*

Weed Description: **A trailing or climbing annual vine with heart shaped leaves that taper to a point with attractive funnel-shaped white flowers. Primarily a weed of agronomic crops, landscapes, nurseries and sometimes in noncrop areas. Pitted morningglory is found throughout the eastern half of the United States except for the far northern states.**

Seedling: **Cotyledons are deeply indented and taper to a point as compared to tall, ivyleaf, and entireleaf morningglories. Cotyledons are also without hairs (glabrous).**

Stems: **Sometimes slightly hairy, trailing along the ground or climbing, and may reach 6 1/2 feet in length.**



Leaves: Occur on relatively long petioles and are arranged alternately along the stem. Leaves can be without hairs or only slightly hairy, but do not have the appressed hairs typical of tall morningglory. Leaves are heart-shaped in outline but taper much more to a narrow tip, unlike those of tall morningglory.

Flowers: Funned-shaped, white in color, approximately 3/4 inches long.

Fruit: A capsule.

Roots: A fibrous root system with a small taproot.

Identifying Characteristics: The deeply indented cotyledons, heart-shaped leaves that taper to a point, and the relatively small white flowers are all characteristics that help in the identification of pitted morningglory. When in the cotyledon stage, pitted morningglory can be easily confused with sharppod morningglory, Cotton Morningglory (*Ipomoea trichocarpa* var. *torreyana*), or Palmleaf Morningglory (*Ipomoea wrightii*), which all also have deeply indented cotyledons. Therefore, first true leaves and/or subsequent leaves will often be required to differentiate between these morningglory species. In Virginia, however, the only species that are typically encountered are ivyleaf, entireleaf, tall, pitted, red, and bigroot morningglories. Pitted morningglory is also similar to Tall Morningglory (*Ipomoea purpurea*) but lacks the appressed hairs on the leaves and has leaves that taper to much more of a narrow tip.

Virginia Tech Weed Identification Guide

Select a Resource...

Palmleaf Morningglory: *Ipomoea wrightii*

Weed Description:
A trailing or climbing annual vine with lobed leaves and attractive pink to light purple flowers. Palmleaf morningglory is primarily a weed of agronomic crops found in the lower southeastern states only.

Seedling:
Cotyledons are deeply indented, have pointed ends, and are without hairs. The cotyledons of palmleaf morningglory are very similar to those of pitted morningglory.

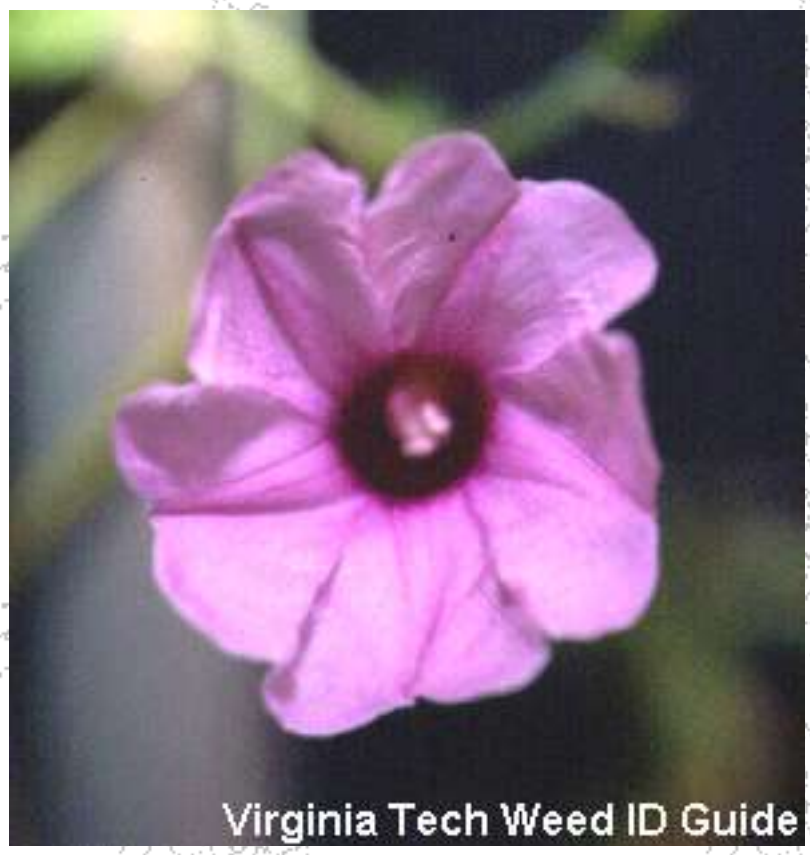
Leaves: First true leaf and all subsequent leaves are distinctly lobed into 3 to 7 segments, giving the overall appearance of fingers on a hand. Individual segments range from 3/4 to 2 1/2 inches long. All lobes also arise from the same point (palmately divided leaves).

Stems: Trailing or climbing, without hairs (glabrous), capable of reaching 6 1/2 feet in length.

Flowers: Typical, morningglory-like flowers occur that are pink to light purple in color with a darker center. Flowers range from 3/4 to 1 inch in length.

Fruit: A brown capsule that is without hairs (glabrous) and has a distinctively coiled or spiraled stalk. The capsules contain several dark brown seed that usually have long white hairs attached to them.

Identifying Characteristics: **The leaves that are divided into 3 to 7 segments that arise from the same point (palmately divided), the pink to light purple flowers, and the seed capsule with a spiraled stalk are all key characteristic that help in the identification of palmleaf morningglory. However, the cotyledons of palmleaf morningglory and Pitted Morningglory (*Ipomoea lacunosa*) are nearly identical, and distinguishing between these two species usually requires waiting for the first true leaf to form.**



Virginia Tech Weed Identification Guide

Select a Resource...

Ivyleaf Morningglory: *Ipomoea hederacea*

Weed Description: **A summer annual twining or climbing vine with distinctive 3-lobed leaves and large showy purple to blue or white flowers. A common weed of agronomic, horticultural, and nursery crops found throughout the southeastern and into the north central and northeastern United States.**

Fruit: **A brown spherical capsule (3-locular) that contains 4-6 seeds.**

Seedling: **Cotyledons are notched at the apex, and this notch forms an angle between the lobes that is less than 90 degrees. The cotyledons are only shallowly or moderately indented, and the lobes are usually rounded or only slightly pointed. Cotyledons are notched at the base, and are close to square in outline, with only a slight flare outwards. The first**

true leaf is unlobed.

Leaves: **Alternate, hairy, petioled, 2-5 inches long, and distinctly 3-lobed or ivy-shaped. The hairs on the leaves and petioles are erect, or stick straight out.**

Roots: **Taproot.**

Stems: **Running along the ground, or more commonly climbing, reaching 10 feet in length. Stems also have hairs that are erect.**

Flowers: **Long (1-2 inches), with petals that are fused into a funnel, and purple to blue or white in color. The bases of the flowers are densely hairy.**

Identifying Characteristics: **Distinctive purple to blue or white flowers, 3-lobed leaves, and leaves, stems, and petioles with hairs that stick straight out. The characteristic leaves of ivyleaf morningglory help to distinguish it from all of the other morningglories at the 'mature' stage of growth. However, identification of morningglories at the cotyledon stage of growth is much more difficult, and often more important. The cotyledons of ivyleaf morningglory most closely resemble those of Entireleaf Morningglory (*Ipomoea hederacea* var. *integriuscula*) and Tall Morningglory (*Ipomoea purpurea*). However, the cotyledons of tall morningglory are usually more square in outline when compared to the cotyledons of both ivyleaf and entireleaf morningglory. The cotyledons of both ivyleaf and entireleaf morningglory are nearly identical and usually cannot be distinguished until the second true leaf emerges.**

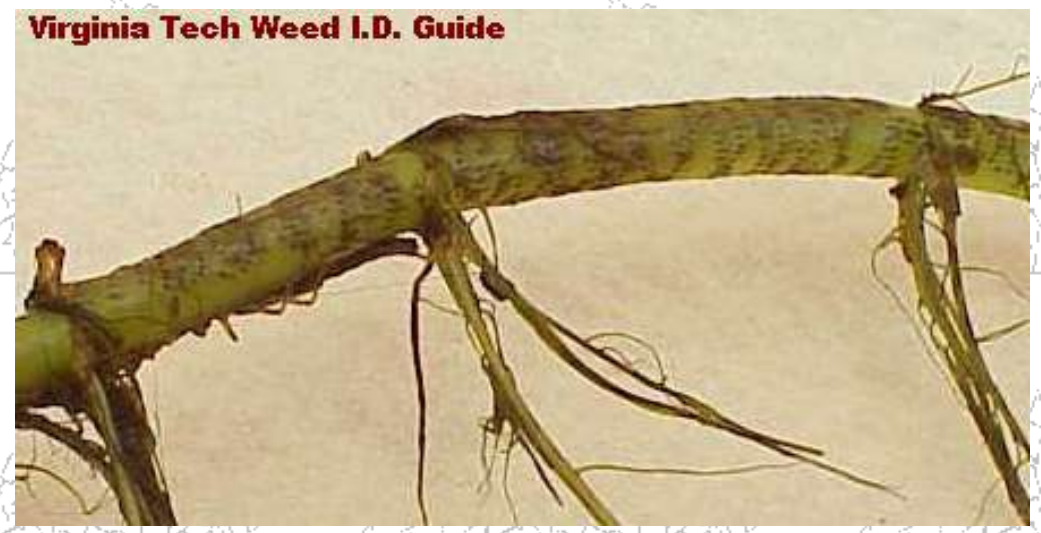
Eurasian Watermilfoil: *Myriophyllum spicatum*

Weed Description:
A mostly submersed perennial with feathery-like leaves that can spread and reproduce by fragmentation of the stems.

Leaves:
Leaves are finely divided and take on a stiff, feathery appearance. Leaves occur in whorls of 4 and are up to 1 inch in length, with at least 12 stiff leaflets that occur oppositely from one another.

Stems:
Stout, rooting often. Fragmented stems are capable of producing

new plants.



Flowers: **Flowering stems are usually emersed and inconspicuous.**

Identifying Characteristics: **Emersed perennial aquatic weeds with leaves that are divided into many stiff leaflets that resemble a feather.**

Virginia Tech Weed Identification Guide

Select a Resource...

Sweet Pea or Everlasting Pea: *Lathyrus latifolius*


Virginia Tech Weed ID Guide

Common Weed Names: F

Common Name	Scientific Name
Fall Panicum	*Panicum dichotomiflorum*
False Dandelion	*Hypochoeris radicata*
Field Balm	*Calamintha nepeta*
Field Bindweed	*Convolvulus arvensis*
Field Madder	*Sherardia arvensis*
Field Pennycress	*Thlaspi arvense*
Field Pepperweed	*Lepidium campestre*
Field Poppy	*Papaver dubium*
Field Violet	*Viola arvensis*
Fireweed	*Erechtites hieracifolia*
Flatsedge, Rice	*Cyperus iria*
Fleabane, Daisy	*Erigeron annuus*
Florida Beggarweed	*Desmodium tortuosum*
Florida Betony	*Stachys floridana*
Four-O' Clock, Wild	*Mirablis nyctaginea*
Foxtail, Giant	*Setaria faberi*
Foxtail, Green	*Setaria viridis*
Foxtail, Yellow	*Setaria glauca*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Field Poppy or Long Smooth-fruited Poppy: *Papaver dubium*

Weed Description:

An annual with divided leaves that develop as a basal rosette and orangish-red flowers. Field poppy rarely occurs as an aggressive weed, but it may be found in some agronomic crops, pastures, hay fields, and roadsides. Field poppy is found throughout North and South Carolina, Tennessee, West Virginia, and Virginia.

Leaves: **Leaves are deeply lobed or divided into segments that are 5 to 15 mm wide. Leaves are 1 1/2 to 4 inches long and covered with hairs.**

Stems: **Erect, covered with hairs.**

Roots: **A taproot.**

Flowers: **Individual flowers are approximately 1 1/2 inches in diameter and orangish-red to pink in color.**

Fruit: **A hard capsule that is without hairs when mature and contains many small poppy seed.**

Identifying Characteristics: **Plants with divided or lobed leaves that are hairy and showy orangish-red flowers. Several other poppy species are similar in appearance to field poppy.**


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Field Violet or Wild Pansy: *Viola arvensis*

Weed Description: **Usually a winter annual weed of winter small grains, nurseries, and landscapes Field violet ranges from 4 to 12 inches in height and has attractive yellow and purple flowers. It is found throughout the northern half of the United States and sporadically into the southeastern and southwestern states.**

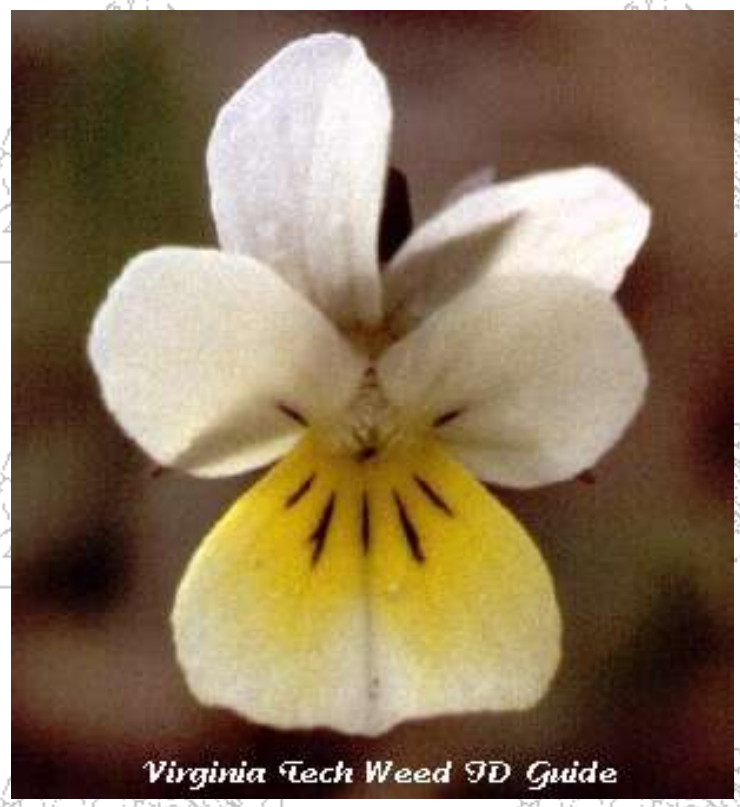
Seedlings:
Cotyledons are oval in outline, only 3 to 5 mm long and 3 to 4 mm wide, and occur on petioles. Subsequent leaves occur alternately but develop as a basal rosette. The first true leaves and subsequent leaves are oval to spatula-shaped in outline with rounded teeth along the margins.

Leaves: Oval to spatula-shaped in outline with round teeth along the margin. Basal leaves are approximately 3/4 to 1 1/2 inches long and almost as wide. Leaves occur on petioles and are arranged alternately, although they initially develop as a rosette so this is often difficult to determine. Leaves are mostly without hairs except for along the veins on the leaf undersides. Upper leaves that occur along the flowering stem are much more linear in outline, ranging from 3/4 to 3 inches long and about 1/2 inch wide. Stipules occur at the base of the leaf petioles in the upper portions of the flowering stem, and these stipules are divided into 5 to 9 linear segments.

Stems:
Reaching as much as 12 inches in height but typically no more than 8 or 9. Stems are erect, branched or unbranched.

Flowers:
Occur on long flower stalks (peduncles) that arise from the area between the leaf petioles and the stem (leaf axils). Individual flowers are typically 1/2 inch in length and width, and consist of 5 petals that are white to yellow in color, usually with some purple markings

or purple tinges. Four smaller petals occur above one larger petal. Many flowers occur on a single plant.



Fruit: **A round capsule approximately 5 to 10 mm long.**

Roots: **Fibrous root system. When crushed, the roots of this weed often emit a wintergreen-type odor.**

Identifying Characteristics: **The winter annual growth habit, leaves with round teeth along the margin, and the typical violet-like flowers are all characteristics that help in the identification of field violet. Field pansy (*Viola rafinesquii*) is very similar in appearance to field violet, however field pansy has leaves that usually lack hairs completely and has flower petals that are about 3 times as long as the sepals. In contrast, field violet usually has leaves with hairs along the veins on the leaf undersides and has flower petals that are about the same length as or shorter than the sepals.**

Virginia Tech Weed Identification Guide

Select a Resource...

Rice Flatsedge: *Cyperus iria*

Weed Description:
An erect annual sedge that is often mistakenly identified as a grass or as one of the perennial nutsedges. Rice flatsedge is a weed of container ornamentals, nurseries, landscapes, and turf. Rice flatsedge is found from Florida eastward to Texas and northward to southeastern Missouri and southern Virginia.

Seedling: **Shiny, without hairs, and distinctly ridged and tougher than most grass seedlings. No ligules or auricles occur, as would be the case with most grass seedlings.**

Leaves: **Dark green, shiny, linear in outline but tapering to a point, and three-ranked. Individual leaves may be from 3 to 8 mm wide and have rough margins toward the leaf tips. A membranous sheath occurs at the leaf bases.**

Stems: **Triangular in cross-section, occurring in bunches, approximately 8 to 24 inches tall.**

Roots: **A fibrous root system.**

Fruit: **A three-angled brown achene.**

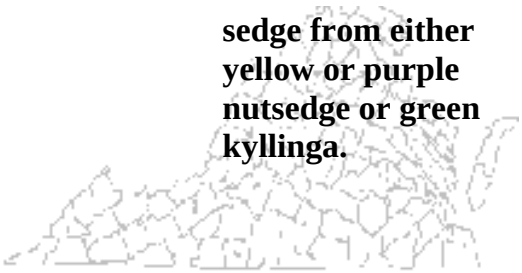
Flowers: **Terminal seedheads occur at the ends of the triangular stems. Seedheads may reach 8 inches in length, are open, and are composed of several dense spikes. Individual spikes are, in turn, made up of many goldish-brown spikelets that are approximately 5 to 13 mm long and 1 ½ to 2 mm wide.**

Seedheads also have 3 to 7 unequal bracts surrounding the inflorescence, the shortest one being much longer than the overall inflorescence.

Identifying Characteristics:

The shiny green ridged leaves and lack of ligule and auricles helps to distinguish this sedge from any grass weed but rice flatsedge seedlings can be easily mistaken for either Yellow Nutsedge (*Cyperus esculentus*), Purple Nutsedge (*Cyperus rotundus*), or Green Kyllinga (*Kyllinga brevifolia*). However, the lack of tubers or rhizomes in rice flatsedge helps to distinguish this

sedge from either yellow or purple nutsedge or green kyllinga.





















Virginia Tech Weed Identification Guide

Select a Resource...

Yellow Nutsedge: *Cyperus esculentus*

Weed Description:
A perennial from rhizomes and tubers that may reach 2 1/2 feet in height. The stems are 3-sided and triangular in cross section and the leaves are yellow to green in color with a distinct ridge. Found throughout North America as a common weed in agronomic and horticultural crops, nurseries, turfgrass, and landscapes.

Seedling:
Seedlings rarely occur. Most plants arise from rhizomes and/or tubers. Leaves do not have ligules or auricles and have a distinct ridge along the midvein, but are nevertheless often mistaken for grasses.

Leaves: **Yellow to green in color and have a distinctly shiny appearance. Leaves are 5 to 8 mm wide and have a distinct ridge along the midvein. Leaves are produced in groups of 3 from the base of the plant. Leaves are without hairs (glabrous) and no auricles or ligules are present. The leaves of yellow nutsedge taper gradually to a sharp point.**

Stems: **Erect, unbranched, and 3-sided and triangular in cross section. Stems are usually solitary and produce terminal spikelets.**

Roots: **Rhizomes and tubers occur on the same plants. Tubers are round, ridged, initially white in color, eventually turning brown or black, and are sweet to the taste. Yellow nutsedge produces solitary tubers that arise either from the basal bulb or from a rhizome. Several tubers do not arise along the entire rhizome, as in purple nutsedge.**

Flowers: **Spikelets occur at the ends of the solitary stems in a cluster where the flower stalks arise from a common point (umbel-like). Individual spikelets are yellow to brown in color.**

Identifying Characteristics:

Purple Nutsedge (*Cyperus rotundus*) is very similar in appearance and growth habit to yellow nutsedge, and the two are often confused. However, the leaves of purple nutsedge taper to a point abruptly whereas those of yellow nutsedge gradually taper to a point. Additionally, the seedhead of purple nutsedge is purple in color, while that of yellow nusedge is yellow. Lastly, the

tubers of purple nutsedge are often connected in chains and bitter to the taste, while those of yellow nutsedge are solitary and sweet to the taste. Rice flatsedge (*Cyperus iria*) and Green Kyllinga (*Kyllinga brevifolia*) are also similar when young, however rice flatsedge has a fibrous root system and green kyllinga has rhizomes that are usually red to purple in color.

Virginia Tech Weed Identification Guide

Select a Resource...

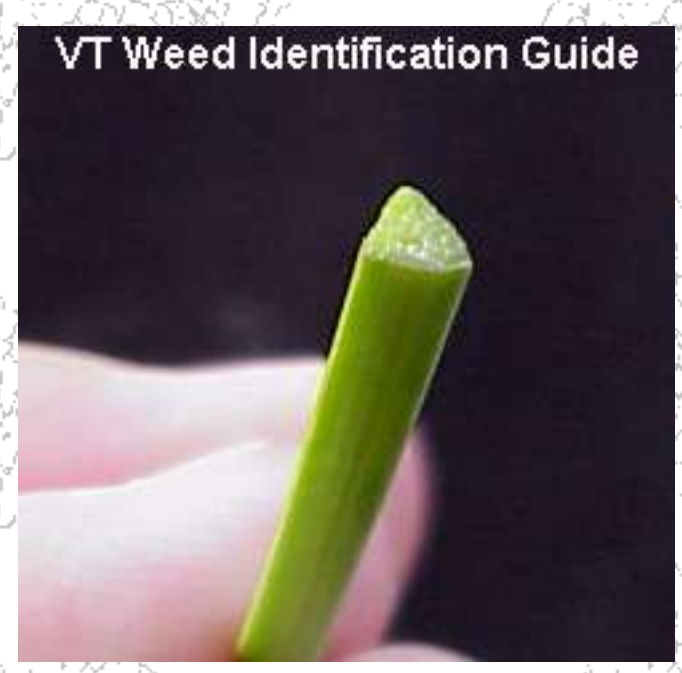
Purple Nutsedge: *Cyperus rotundus*

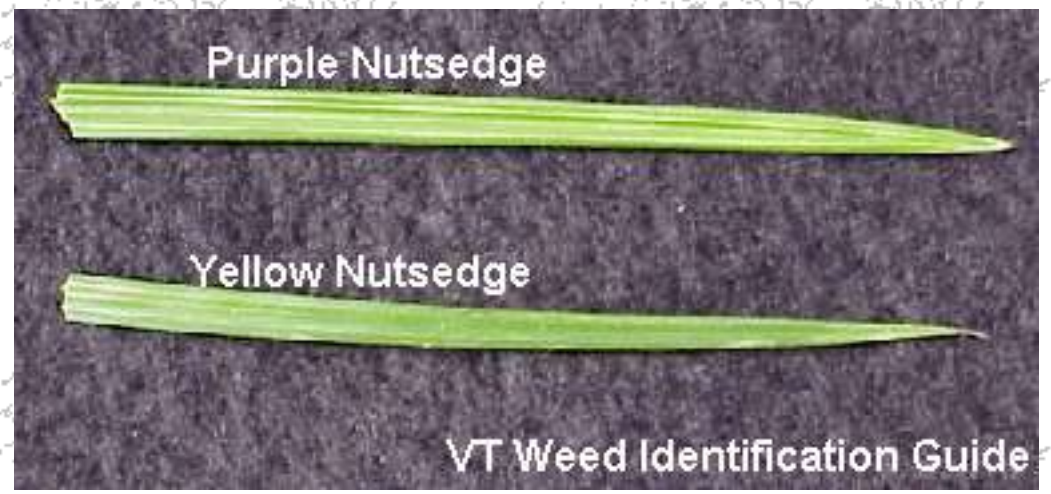
Weed Description: **A perennial from rhizomes and tubers that may reach 2 1/2 feet in height. The stems are 3-sided and triangular in cross section and the leaves are yellow to green in color with a distinct ridge. Found throughout the southeastern United States as a common weed of agronomic and horticultural crops, nurseries, turfgrass, and landscapes.**

Seedling: **Seedlings rarely occur. Most plants from rhizomes and/or tubers. Leaves do not have ligules or auricles and have a distinct ridge along the midvein, but are nevertheless often mistaken for grasses.**

Stems: **Erect, unbranched, and 3-sided and triangular in cross section. Stems are usually solitary and produce terminal spikelets.**

Leaves: **Dark green in color and have a distinctly shiny appearance. Leaves are 5 to 8 mm wide and have a distinct ridge along the midvein. Leaves are produced in groups of 3 from the base of the plant. Leaves are without hairs (glaucus) and no auricles or ligules are present. The leaves of purple nutsedge taper abruptly to a sharp point, unlike the gradual taper of yellow nutsedge leaves.**





Roots: **Rhizomes and tubers occur on the same plants. Tubers are oblong, ridged, initially white in color, eventually turning brown or black, and are bitter to the taste. Purple nutsedge produces chains of tubers that develop along the entire rhizome.**

Flowers: **Spikelets occur at the ends of the solitary stems in a cluster where the flower stalks arise from a common point (umbel-like). Individual spikelets are reddish-purple to reddish-brown in color.**

Identifying Characteristics: **Yellow Nutsedge** (***Cyperus esculentus***) **is very similar in appearance and growth habit to purple nutsedge, and the two are often confused. However, the leaves of yellow nutsedge taper to a point gradually whereas those of purple nutsedge taper to a point abruptly. Additionally, the seedhead of yellow nutsedge is yellow in color, while that of purple nusedge is purple. Lastly,**

the tubers of purple nutsedge are often connected in chains and bitter to the taste, while those of yellow nutsedge are solitary and sweet to the taste. Rice flatsedge (*Cyperus iria*) and Green Kyllinga (*Kyllinga brevifolia*) are also similar when young, however rice flatsedge has a fibrous root system and green kyllinga has rhizomes that are usually red to purple in color.

Virginia Tech Weed Identification Guide

Select a Resource...

Green Kyllinga: *Kyllinga brevifolia*

Weed Description: **Perennial sedge from rhizomes that is capable of forming dense infestations. Green kyllinga is primarily a weed of turfgrass and lawns that is usually found in damp or wet areas. This weed may be found from Rhode Island south to Florida, and west to Texas.**

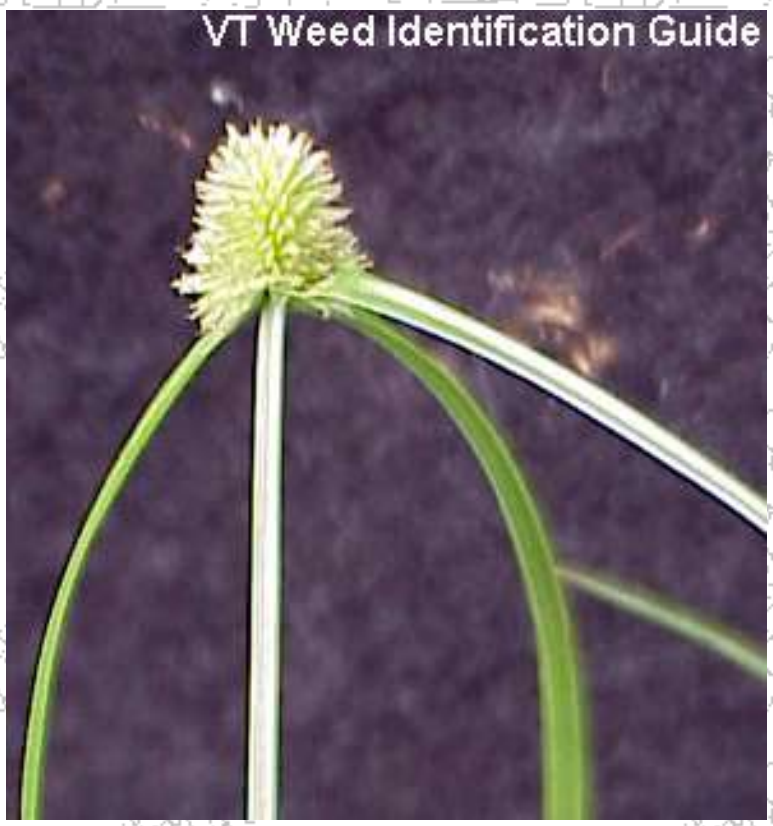
Seedling: **Seedlings occur less often than plants that arise from rhizomes. Leaves do not have ligules or auricles and**

have a distinct ridge along the midvein, but are nevertheless often mistaken for grasses.

Leaves: Dark green in color and have a distinctly shiny appearance. Leaves have a distinct ridge along the midvein. Leaves are without hairs (glabrous) and no auricles or ligules are present. The leaves of green kyllinga taper gradually to a sharp point.

Stems: Three-sided and triangular in cross-section. Stems may reach 6 inches in height and produce a terminal seedhead.

Roots: A dense system of rhizomes that are red to purple in color.



Flowers: Round or oblong in outline, produced at the ends of the triangular stems. Three shorter leaves (bracts) usually occur just below the seedhead.

Identifying Characteristics: **The shiny green ridged leaves and lack of ligule and auricles helps to distinguish this sedge from most grass weeds but green kyllinga seedlings or young plants can be easily mistaken for either Yellow Nutsedge (*Cyperus esculentus*), Purple Nutsedge (*Cyperus rotundus*), or Rice Flatsedge (*Cyperus iria*). However, green kyllinga lacks tubers unlike yellow or purple nutsedge, and rice flatsedge only has a fibrous root system, unlike any of the other species. Additionally, the three distinctive leaves below the seedhead of green kyllinga helps to distinguish this weed from either yellow or purple nutsedge.**

Virginia Tech Weed Identification Guide

Select a Resource...

Florida Betony or Rattlesnake Weed: *Stachys floridana*

Weed Description:
A perennial weed primarily of turfgrass and lawns with large, segmented underground tubers that resemble a rattlesnake's tail. Florida betony may also occur as a weed of landscapes, nursery stock, and ornamentals and is found throughout the southeastern United States. Florida betony has spread northward from Florida since the 1940's but is still somewhat rare in Virginia.

Leaves: **Arranged oppositely along the stem and occurring on petioles. Leaves are lance-shaped in outline, approximately 3/4 to 3 inches long and 1/4 to 1 inch wide. Leaf margins have rounded, or 'scalloped' margins.**

Stems: **Erect, ranging from 8 to 20 inches tall and square in cross section.**

Flowers: **Occur in clusters at the top of the erect flowering stems. Individual flowers are white to pink with purple spots, only 10 to 11 mm long.**

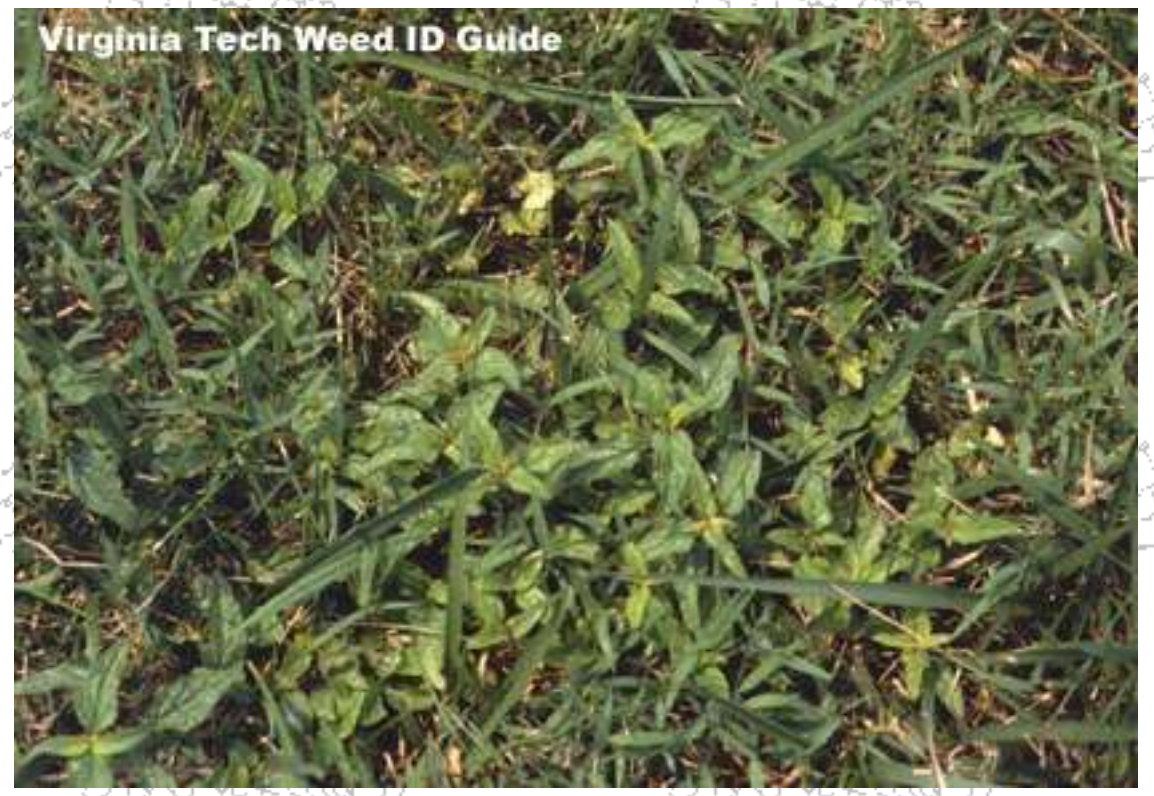
Roots:
Large, white, segmented tubers that resemble a rattlesnake's tail.

Identifying Characteristics:
The lance-shaped leaves with scalloped margins, stems that are square in cross section, and the 'rattlesnake' tubers are all characteristics that help in the identification of Florida betony. Healall (*Prunella vulgaris*) is somewhat similar in leaf shape and growth habit, however this weed does not have the scalloped leaf margins and underground tubers like Florida betony.

Virginia Tech Weed Identification Guide

Select a Resource...

Healall: *Prunella vulgaris*



Weed Description:
A perennial from stolons with square stems and light blue to purple flowers. Healall is primarily a weed of turfgrass and lawns, but is also found along roadsides or occasionally in pastures and hay fields. Healall is found throughout the United States.

Seedlings: Cotyledons are spatula-shaped and occur on hypocotyls (stems below the cotyledons). Cotyledon apexes are notched. First true leaves as well as all subsequent leaves have 'crinkled' leaf surfaces.

Roots: Stolons, fibrous roots, and stems that root at the nodes.

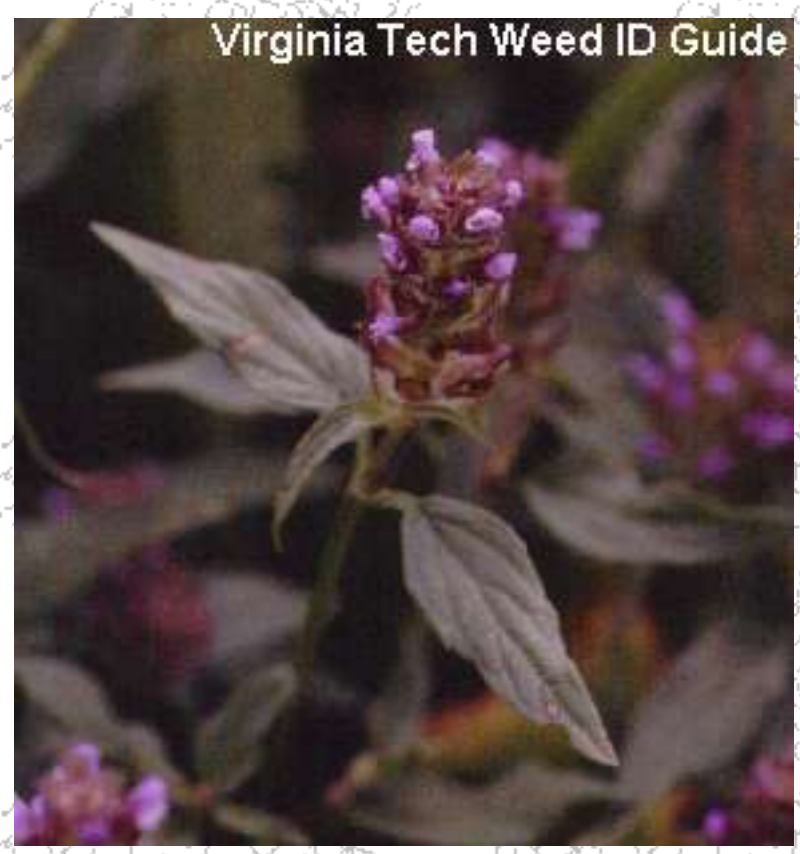
Fruit: A brown nutlet containing 1 seed each. Four nutlets occur per flower.

Leaves: Arranged oppositely along the stem, oval-shaped in outline. Leaves are approximately 3/4 to 3 1/2 inches in length and 1/4 to 1 1/2 inches wide. Lower leaves occur on petioles while upper leaves may not. Leaves are usually without hairs or only slightly hairy. All leaves have 'crinkled' upper surfaces.

Stems: Branched, usually growing prostrate along the ground and relatively tolerant of mowing, but can grow erect and reach as much as 2 feet in height. Stems are distinctly square and hairy when young but usually without hairs on

older plants. Stems can root at the nodes.

Flowers:
Occur in spikes at the ends of erect stems. Many 2-lipped flowers occur in clusters in these spikes at the ends of the erect stems. Individual flowers are are tube-shaped and light blue to purple in color.



Identifying Characteristics: **The 'crinkled' leaf surfaces, square stems, stolons, stems that root at the nodes, and cluster of tube-shaped flowers are all characteristics that help in the identification of healall. Healall is sometimes confused with Henbit (*Lamium amplexicaule*) and Purple Deadnettle (*Lamium purpureum*), however both of these weeds have leaves with rounded teeth along the margins unlike those of healall. Florida Betony (*Stachys floridana*) also has a similar leaf shape and growth habit, however this weed has scalloped leaf margins and large, white underground tubers unlike healall.**

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Four-O' Clock: *Mirablis nyctaginea*

Weed Description: **Erect perennials with tuberous thickened roots that may reach 4 1/2 feet in height. Wild four-o' clock is primarily a weed of pastures, hay fields, roadsides, and abandoned locations that is found in North Carolina, Kentucky, Virginia, and West Virginia.**

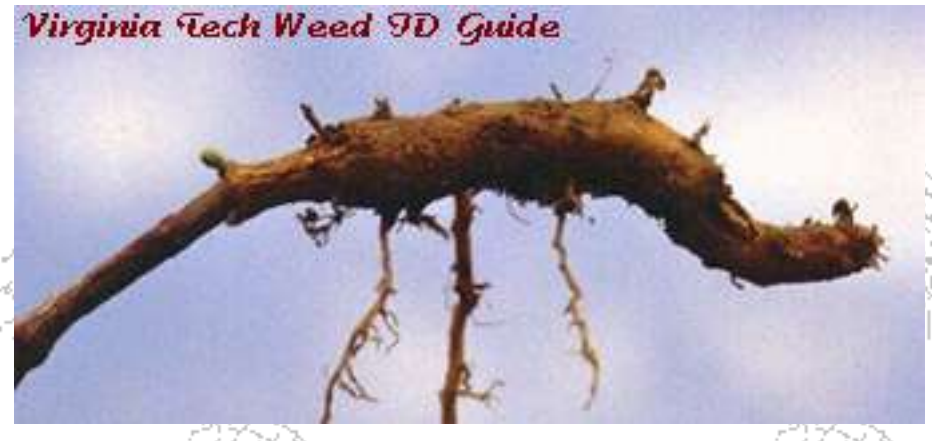
Roots: **Very thick and tuber-like in some places.**

Stems: **Plants usually range from**

1 1/2 to 4 1/2 feet in height. Stems are erect and branching.

Leaves: **Leaves are triangular to triangular-lanceolate in outline, from 1 1/2 to 3 inches long and 1 to 2 inches wide. Leaves occur on petioles that are approximately 3/4 inch or less in length. Leaves have a deep green color and have prominent white midveins.**

Flowers: **Flowers are pink to lavender in color and occur on flower stalks (peduncles) that range from 3 to 10 mm in length.**



Fruit: **A gray or brown achene that is 4 to 5 mm long and elliptical.**

Identifying Characteristics: **Plants with thick rootstocks and triangular leaves that are dark green in color with prominent white midveins.**

Virginia Tech Weed Identification Guide

Select a Resource...

Giant Foxtail: *Setaria faberi*

Weed Description: **A clump-forming summer annual with a seedhead that resembles a fox's tail. A weed of many agronomic crops, turf, landscapes, and nurseries. Found throughout the United States, especially on fertile soil.**

Seedling: **Leaves are rolled in the bud, leaf sheaths are mostly without hairs, but the leaf blades have many short hairs on the upper leaf surface and along the leaf margins. The ligule of the seedlings is a fringe of hairs approximately 1/2 mm long, often very difficult to see with the naked eye.**

Roots: **A fibrous root system.**

Stems: **Erect, round, usually without hairs, reaching 3 to 4 feet in height.**

Leaves: **Leaf blades may reach 16 inches in length and 15 to 25 mm in width, and are generally covered with many small hairs on the upper leaf surface, except near the leaf base. Auricles are absent and the ligule is a fringe of hairs reaching 3 mm in length.**

Flowers: **The seedhead is a cylindrical, bristly panicle that becomes drooping with maturity. Spikelets are approximately 3 mm long, green, and each spikelet has 1-3 bristles that are 5-10 mm long.**

Identifying Characteristics: **Characteristic foxtail-like seedhead that droops when mature and leaves with many hairs on the upper leaf surface, which helps to distinguish this weed from both Green Foxtail (*Setaria viridis*) and Yellow Foxtail (*Setaria glauca*). Giant foxtail may be identified by the presence of many short hairs on the upper surface of the leaf blades, unlike the other foxtails. Additionally, giant foxtail is generally larger and has a nodding seedhead, unlike the other foxtails.**

Virginia Tech Weed Identification Guide

Select a Resource...

Green Foxtail: *Setaria viridis*

Weed Description: **A clump-forming summer annual with a seedhead that resembles a fox's tail. A weed of many agronomic crops, turf, landscapes, and nurseries. Found throughout the United States.**

Seedling: **Leaves are rolled in the bud, leaf sheaths and blades without hairs, but the leaf sheaths often have slightly hairy margins. The ligule is a row of hairs approximately 1/2 mm long, therefore this is rarely seen by the casual observer.**

Roots: **Fibrous.**

Leaves: **Leaf blades may reach 12 inches in length and 5-15 mm in width, and are most often without hairs or only very sparsely hairy. The leaf sheath is closed and is without hairs, except along the margin near the mouth. The ligule is short and fringed with hairs to 2 mm long.**

Stems: **Erect, without hairs, bent at the nodes, may be branched at the base, reaching 3 feet in height.**

Flowers: **The seedhead is a cylindrical bristly panicle, reaching 6 inches in length and 1/3-2/3 inch in width. Spikelets are approximately 3 mm long, green, and each spikelet has 1-3 bristles that are 5-10 mm long.**

Identifying Characteristics:
Characteristic foxtail-like seedhead and leaves with no hairs, which helps to distinguish this weed from both Giant Foxtail (*Setaria faberi*) and Yellow Foxtail (*Setaria glauca*). Giant foxtail may be identified by the presence of many short hairs on the leaf blades, unlike the other foxtails. Yellow foxtail is also similar to green foxtail but has long wiry hairs on the leaf blades where the leaf blades and sheaths meet.

Virginia Tech Weed Identification Guide

Select a Resource...

Yellow Foxtail: *Setaria glauca*

Weed Description: **A clump-forming summer annual with a seedhead that resembles a fox's tail. A weed of many agronomic crops, turf, landscapes, and nurseries. Found throughout the United States, especially on fertile soil.**

Seedling: **Leaves are rolled in the bud, leaf sheaths are without hairs, but the leaf blades have long silky hairs on the upper surface near the leaf base (shown in picture on left). The ligule is a fringe of hairs approximately 1/2 mm long, often very difficult to see with the naked eye.**

Roots: **A fibrous root system and stems that do not root at the nodes.**

Stems: **Stems are erect, often flattened, without hairs (glabrous), reaching 3 feet in height, and often with**

a reddish tint at the base.

Leaves: Leaf blades may reach 12 inches in length and 7 to 12 mm in width, and have long silky hairs at the leaf bases. Auricles are absent and the ligule is a fringe of hairs reaching 2 mm in length.

Flowers: The seedhead is a cylindrical bristly panicle, reaching 6 inches in length and 1/3-2/3 inch in width. Spikelets are approximately 3 mm long, green, and each spikelet has 1-3 bristles that are 5-10 mm long. The bristles turn yellow at maturity, giving the plant it's name.

Identifying Characteristics: **Characteristic foxtail-like seedhead that appears yellow when mature and leaves with long silky hairs at the base only, which helps to distinguish this weed from both Giant Foxtail (*Setaria faberi*) and Green Foxtail (*Setaria viridis*). Giant foxtail has many short hairs on the upper surfaces of the leaf blades, unlike yellow foxtail which only has a few long, silky hairs near the leaf base. Similarly, green foxtail has no hairs on the leaf blades or at the leaf bases.**

Common Weed Names: G

Common Name	Scientific Name
Galinsoga, Hairy	*Galinsoga ciliata*
Gama-grass	*Tripsacum dactyloides*
Garlic Mustard	*Allaria petiolata*
Garlic, Wild	*Allium canadense*
German Moss	*Scleranthus annuus*
Giant Foxtail	*Setaria faberi*
Giant Ragweed	*Ambrosia trifida*
Goat's-beard	*Tragopogon dubius*
Goldenrod, Canada	*Solidago canadensis*
Goosegrass	*Eleusine indica*
Grapehyacinth, Starch	*Muscari racemosum*
Grape, Wild	*Vitis* spp.
Grass, Deer-tongue	*Panicum clandestinum*
Green Foxtail	*Setaria viridis*
Green Kyllinga	*Kyllinga brevifolia*
Groundcherry, Clammy	*Physalis heterophylla*
Ground Ivy	*Glechoma hederacea*
Groundsel, Common	*Senecio vulgaris*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Eastern Gamagrass or Gamagrass:

Tripsacum dactyloides

Weed Description: **A perennial from large, thick rhizomes that may reach 6 feet in height. Eastern Gamagrass has a conspicuous spike seedhead that is 'jointed' and is primarily a weed of pastures, hay fields, abandoned fields, roadsides, and along the edges of woods. This grass is found from Massachusetts south to Florida.**

Roots: **Plants have very thick rootstocks, usually much larger than the width of the plant itself.**

Leaves: **Leaf blades may reach 2 feet in length and 1 inch in width, and are rough to the touch but mostly without hairs except those that occur at the base of the upper leaf surfaces. Leaves lack auricles but have a ligule that is a fringe of hairs, approximately 1 to 1 1/2 mm in length. Ligules may be fused at the base taking on the appearance of a ligule that is both membranous and a fringe of hairs.**

Stems: **Sheaths are without hairs and are split at least part way up the stem with overlapping margins. Stems may reach 6 feet or more in height.**

Flowers: **Seedheads (usually 1 to 3) are terminal spikes that are from 4 to 12 inches in length. Spikes consist of many tightly fused spikelets that eventually take on the appearance of being 'jointed'.**

Identifying Characteristics: **The large, thick rootstocks and relatively large leaves of this plant helps to distinguish it from almost any other grass. Additionally, the rather unique terminal seedhead is a good identifying characteristic of this species.**

Virginia Tech Weed Identification Guide

Select a Resource...

Garlic Mustard: *Allaria petiolata*

Virginia Tech Weed Identification Guide

Select a Resource...

Goat's-beard or Western Salsify: *Tragopogon dubius*

Weed Description: **A biennial, often mistaken for a grass especially before flowering, with yellow flowers and a large 'puff-ball' seedhead. Goat's-beard is primarily a weed of pastures, hay fields, and other forages, but is also found in nurseries, orchards, and along roadsides. This weed is more common in the western United States but is becoming more common in the eastern United States as well.**

Seedlings: **Cotyledons are linear and collectively the seedlings resemble a young grass. Cotyledons may reach up to 4 1/2 inches in length and are only about 2 mm wide. The first true leaves and subsequent leaves form a basal rosette. These leaves may have some long hairs, especially near the base.**

Leaves: **Mature leaves are approximately 12 inches long and 2 mm wide, linear in outline, and resemble the leaves of grasses but are generally thicker. Leaves may have a few long hairs near their bases. The leaf bases are wider than the apex, and leaf bases clasp the stem. Leaves emit a milky sap when cut.**

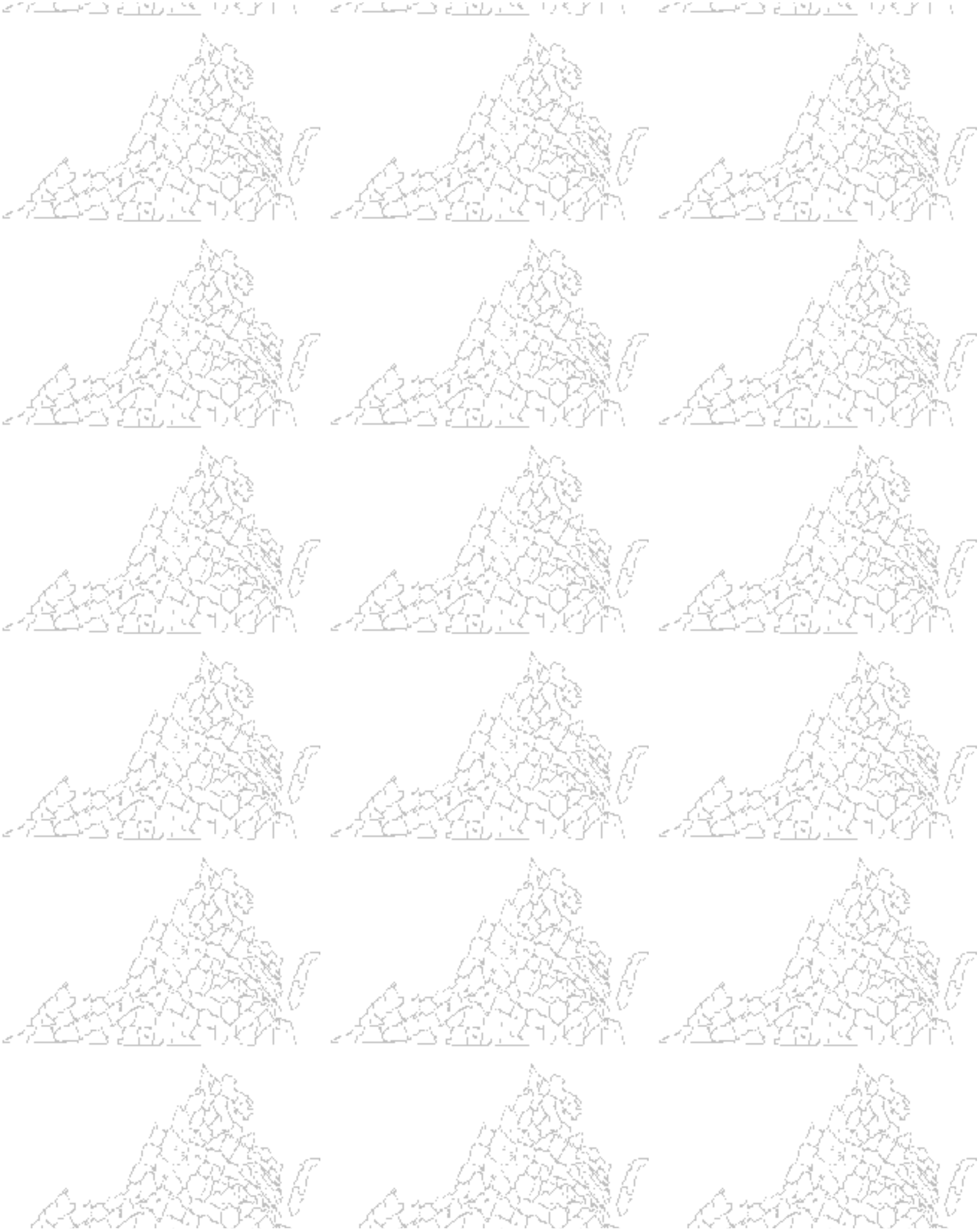
Stems: **Flowering stems are generally produced during the second year of growth. Stems are without hairs, round, and usually unbranched. Stems emit a milky sap when cut.**

Roots: **A taproot that emits a milky sap when broken.**

Flowers: **Occur singly at the ends of the flowering stems. Flowers are yellow, approximately 3/4 to 1 1/2 inches in length. Bracts occur at the base of the flowers and these are generally longer than the flowers themselves and somewhat pointed.**

Fruit: **Achenes that occur in a round, 'puff-ball' seedhead similar to, but larger than that of dandelion. Each achene has a feathery pappus that facilitates wind dispersal of the seed. Seedheads are approximately 3 to 4 inches in diameter.**

Identifying Characteristics: **Plants that emit a milky sap when broken, leaves that resemble a grass, and the flowers and seedheads that resemble those of dandelion (but are considerably larger) are all characteristics that help in the identification of goat's beard.**



Virginia Tech Weed Identification Guide

Select a Resource...

Goosegrass: *Eleusine indica*

Weed Description: **Summer annual with stems radiating outwards from a central distinctive white center. Primarily a weed of turfgrass, landscapes and agronomic crops from Massachusetts to South Dakota and Kansas, South to Florida and Texas, and along the West Coast.**

Seedling: **First leaf 3-5 times longer than wide, and opens parallel to the ground. Leaf sheaths are flattened, smooth, and even on seedlings often are distinctly white to silver at the base.**

Roots: **Fibrous.**

Leaves: **Leaf blades are 2-14 inches long, 3-8 mm wide, without hairs or only sparsely hairy, and folded along the midvein. The ligule is 1-2 mm long, fringed, uneven, and membranous. Sheaths are flattened, whitish at the base, and sparsely hairy in the collar region.**

Flowers: **Seedheads composed of 2-13 spikes each 1 1/2 to 6 inches long, 3-7 mm wide, in clusters at the top of stems. Two rows of flattened spikelets occur along each spike.**

Seed: **Each spikelet contains 3-6 light brown to black seeds that are 1-2 mm long.**

Identifying Characteristics:
Flattened stems with a distinctive white or silver center. Plants often appear compressed to the soil, as if they have been repeatedly stepped on. This weed may be confused with Smooth Crabgrass (*Digitaria ischaemum*), but the leaves of smooth crabgrass are rolled in the bud, while those of goosegrass are folded in the bud. Additionally, the distinctive white center of goosegrass distinguishes it from most other grass weeds.

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Grapes: *Vitis* spp.

Weed Description:

Woody vines that may grow prostrate along the ground or climb over other vegetation and objects. Wild grapes can form large thickets and choke-out much of the existing vegetation. Several species of wild grapes occur throughout the eastern half of the United States, and these are primarily weeds of orchards, vineyards, ornamental nurseries, fence rows,

landscapes, and pastures.

Leaves: Several species of *Vitis* occur with leaves that are generally ovate in outline and taper to a distinct point. Some species has leaves that are divided into 3 to 5 lobes. Leaves are arranged alternately along the stem, have veins that arise from a common point, and have toothed margins.

Stems: Climb over other vegetation or objects by way of tendrils or grow prostrate along the ground. Stems become woody with age and the bark sheds in strips. The tendrils that aide in climbing are forked and arise opposite from the leaves. Stem sections that have been cut can easily generate new plants.

Fruit: Many berries that occur in a cluster, each berry ranging from 1/2 to 3/4 inch in diameter. Berries are purplish-black when mature.

Flowers: Occur in clusters that arise from the area between the stem and leaf petiole (leaf axils). Individual flowers are relatively inconspicuous and greenish-yellow in color.

Identifying Characteristics: The ovate leaves that taper to a point with toothed margins, forked tendrils that arise oppositely from the leaves, and climbing growth habit are all features that help in the identification of wild grapes. Burcucumber (*Sicyos angulatus*), Japanese Hops (*Humulus japonicus*), Virginia Creeper (*Parthenocissus quinquefolia*), Poison Ivy (*Toxicodendron radicans*), and Kudzu (*Pueraria lobata*) are all species that have a climbing or trailing growth habit and may be encountered as a weed in similar environments, however none of these weeds have the forked tendrils that are characteristic of the *Vitis* species.

Virginia Tech Weed Identification Guide

Select a Resource...

Virginia Creeper: *Parthenocissus quinquefolia*

Weed Description: **A perennial woody vine that climbs on other objects or trails along the ground. Primarily a weed of fence rows, landscapes, and vineyards. Virginia creeper occurs throughout the eastern United States.**

Leaves: **Leaves consist of 3 to 7 (usually 5) leaflets that originate from a common point (palmately compound leaves). Leaflets are from 2 1/2 to 5 inches long and have toothed margins. Leaves turn red to maroon in the fall, which is why this plant is often grown as an ornamental.**

Flowers: **Small and greenish-white in color.**

Fruit: **Small, dark blue to black berries.**

Roots: **Fibrous roots occur, and stems root where they touch the ground.**

Stems: **Stems climb by tendrils and root where they touch the ground.**

Identifying Characteristics: **A climbing woody vine with 5 leaflets that originate from the same point. Virginia creeper is often confused with Poison-Ivy (*Toxicodendron radicans*). However, poison-ivy has 3 leaflets while Virginia creeper usually has 5.**

Poison Ivy: *Toxicodendron radicans*

Weed Description: **A woody vine that may occur as a weed of landscapes, woods, fencerows, pastures, and hay fields. Poison ivy is the major cause of allergenic dermatitis in the eastern United States, which causes inflammation, blistering, and itching of the skin. The plant sap contains a chemical called urushiol, which is found within ducts in the leaves, flowers, stems, and roots of this weed. When poison ivy plants are bruised or damaged, this chemical is emitted onto the leaf and stem surfaces where humans and animals may come into contact with it. Poison ivy is found throughout the southern United States east of the Mississippi River. It also occurs more sporadically in the midwestern and**

northern United States.

Leaves: Leaves occur on petioles and are divided into 3 leaflets which are generally oval in outline. Leaflets may be either toothed, untoothed, or lobed. Older leaves are generally either toothed and lobed or untoothed and lobed. The two lateral leaflets occur on very short petioles, while the central leaflet occurs on a much longer petiole. Although leaf shape is highly variable, the lateral leaflets are often distinctly lobed on one side of the leaflet and not on the other. Each leaflet is hairless and ranges from 3/4 to 4 inches in length and width.

Stems: Woody, climbing on other vegetation or objects or trailing along the ground. When climbing, poison ivy attaches to other objects by way of

aerial roots. Stems are capable of rooting when they come into contact with the soil.

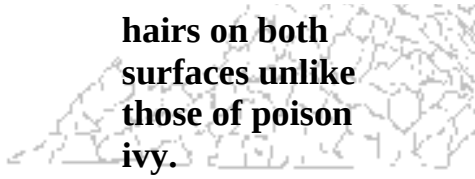
Roots: A fibrous root system and stems that root where they come into contact with the ground.

Flowers: Flowers are small and inconspicuous, yellowish green to green in color. Flowers occur in clusters of 2 to 6 on stalks that arise from the position between the leaf petioles and stems (leaf axils).

Fruit: A berry, gray to white in color, approximately 5 mm wide.

Identifying Characteristics: **The climbing or trailing nature of this weed, woody growth habit, and irregularly lobed and toothed leaflets are all characteristics that help in the identification of poison ivy. Virginia Creeper (*Parthenocissus quinquefolia*) is often mistakenly identified as poison ivy, however this weed has leaves that are divided into 5 leaflets while poison ivy has leaves that are divided into 3 leaflets. Poison oak (*Toxicodendron toxicarium*) is very similar to poison ivy, however poison oak has much duller green leaves that are usually more distinctly lobed or toothed. Additionally, poison oak's leaflets have**





hairs on both surfaces unlike those of poison ivy.





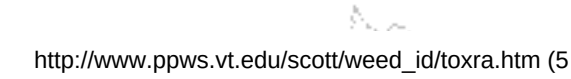
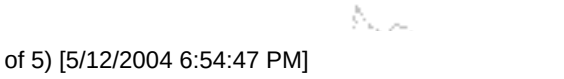











Virginia Tech Weed Identification Guide

Select a Resource...

Kudzu: *Pueraria lobata*

Weed Description: An invasive perennial vine with trifoliate leaves that was initially brought to the Unites States from Japan in 1876 as a soil cover to prevent erosion. Kudzu is one of the most common and troublesome weeds of rights-of-way, power lines, roadsides, and forests, and now invades an estimated 2,00,000 acres in the southeastern United States. It is common for this weed to completely overgrow all trees and other vegetation once it is established in an area. It is estimated that a single acre of kudzu would expand to 5,250 acres if left uncontrolled for 100 years.

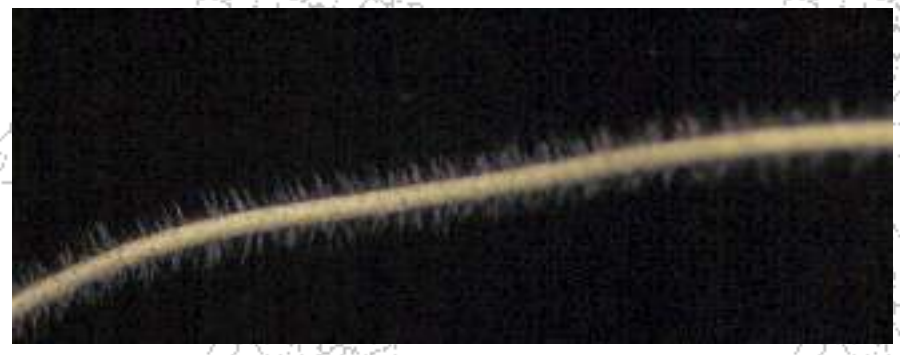
Seedlings: Cotyledons are oval to oblong. First true leaves are covered with short bronze hairs and are arranged oppositely. All subsequent leaves consist

of 3 leaflets (trifoliate) and each set of 3 leaflets are arranged alternately along the stem.

Roots: Both fibrous and tuberous roots occur.

Leaves: Consist of 3 leaflets (trifoliate leaves). Each set of 3 leaflets is arranged alternately along the stem. All leaflets occur on petioles, however the lateral leaflets are on very short petioles (less than 1/2 inch), while the center leaflet occurs on a petiole approximately 3/4 inch long. All leaves are ovate in outline, hairy, and lobed. Lateral leaflets are usually lobed on one side only while the center leaflet is usually lobed on both sides.

Stems: **Climbing on other vegetation or trailing along the ground. When young, stems are covered with stiff bronze hairs but these become much less common on older plants. Stems may become woody when mature.**



Flowers: **Occur in racemes that arise from the area between the leaflet petiole and the stem (axillary regions). Each raceme is approximately 4 to 8 inches long and is reddish purple in color. Flowers are often inconspicuous due to the dense vegetation that often covers them, but generally emerge in August-September in Virginia.**

Fruit: **A pod, approximately 1 1/2 to 2 inches long that contains many kidney bean-shaped seed.**

Identifying Characteristics: **The rapid growth, climbing or trailing nature, and invasive habit of kudzu make it easy to distinguish from most other weeds. The hairy leaves and stems and lobed leaves are also characteristics that help in the identification of kudzu.**

Common Weed Names: H

Common Name	Scientific Name
Hairy Bittercress	*Cardamine hirsuta*
Hairy Galinsoga	*Galinsoga ciliata*
Hawksbeard, Smooth	*Crepis capillaris*
Hawkweed, Mouseear	*Hieracium pilosella*
Healall	*Prunella vulgaris*
Hedge Bindweed	*Calystegia sepium*
Hedge Mustard	*Sisymbrium officinale*
Hemlock, Poison	*Conium maculatum*
Hemp Dogbane	*Apocynum cannabinum*
Hemp Sesbania	*Sesbania exaltata*
Henbit	*Lamium amplexicaule*
Hoary Plantain	*Plantago virginica*
Honeysuckle, Japanese	*Lonicera japonica*
Honeysuckle, Morrow's Bush	*Lonicera morrowii*
Honeyvine Milkweed	*Ampelamus albidus*
Hophornbeam Copperleaf	*Acalypha ostryifolia*
Hops, Japanese	*Humulus japonicus*
Horehound	*Marrubium vulgare*
Hornwort	*Ceratophyllum demersum*
Horsenettle	*Solanum carolinense*
Horseweed	*Conyza canadensis*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Smooth Hawksbeard: *Crepis capillaris*

Weed Description: **An erect biennial or perennial with conspicuous leaves that clasp the stem. Smooth hawksbeard is primarily a weed of pastures, hay fields, and roadsides, and is found throughout Virginia, North Carolina, and Tennessee.**

Stems:
Erect, reaching 3 1/3 feet in height, without hairs, branching from the base.

Leaves: **Leaves are lanceolate in outline, approximately 2 1/2 to 8 inches long, 1/2 to 3 inches wide. Leaves are usually dissected or lobed, and often have bases that clasp the stem. Basal leaves occur on petioles, stem leaves do not.**

Flowers: **Flowers bloom in late May-early June in Virginia. Many yellow flowers occur at the ends of branches. Individual flowers are 8 to 10 mm long.**

Identifying Characteristics:

Erect weeds with petioled leaves at the base and leaves without petioles above. Additionally, smooth hawksbeard has lanceolate, lobed leaves that clasp the stem, which helps in the identification of this species.

Virginia Tech Weed Identification Guide

Select a Resource...

Hedge Mustard: *Sisymbrium officinale*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Virginia Tech Weed Identification Guide

Select a Resource...

Hemp Sesbania: *Sesbania exaltata*

Weed Description: **Erect annual, reaching 3-6 feet in height, with distinctive seed pods and showy yellow flowers. Primarily a weed of agronomic crops found in the coastal plain but occasionally in the piedmonts of North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, and Virginia.**

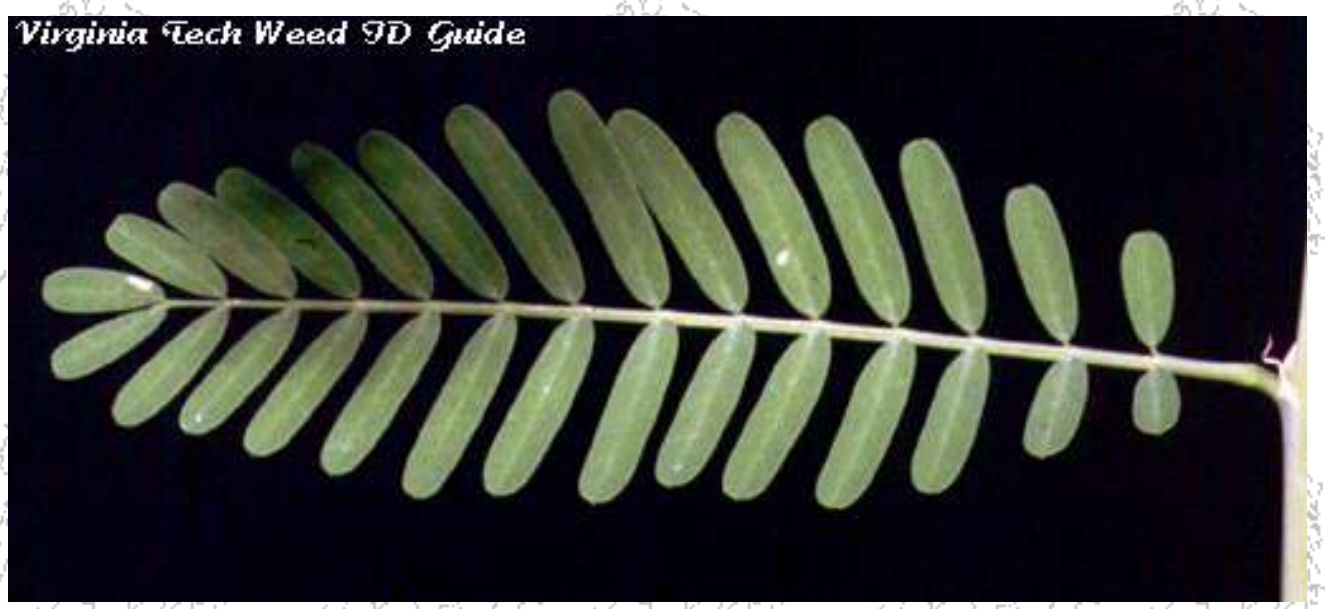
Seedlings: **Cotyledons spoon-shaped (2 times longer than wide), thick, green on the upper surface, gray-green on the lower surface, and without hairs. The first true leaf is simple, subsequent leaves are composed of six to eight leaflets that occur oppositely along the leaf axis (pinnately compound).**

Leaves: **Composed of 20-70 leaflets per individual leaf (pinnately compound). Leaflets are arranged oppositely, although individual leaves are alternate. Leaflets 1/3-1 inch long, 2-6 mm wide, without hairs above and somewhat hairy below.**

Roots: **Taproot.**

Fruit: **A legume containing 30 to 40 seeds. Legumes are linear, curved, 4-8 inches long, and often tipped with a small 'beak'.**

Flowers: **Two to six individual flowers occur on elongated inflorescences with each flower occurring on a flower stalk (raceme). Each raceme arises from the area between the stem and leaf petioles. Flowers are yellow and may be streaked or spotted with purple, with the largest petal reaching 2/3 inch in length.**



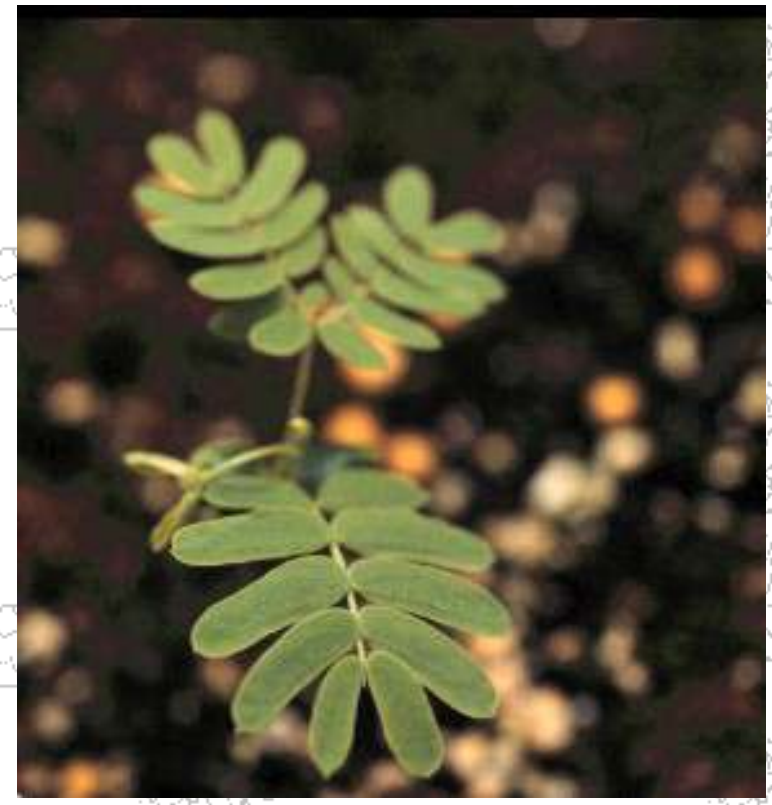
Stems: **Green, without hairs, may become woody with age.**

Identifying Characteristics: **Leaves composed of many smaller leaflets, large yellow flowers, and distinctive curved seedpod, often tipped with a beak. These features distinguish this weed from most other agronomic weeds, however seedling Mimosa (*Albizia julibrissin*) plants closely resemble those of Hemp Sesbania. Mimosa seedlings are rarely encountered and will eventually become woody and develop into a tree that may reach 40 feet in height. Additionally, with maturity the individual leaflets of Mimosa leaves become more tightly compacted to the point that neighboring leaves actually overlap one another. This is not the case with the much wider-spaced leaflets of Hemp Sesbania. Hemp sesbania may also be confused with Partridgepea (*Cassia fasciculata*), however partridgepea only has 16 to 30 leaflets per leaf and also has a distinctive spherical gland near the base of each leaf petiole.**

Virginia Tech Weed Identification Guide

Select a Resource...

Mimosa: *Albizia julibrissin*



Weed Description: **A prostrate perennial that develops into a tree and may reach 40 feet in height. Found throughout the southeastern United States along roadsides, woodland edges, in turf, and also most recently as seedlings or sprouts in many no-till crops.**

Seedling: **Plants arise from seed and stem fragments and resemble mature plants.**

Stems: **Contain many stiff hairs that are closely pressed against the stem (appressed). Stems are usually prostrate and creeping.**

Leaves:
Divided into four to six pairs of branched (pinnae) that are approximately opposite from one another and from 1.5 to 4 inches in length. Each pinnae is then further divided into 10 to 20 pairs of leaflets that are also opposite from one another. Individual leaflets are 8-15 mm long and 3-5 mm wide. With maturity, individual leaflets become tightly compacted to the point that neighboring leaves overlap one another.

Flowers: **Bright pink in color and occur in round heads at the ends of flower stalks (pedicels).**

Fruit: **A legume that is thin and flat, approximately 3 to 7 1/2 inches long and 3/4 to 1 inch wide.**

Identifying Characteristics: **A creeping perennial that becomes woody and has leaves divided into pinnae and many smaller leaflets. The woody habit of mimosa helps to distinguish this weed from others when mature, however seedling or sprouting mimosa plants may be confused with Hemp Sesbania (*Sesbania exaltata*). However, with maturity the individual leaflets of mimosa become**

tightly compacted to the point that neighboring leaves actually overlap one another. This is not the case with the much wider-spaced leaflets of hemp sesbania. Additionally, the stems of hemp sesbania do not have hairs like those of mimosa.

Paleseed or Hoary Plantain: *Plantago virginica*

Weed Description: **A winter annual with densely hairy elliptic leaves and slightly toothed to entire leaf margins. Found in the United States from Rhode Island to Florida and west to California. Paleseed plantain is primarily a weed of lawns, turfgrass, pastures, and occasionally landscapes.**

Leaves: **Elliptic in outline, from 3/4 to 6 inches long and 1 to 7 mm wide. Leaves are densely hairy**

when young, becoming less hairy with age. Leaf margins are either untoothed (entire) or slightly toothed.

Stems: **Several unbranched, leafless, flowering stems (scapes) occur on each plant. Scapes are hollow, from 1 1/2 to 7 inches in length.**

Roots: **A taproot.**

Flowers: **A scape that is unbranched and leafless to 10 cm long and contains many inconspicuous green flowers.**

Fruit: **A capsule.**

Identifying Characteristics: **A winter annual with hairy, elliptic leaves and erect, leafless flowering stems with inconspicuous flowers. Paleseed plantain is similar in appearance to some of the other plantain species, especially Buckhorn**

Plantain (*Plantago lanceolata*). However, buckhorn plantain is not a winter annual and may be only sparsely hairy without toothed leaf margins.

Virginia Tech Weed Identification Guide

Select a Resource...

Japanese Honeysuckle: *Lonicera japonica*

Weed Description:
A climbing or trailing vine with attractive and fragrant flowers. Japanese honeysuckle is primarily a weed of fence rows, landscapes, nurseries, and container ornamentals. This weed is now distributed throughout the United States, but is primarily a problem in the southeastern states.

Leaves: Leaves are hairy and arranged oppositely along the stem. Leaves are ovate to elliptic in outline, reaching 3 inches in length and 2 inches in width. Leaves occur on short petioles that range from 3 to 10 mm in length.

Stems: Climb on other vegetation or trail along the ground. Stems become woody with maturity. Stems are usually hairy but sometimes may be without hairs.

Flowers: Flowers occur in pairs and arise from the positions between the

stems and leaves (leaf axils). Flower pairs occur on short flower stalks (peduncles). Individual flowers are very fragrant, and are white to yellow in color.

Fruit: A round, black berry approximately 6 mm in diameter.

Identifying Characteristics:
Climbing or trailing vine with opposite, hairy leaves and fragrant white or yellow flowers.
Morrow's Bush-honeysuckle (*Lonicera morrowii*) and tatarian honeysuckle are both species that resemble japanese

honeysuckle, however both of these weeds have red berries and are more shrub-like when compared to japanese honeysuckle.

Morrow's Bush-Honeysuckle: *Lonicera morrowii*

Weed Description: **An erect shrubby honeysuckle that has escaped cultivation to become a weed of fencerows in a few isolated locations.**

Leaves: **Oval in outline and arranged oppositely along the stem. Leaves are fairly thick and have somewhat of a grayish cast.**

Stems: **Hairy, taking on a shrubby growth habit, becoming 3 1/2 feet high.**

Flowers: **Almost completely white in color, approximately 6 to 8 mm long.**

Fruit: **A globular red berry.**

Identifying Characteristics: **Opposite leaves with a grayish cast and shrubs with typical honeysuckle-like flowers.**

Japanese Honeysuckle (*Lonicera japonica*) is similar but is

more of a climbing and trailing plant and has black berries.

Virginia Tech Weed Identification Guide

Select a Resource...

Honeyvine Milkweed: *Ampelamus albidus*

Weed Description: **A perennial with slender, twining stems that may reach 10 ft in length. Found throughout the southeastern United States. Although the name implies a secretion of milky sap as in other milkweed species (*Asclepias* spp.), this does not occur in the leaves or stems of honeyvine milkweed.**

Leaves: **Opposite, entire, heart-shaped, 3-7 inches long, 1.5-5 inches wide. Leaves do not have hairs and occur on petioles that are 1-4 inches long. Leaf surfaces have conspicuous white veins that arise from a common point (palmate venation).**

Roots: **Clustered and fibrous.**

Stems: **Slender, without hairs, twining to 10 ft long.**

Fruit: **A smooth, angled follicle that is 3.5–5.5 inches long, 1-2.5 inches wide.**

Flowers: **Small (2-3 mm broad), white, numerous, and occur on flower stalks that arise between stems and leaves (axillary).**

Identifying Characteristics: **A perennial twining vine with opposite leaves and relatively large fruit (follicle). This weed is often incorrectly identified as a morningglory (*Ipomoea* spp.) or Field Bindweed (*Convolvulus arvensis*). However, the prominent white veins distinguishes this weed from any of the morningglories, and the heart-shaped leaf distinguishes this weed from field bindweed.**

Virginia Tech Weed Identification Guide

Select a Resource...

Horehound or White Horehound: *Marrubium vulgare*


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Horsenettle: *Solanum carolinense*

Weed Description: **A perennial from rhizomes with conspicuous spines on the leaves and stems that may reach 3 ft in height. Horsenettle is found throughout the southeastern, eastern, and north-central United States. All parts of the plant, except the mature fruit, are poisonous to livestock even when this weed is consumed in dry hay. However, consumption of this weed rarely occurs due to the prickly stems and leaves.**

Seedling:
Cotyledons oblong, glossy green above, light green below with hairs on the margins. Short, stiff hairs cover the hypocotyl, which is often purple-tinged.

Leaves:
Simple, elliptic-oblong to oval, alternate,

petioled, 2 1/2-4 1/2 inches long and covered on both surfaces with star-shaped hairs. Leaves also emit a potato odor when crushed, and contain prominent prickles (6-12 mm long) on the midvein and petiole.

Roots: **Deep, spreading rhizomes.**

Flowers: **Occur in clusters on prickly flower stalks and are star-shaped with 5 white to violet petals and a yellow cone-shaped center, which is actually 5 stamens with yellow anthers.**

Fruit: **A berry, 1/2-3/4 inches in diameter, green when immature turning yellow and wrinkled with maturity. A single berry may contain from 40 to 120 seed.**

Stems: **Angled at the nodes, become woody with age, and also have prickles and star-shaped hairs.**

Identifying Characteristics:
Stems and leaves with prickles and star-shaped hairs. Horsenettle might be confused with other solanaceous species like Clammy Groundcherry (*Physalis heterophylla*). However, groundcherries do not have prickles on the stems and leaves and have papery membranes enclosing their berries.

Common Weed Names: I

Common Name	Scientific Name
Indian Currant	*Symphoricarpos orbiculatus*
Indian Mock-strawberry	*Duchesnea indica*
Ironweed, New York	*Vernonia noveboracensis*
Italian Ryegrass	*Lolium multiflorum*
Ivyleaf Morningglory	*Ipomoea hederacea*
Ivy, Poison	*Toxicodendron radicans*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Indian Mock-Strawberry: *Duchesnea indica*

Weed Description:
Perennial from stolons often found in shady locations. Primarily a weed of landscapes and turfgrass found throughout the southeastern United States.

Seedling:
Cotyledons slightly thickened, with hairs along the margins only. First two or three leaves simple, subsequent leaves trifoliate. Stolons develop at least by the time the fifth leaf emerges.

Leaves: Each leaf is composed of three leaflets (trifoliolate). Leaflets are ovate to elliptic, 3/4-3 inches long, 1/3-1 1/2 inches wide, hairy, with rounded teeth (crenate). Individual leaflets are connected to the much longer petiole by very small petiolules (1-6 mm long). Petioles are also hairy.

Stems: Stolons are hairy and creeping.

Roots: Stolons.

Flowers: Occur alone on long stalks (peduncles) that arise from the region between the stem and leaf petioles (leaf axils). Flowers consist of 5 yellow petals with large leafy sepals beneath.

Fruit: A red, fleshy, berry, similar to the commercially produced strawberries. The surface of the fruit contains many small pits (achenes).

Identifying Characteristics: Creeping plants from stolons with trifoliolate leaves and distinctive strawberry-like berry. This weed is similar in appearance to wild strawberry (*Frageria virginiana*), but wild strawberry has leaflets with pointed teeth on the upper 2/3 to 3/4 of the leaflet only. Additionally, wild strawberry has white flowers, unlike the yellow flowers of Indian mock-strawberry. Certain Cinquefoil species (*Potentilla* spp.) may also resemble this weed, however sulfur and oldfield cinquefoil have 5 leaflets rather than 3 leaflets of Indian mock-strawberry.

Common Weed Names: J

Common Name	Scientific Name
Japanese Bamboo	*Polygonum cuspidatum*
Japanese Clover	*Lespedeza striata*
Japanese Honeysuckle	*Lonicera japonica*
Japanese Hops	*Humulus japonicus*
Japanese Knotweed	*Polygonum cuspidatum*
Japanese Stiltgrass	*Microstegium vimineum*
Jerasulem Artichoke	*Helianthus tuberosus*
Jewelweed	*Impatiens capensis*
Jewgrass, Annual	*Microstegium vimineum*
Jimsonweed	*Datura stramonium*
Johnsongrass	*Sorghum halepense*
Jointhead Arthraxon	*Arthraxon hispidus*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Touch-me-not or Jewelweed: *Impatiens capensis*

Weed Description:
Branching annual with distinctive orange to red funnel-shaped flowers. Touch-me-not is found primarily along roadsides, along the edges of streams and marshes, and in other noncrop areas throughout Virginia, Georgia, Alabama, Tennessee, Kentucky, and West Virginia.

Leaves: **Leaves are elliptic to triangular in outline, approximately 2 to 4 1/2 inches long and 1 1/4 to 3 inches wide. All leaves are without hairs (glabrous), have margins that are slightly toothed and occur on petioles that may reach 2 1/2 inches in length.**

Stems: **Without hairs (glabrous), reaching 6 1/2 feet in height.**

Flowers: **Bright orange to red in color, forming a triangular funnel with a spotted sepal at the 'mouth' of the funnel.**

Fruit: **A capsule.**

Identifying Characteristics: **The orange funnel shaped flowers and triangular leaves with toothed margins are both characteristics that help in the identification of touch-me-not.**

Virginia Tech Weed Identification Guide

Select a Resource...

Jimsonweed: *Datura stramonium*

Weed Description: **An erect summer annual with large white to purple flowers and a distinctive odor. Primarily a weed of agronomic crops found throughout most of the US except for the Northwest.**

Seedling: **Cotyledons thick, without hairs, long and linear in outline (2 inches long, 6 mm wide). Cotyledons also have a clearly evident midvein. The stem below the cotyledon (hypocotyl) is initially maroon in color toward the base, eventually becoming maroon throughout. First true leaves have a continuous, untoothed margin (entire), while later leaves are toothed.**

Leaves: **Large, 3-8 inches long, 6 inches wide, ovate, without hairs, on long stout petioles. Margins with a few large triangular teeth. Leaves emit an unpleasant odor, especially when touched.**

Roots: **Thick and extensively branched taproot system.**

Fruit: **An egg-shaped capsule (1-2 inches long), covered with stiff prickles, and splitting into 4 segments when mature.**

Flowers: **Large, 2-5 inches long, white to purple in color and funnel-shaped. Individual flowers occur on short stalks (pedicels) that arise from leaf or branch axils. Sepals enclose the lower part of the flower.**

Stems: **Very stout, hollow, smooth, branching, green or more often purple, with inconspicuous hairs.**

Identifying Characteristics: **Plants with large conspicuous flowers and fruit. Also, the distinctive odor of jimsonweed helps in identification. The cotyledons of Common Cocklebur (Xanthium strumarium) might be confused with those of Jimsonweed. However, Common Cocklebur cotyledons lack the distinctive midvein and are generally larger and less linear than those of Jimsonweed.**

Common Weed Names: K

Common Name	Scientific Name
Knapweed, Spotted	*Centaurea maculosa*
Knawel	*Scleranthus annuus*
Knotweed, Japanese	*Polygonum cuspidatum*
Knotweed, Prostrate	*Polygonum aviculare*
Knotweed, Tufted	*Polygonum caespitosum**
Knotweed, Virginia	*Polygonum virginianum*
Kochia	*Kochia scoparia*
Kudzu	*Pueraria lobata*
Kyllinga, Green	*Kyllinga brevifolia*

The full scientific name is *Polygonum caespitosum* var. *longisetum

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Virginia Cooperative Extension

Knowledge for the CommonWealth

Prostrate Knotweed: *Polygonum aviculare*

Weed Description:
A prostrate summer annual with small, elliptic leaves that is primarily found in compacted areas of turfgrass such as pathways or sports fields. Prostrate knotweed is found throughout the United States.

Seedlings:
Cotyledons are narrow, linear in outline, often resembling and being mistaken for a grass. The stem below the cotyledons (hypocotyl)

is often reddish in color.

Roots: **A taproot.**

Leaves: **Arranged alternately along the stem, lanceolate in outline, approximately 1/2 to 1 1/4 inches long and 1 to 8 mm wide. Leaves have short petioles and a distinctive thin membranous sheath (ocrea) that encircles the stem at the leaf base.**

Fruit: **A dark red to brown achene.**

Stems: **Branching, growing prostrate along the ground, ranging from 4 to 24 inches in length. Stems are swollen at the nodes with a thin membranous sheath (ocrea) encircling the stem at each leaf base.**

Flowers: **Occur in the area between the stems and leaves (leaf axils). From 1 to 5 flowers occur in clusters and are very small and inconspicuous, white to pinkish-white in color.**

Identifying Characteristics: **Prostrate-growing plants with small lanceolate leaves that are primarily found in hard compacted areas of turfgrass and landscapes. Some of the spurges like Spotted Spurge (*Euphorbia maculata*) may be confused with prostrate knotweed, however the spurges do not have an ocrea and emit a milky sap when cut unlike prostrate knotweed.**

Spotted Spurge: *Euphorbia maculata*

Weed Description: **A prostrate summer annual that often forms dense mats that may reach 16 inches in diameter. All parts of the plant emit a milky sap when broken. Spotted spurge if found throughout the eastern half of the United States and also in California and Oregon. This plant primarily occurs as a weed of landscapes, nurseries, turfgrass, lawns, and some agronomic crops.**

Roots: **Small taproot and more noticeable fibrous root system.**

Seedling: **Cotyledons are without hairs (glabrous), oval, green above and tinted maroon below, and occur on short petioles that are maroon to purple in color. Stems below the cotyledons (hypocotyls) are also without hair and pink to maroon in color.**

Stems: **Prostrate, branching out from a central point, densely hairy, and pink to red in color. Spotted spurge stems do not root at the nodes.**

Fruit: **A hairy capsule approximately 1 1/2 mm long.**

Leaves: **Egg-shaped in outline, 4 to 15 mm long, and usually without hairs but sometimes long hairs may occur. Leaves are arranged oppositely along the stem and often have a maroon spot on the upper leaf surface. Leaves occur on very short petioles and leaf margins may be very finely toothed (often indistinguishable) near the leaf apex.**

Flowers: **Arise from the positions between the leaves and stems (leaf axils). Flowers are relatively inconspicuous.**

Identifying Characteristics: **Small prostrate plants that emit a milky sap when broken and form dense mats that radiate out from a central point. Spotted spurge is very similar in appearance to prostrate spurge (*Euphorbia humistrata*), however prostrate spurge roots at the nodes while spotted spurge does not. Prostrate Knotweed (*Polygonum aviculare*) also grows prostrate and forms dense mats that radiate out from a central point, however prostrate knotweed has an ochrea and also does not emit a milky sap like the spurges.**

Virginia Tech Weed Identification Guide

Select a Resource...

Tufted Knotweed: *Polygonum caespitosum* var.*longisetum*

Weed Description: **A summer annual weed of horticultural, agronomic, and nursery crops that may reach 3 1/2 feet in height.**

Seedlings: **Cotyledons are elliptic to lanceolate in outline, whit hairs along the margins. First true leaves are alternate, lanceolate in outline, and hairy on the upper surfaces.**

Roots: **Fibrous roots with a shallow taproot.**

Fruit: **A black achene.**

Leaves: **Arranged alternately along the stem, lanceolate to elliptic in outline, approximately 3/4 to 3 inches long and 1/2 to 1 1/4 inches wide. Older leaves are usually only slightly hairy. Leaves taper to short petioles, which have an ocrea that encircles the stem. Leaves often, but not always, have a purple spot in the middle of the leaf.**

Flowers: **Flowers are clustered in terminal spikes at the ends of stems. Individual flowers are small and are dark pink to red in color.**

Stems: **Branched, often reddish in color and swollen at the nodes. A thin membranous sheath called an ocrea encircles the stem at the base of each leaf petiole. The ocrea's of tufted knotweed have stiff hairs arising from the top of the ocrea, which are from 5 to 10 mm long.**

Identifying Characteristics: **The elliptic to lanceolate leaves with a purple spotted 'lady's thumb' print in the middle and distinctive ocrea with stiff hairs are all characteristics that help to distinguish tufted knotweed from other similar weeds. Pennsylvania Smartweed (*Polygonum pensylvanicum*) is very similar in**

appearance and growth habit, but does not have hairs on the ocrea like that of tufted knotweed. Ladysthumb (*Polygonum persicaria*) is also similar in appearance and growth habit, but has hairs on the ocrea that are much shorter (2 mm) than those of ladysthumb, and also has generally smaller leaves and dark pink to red flowers.

Virginia Tech Weed Identification Guide

Select a Resource...

Pennsylvania Smartweed: *Polygonum pensylvanicum*

Weed Description: **A summer annual weed of horticultural, agronomic, and nursery crops that may reach 3 1/2 feet in height. Pennsylvania smartweed is distributed throughout the United States.**

Seedlings: **Cotyledons are elliptic to lanceolate in outline, whit hairs along the margins. First true leaves are alternate, lanceolate in outline, and hairy on the upper surfaces.**

Leaves: **Arranged alternately along the stem, lanceolate to elliptic in outline, approximately 2 to 6 inches long and 1 1/4 inches wide. Older leaves are usually only slightly hairy. Leaves taper to short petioles, which have an ocrea that encircles the stem. Leaves often, but not always, have a purple spot in the middle of the leaf.**

Stems: **Branched, often reddish in color and swollen at the nodes. A thin membranous sheath called an ocrea encircles the stem at the base of each leaf petiole. The ocrea's of Pennsylvania smartweed do not have any hairs arising from the the ocrea, as is the case with many other similar weeds.**

Fruit: **A black achene.**

Flowers: **Flowers are clustered in terminal spikes at the ends of stems. Individual flowers are small and usually pink in color but can occasionally be white.**

Identifying Characteristics: **The elliptic to lanceolate leaves with a purple spotted 'lady's thumb' print in the middle and distinctive ocrea are all characteristics that help**

to distinguish Pennsylvania smartweed from other similar weeds. Ladysthumb (*Polygonum persicaria*) is very similar in appearance and growth habit, but has stiff hairs on the ocrea that are approximately 2 mm long unlike that of Pennsylvania smartweed. Tufted Knotweed (*Polygonum caespitosum* var. *longisetum*) is also similar in appearance and growth habit, but has hairs on the ocrea that are much longer (5 to 10 mm) than those of ladysthumb.

Virginia Tech Weed Identification Guide

Select a Resource...

Ladysthumb: *Polygonum persicaria*

Weed Description:
A summer annual weed of horticultural, agronomic, and nursery crops that may reach 3 1/2 feet in height. Ladysthumb is distributed throughout the United States.

Seedlings:
Cotyledons are elliptic to lanceolate in outline, whit hairs along the margins. First true leaves are alternate, lanceolate in outline, and hairy on the upper surfaces.

Leaves:
Arranged alternately along the stem, lanceolate to elliptic in outline, approximately 2 to 6 inches long and 1 1/4 inches wide. Older leaves are usually only slightly hairy. Leaves taper to short petioles, which have an ocrea that encircles the stem. Leaves often, but not always, have a purple spot in the middle of the leaf which resembles the mark of a lady's thumb, thus the name of this weed.

Roots:
Fibrous roots with a shallow taproot.

Stems: **Branched, often reddish in color and swollen at the nodes. A thin membranous sheath called an ocrea encircles the stem at the base of each leaf petiole. The ocrea's of ladysthumb have stiff hairs arising from the top of the ocrea, which are approximately 2 mm long.**

Flowers: **Flowers are clustered in terminal spikes at the ends of stems. Individual flowers are small and usually pink in color but can occasionally be white.**

Fruit: **A black achene.**

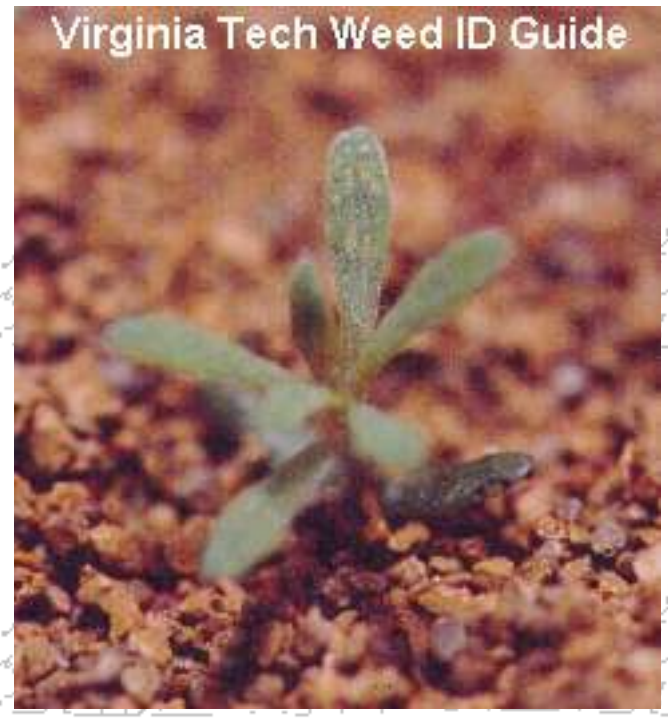
Identifying Characteristics: **The elliptic to lanceolate leaves with a purple spotted 'lady's thumb' print in the middle and distinctive ocrea with stiff hairs are all characteristics that help to distinguish ladysthumb from other similar weeds. Pennsylvania Smartweed (*Polygonum pensylvanicum*) is very similar in appearance and growth habit, but does not have hairs on the ocrea like that of ladysthumb. Tufted Knotweed (*Polygonum caespitosum* var. *longisetum*) is also similar in appearance and growth habit, but has hairs on the ocrea that are much longer (5 to 10 mm) than those of ladysthumb.**

Virginia Tech Weed Identification Guide

Select a Resource...

Virginia Knotweed: *Polygonum virginianum*

Kochia: *Kochia scoparia*

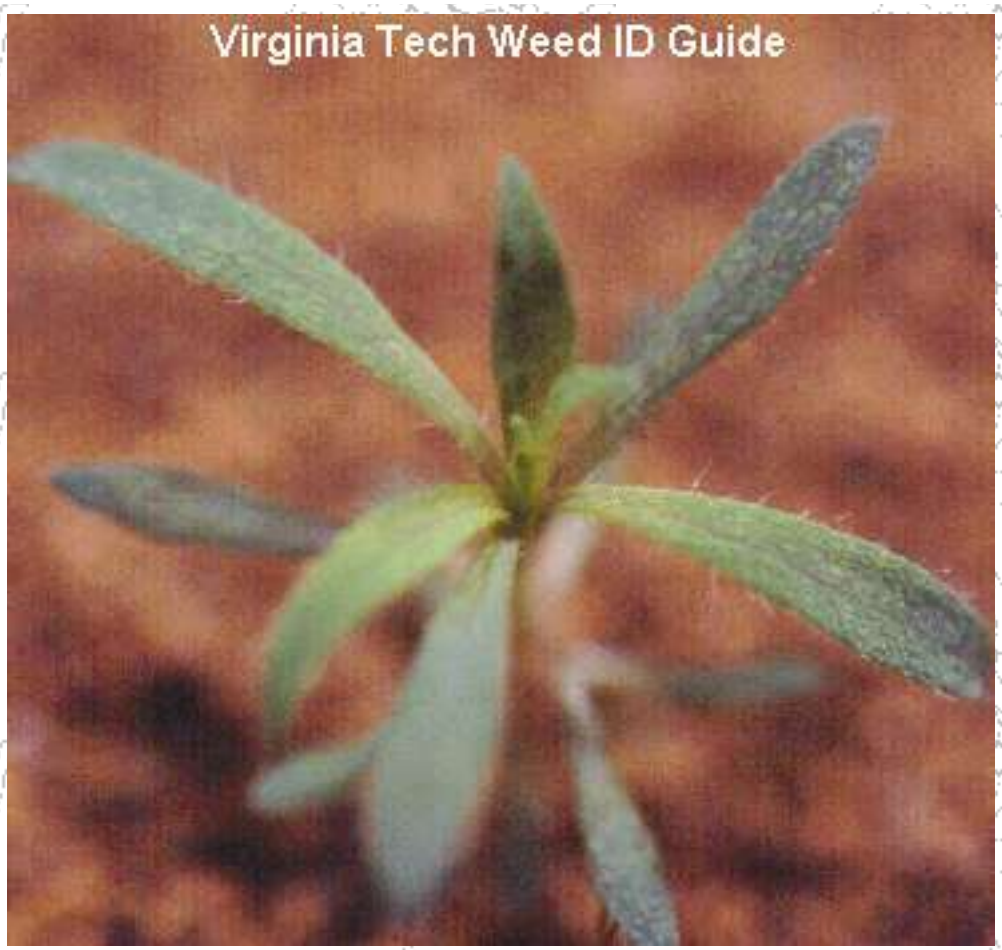


Weed Description: **An erect, much-branched summer annual weed of agronomic crops, pastures, and roadsides. Kochia does not occur in Virginia, but is continually spreading South from the northern United States where it is a common weed. Kochia is also present in the western and southwestern United States.**

Seedlings:
Cotyledons are very narrow, essentially linear in outline, dull green in color, and covered with hairs. The first true leaves are also very narrow and linear to elliptic in outline. Young leaves are also covered with hairs and especially have hairs along the leaf margins.

Stems: **Erect, ranging from 1 to 4 feet in height. Stems are much branched**

and often have a reddish tint.



Leaves: **Occur alternately along the stem. Leaves are linear to lanceolate in outline, ranging from 1 to2 inches in length, and taper to a point. Leaves do not occur on petioles (sessile) and usually only have hairs along the leaf margins.**

Flowers: **Occur in clusters at the ends of stems (terminal panicles) and also in the position between the leaf bases and stems (leaf axils). Flowers are relatively inconspicuous, green in color, and**

approximately 5 to 10 mm long. Flowers have distinctive hairy bracts beneath which tends to give the flowering stems a 'prickly' appearance.

Roots: **A taproot and fibrous root system.**

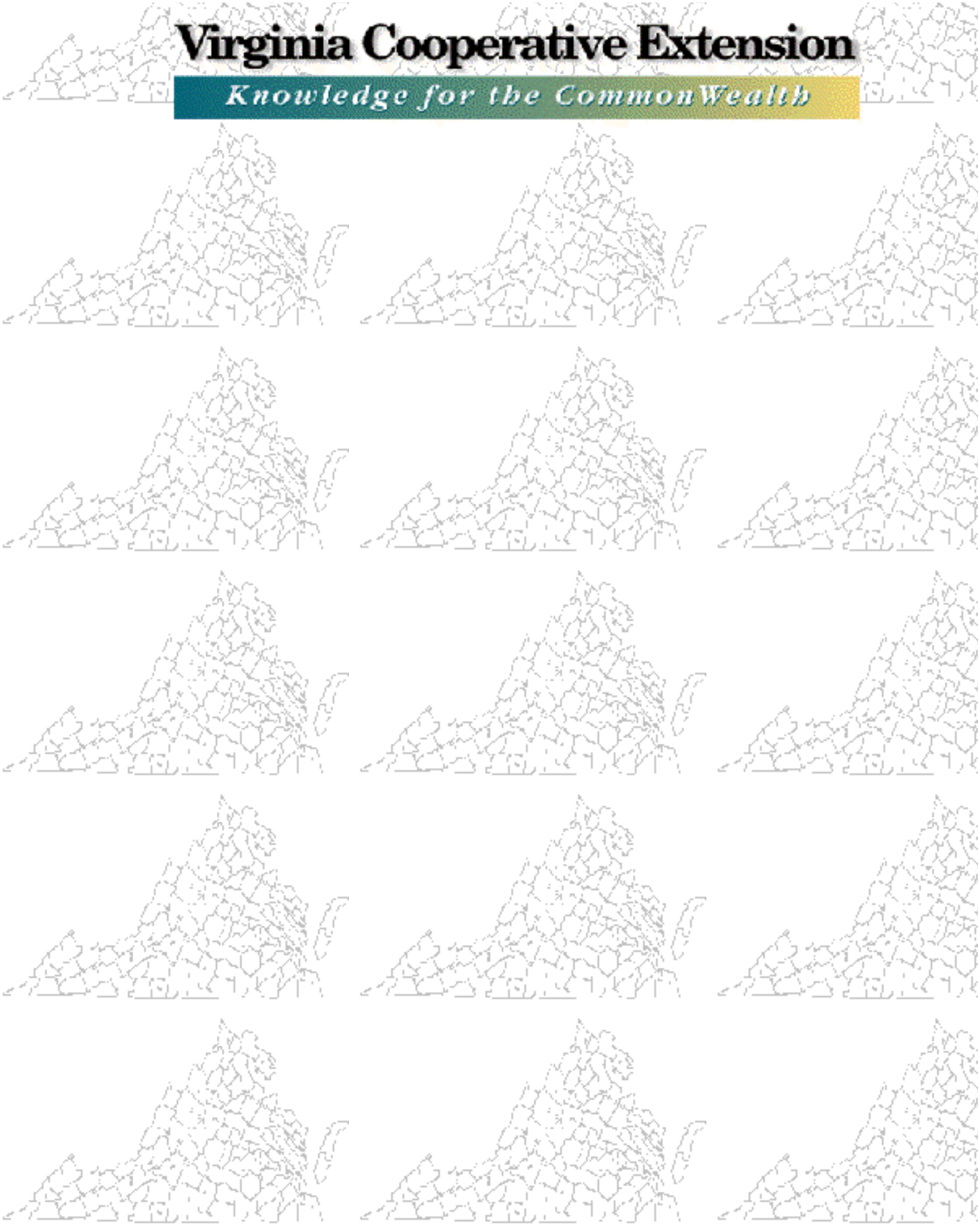
Fruit: **A small bladder known as an utricle.**

Identifying Characteristics:
The highly branched nature of kochia and the hairs that

occur along the leaf margins are characteristics that help to distinguish this weed from most other species. Young kochia seedlings may be confused with Common Lambsquarters (*Chenopodium album*) seedlings but the cotyledons of this weed are hairless.

Common Weed Names: L

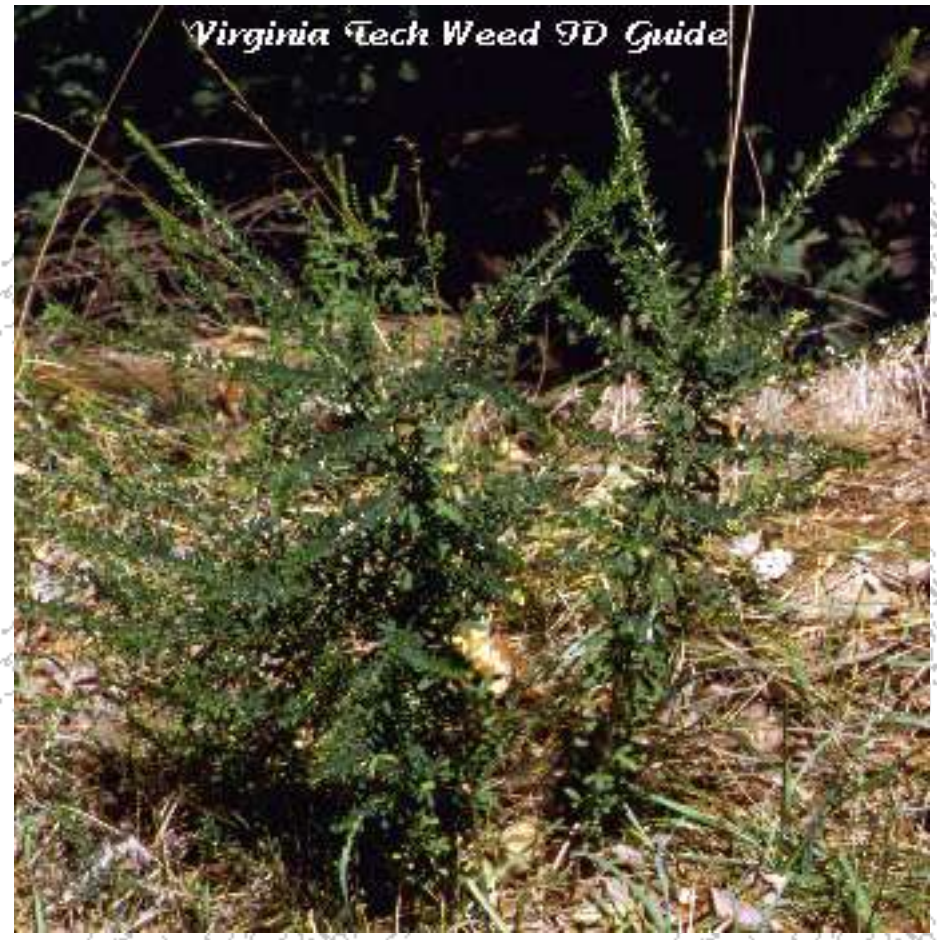
Common Name	Scientific Name
Ladysthumb	*Polygonum persicaria*
Lambsquarters, Common	*Chenopodium album*
Large Crabgrass	*Digitaria sanguinalis*
Lawn Burweed	*Soliva pterosperma*
Leaf-cup, Yellow-flowered	*Smallanthus uvedalia*
Lespedeza, Common	*Lespedeza striata*
Lespedeza, Sericea	*Lespedeza cuneata*
Lettuce, Prickly	*Lactuca serriola*
Little Barley	*Hordeum pusillum*
Lizard's Tail	*Saururus cernuus*
Locust, Black	*Robinia pseudoacacia*
Long-beaked Arrowhead	*Sagittaria australis*
Long Smooth-fruited Poppy	*Papaver dubium*
Longspine Sandbur	*Cenchrus longispinus*
Long-stalked Phyllanthus	*Phyllanthus tenellus*
Loosestrife, Purple	*Lythrum salicaria*
Lovegrass, Purple	*Eragrostis spectabilis*
Lupine, Perennial	*Lupinus perennis*


Virginia Cooperative Extension
Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Sericea Lespedeza: *Lespedeza cuneata*



Weed Description: **A perennial with erect stems that may reach 5 feet in height. Sericea lespedeza is often a weed of pastures, hay fields, roadsides, and abandoned fields. It is found throughout the southeastern United States.**

Leaves: **Leaves are arranged alternately along the stem and are divided into 3 smaller leaflets. Individual leaflets range from 1/2 to 3/4 inches long, and have many short hairs on both surfaces. Leaflets are also oblong to linear in outline, and have a grayish cast.**

Stems: **Become somewhat woody with age and have stiff bristles.**

Flowers: **Emerge from the position between the stem and leaves (leaf axils) in the middle to upper portions of the plant. Flowers occur either singly or in clusters of 2 to 4. Individual flowers are white with violet or purple markings.**

Identifying Characteristics:

The alternately arranged leaves that are divided into 3 smaller leaflets and erect stems with stiff hairs are all characteristics that help in the identification of sericea lespedeza.

Virginia Tech Weed Identification Guide

Select a Resource...

Lizard's Tail: *Saururus cernuus*

Weed Description: **A perennial with rhizomes that primarily occurs along the edges of ponds or in swamps and marshes. Lizard's tail has distinctive heart-shaped leaves and a curved or drooping raceme with many white, inconspicuous flowers.**

Leaves: **Heart-shaped, arranged alternately along the stem, reaching as much as 5 inches in length. The leaves are almost waxy in appearance and dark green in color on the upper surfaces.**

Stems: **Erect, reaching 3 feet in**

height, usually hairy.

Roots: **Rhizomes and a fibrous root system.**

Flowers: **A curved or drooping raceme that ranges from 4 to 8 inches in length and is approximately 1/2 inch in width. These racemes occur on flower stalks (peduncles) that may reach 3 inches in length. Individual flowers within the raceme are inconspicuous and white in color, with no distinctive sepals or petals.**

Fruit: **A capsule.**

Identifying Characteristics:

Emersed, aquatic perennials with rhizomes and drooping racemes that primarily occur in swamps, marshes, or around the edges of ponds. The drooping racemes of lizard's tail may lead to misidentification of this weed as one of the aquatic smartweeds,

such as nodding smartweed (*Polygonum lapathifolium*), however all of the smartweeds have a thin membranous sheath (ocrea) that encircles the stem unlike lizard's tail.

Virginia Tech Weed Identification Guide

Select a Resource...

Longspine Sandbur: *Cenchrus longispinus*

Weed Description: **Annual grass with conspicuous burs along the seedhead that may reach 20 inches in height. Longspine sandbur is primarily found in sandy woods in fields of the coastal plain of the southeastern United States.**

Roots: **A fibrous root system.**

Leaves: **Leaves are rolled in the shoot and are without auricles. Leaf blades may reach 8 inches in length and 6 mm in width and are rough above but without hairs below. The ligule is a fringe of hairs that is approximately 1 mm long.**

Stems: **Sheaths may reach 20 inches in height and are without hairs and somewhat flattened in appearance. Sheath margins are split at least part way up the stem, and have overlapping margins that are virtually transparent (hyaline margins).**

Flowers: **Seedheads consist of many round, spiny burs. Each bur is somewhat hairy and is approximately 5 to 7 mm wide. Each bur contains 2 to 4 spikelets that are 4 to 5 mm long.**

Identifying Characteristics: **An annual grass with a ligule that is a fringe of hairs approximately 1 mm long and a seedhead that consists of several spiny burs. Once the seedheads appear on longspine sandbur, it should be easily identified as a *Cenchrus* spp. However, further investigation may be required as there are several other sandbur species.**

Virginia Tech Weed Identification Guide

Select a Resource...

Long-stalked Phyllanthus: *Phyllanthus tenellus*

Weed Description: **An erect perennial with alternately arranged leaves that consist of two rows of alternately arranged leaflets. Long-stalked phyllanthus is primarily a weed of greenhouses, and container ornamentals, and has only appeared recently in Virginia due to transportation of nursery stock, ornamental flowers, etc. across state lines. It has also been found in some other southeastern states.**

Leaves: **Arranged alternately along the central stem. Leaves are divided into two rows of alternately arranged leaflets. Each leaflet is oval to elliptic in outline with a small projecting tip at the apex, especially on older leaves. Leaflets are without petioles. Leaves are**

without hairs (glabrous).

Stems: Erect, without hairs (glabrous).

Flowers: Small, inconspicuous, white to greenish-white in color, arising from the area between the leaflets and central axis of the leaf. Individual flowers occur on flower stalks

(peduncles) and are star-shaped in outline.

Fruit: **Small capsules that arise from the area between the leaflets and the central axis of the leaf. The capsules are green in color, round, without hairs, and also occur on long stalks that often dangle below the leaves.**

Identifying Characteristics: **The alternately arranged leaves that consist of 2 rows of alternately arranged oval leaflets, erect growth habit, and small inconspicuous star-shaped flowers are all characteristics that help to distinguish long-stalked phyllanthus from most other weeds.**

Virginia Tech Weed Identification Guide

Select a Resource...

Purple Loosestrife: *Lythrum salicaria*

Weed Description: A perennial with large spikes of showy flowers that are pink to purple in color. Purple loosestrife primarily grows in wet areas like roadside ditches, wetlands, marshes, and swamps. It is an invasive weed introduced from Europe that now occurs in the northern and northeastern United States as far south as Virginia. It is also sold commercially as an ornamental.

Seedlings: **Seedlings can occur but plants also arise from crowns and stem segments. Young plants that arise from crowns and stem segments closely resemble the mature plants. Seedlings have small, spatula-shaped cotyledons. The first true leaves are opposite.**

Leaves: **Leaves are arranged oppositely along the stem and lanceolate to linear in outline. Leaves do not have petioles (sessile), often have short hairs, and range from 1 1/4 to 4 inches in length. Some leaves may occur in groups of 3 but are still arranged oppositely along the stem.**

Stems: **Square in cross-section, highly branched, erect, ranging from 3 1/2 to 6 1/2 feet in height. Stems may also have short hairs.**

Roots: **A thick crown from which new plants can arise and a fibrous**

root system. Stem segments that have been cut or knocked down can also root and form new plants.

Flowers: Flowers occur in long (4 to 16 inches long) spikes at the ends of the erect stems. Many individual flowers occur on a single spike. Flowers are pink to purple in color and each have 5 to 7 petals.

Fruit: A capsule that is approximately 1 mm long and contains many seed.

Identifying Characteristics: The habitat in which this plant is most commonly found, the oppositely arranged leaves,

highly branched nature, and the distinctive flower stalks are all characteristics that help to distinguish purple loosestrife from most other species.

Virginia Tech Weed Identification Guide

Select a Resource...

Purple Lovegrass: *Eragrostis spectabilis*

Weed Description: **A perennial grass weed with rhizomes that has a relatively large, open panicle that is purple in color. Purple lovegrass is primarily a weed of pastures, hayfields, and noncrop areas and is found throughout the southeastern United States.**

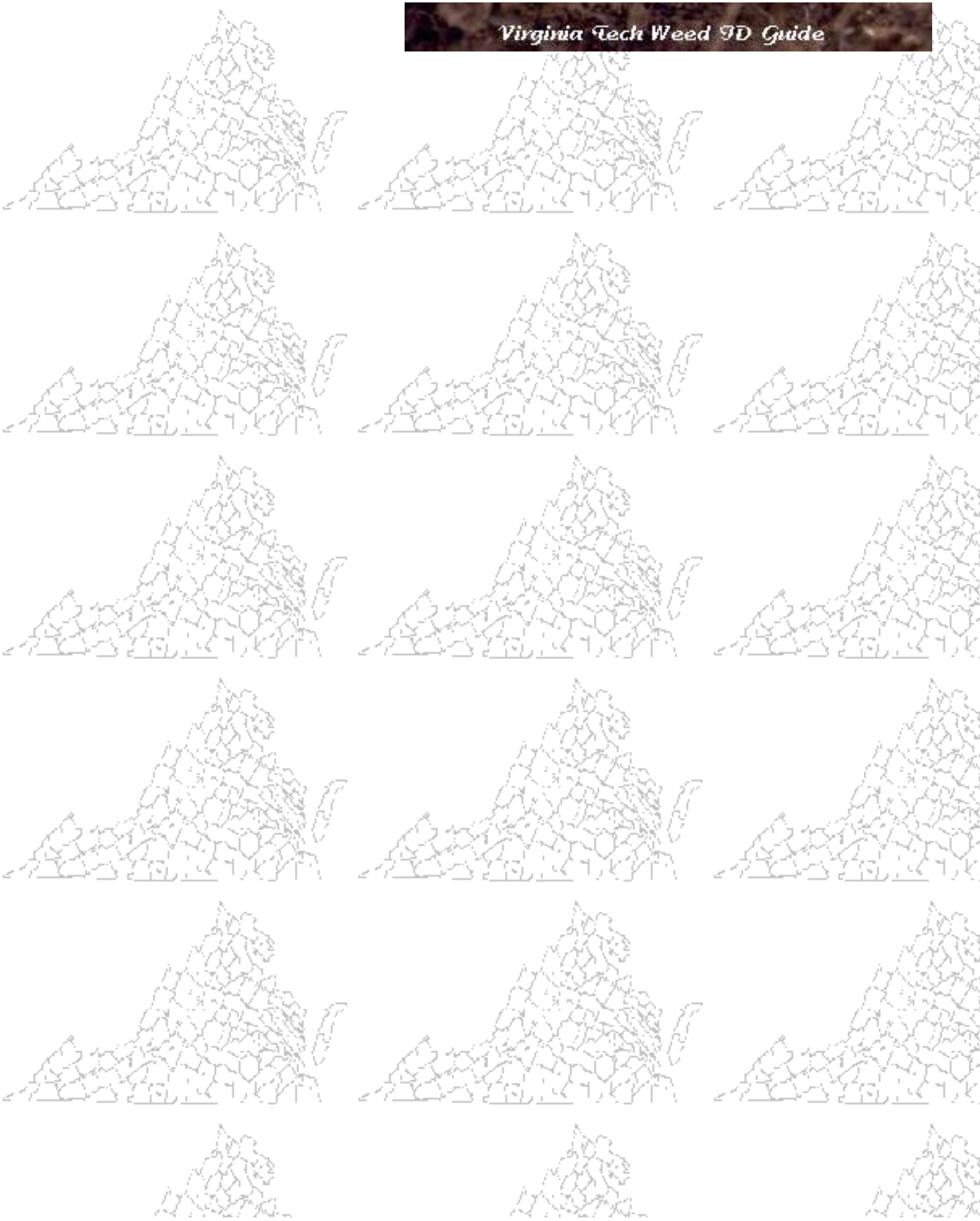
Leaves: **Leaves are rolled in the bud and may reach as much as 16 inches in length and are 2 to 11 mm wide. Both leaf surfaces usually have hairs, especially at the collar regions, but some plants can be found with leaves without hairs (glabrous). Ligules are membranous and are much less than 1 mm long. Auricles are absent.**

Stems: **Leaf sheaths are round and hairy, especially at the collar region.**

Roots: **Rhizomes and a fibrous root system.**

Flowers: **Seedhead an open panicle that may be as much as two-thirds the entire height of the plant. The panicles have a bright purple tint due to the individual purple spikelets that are approximately 1 to 6 mm long and 1 1/2 mm wide.**

Identifying Characteristics:
The distinctive purple panicle, low-growing habit, rhizomes, and leaves that have long hairs especially near the collar region are all characteristics that help to distinguish purple lovegrass from most other grass weeds.



Virginia Tech Weed Identification Guide

Select a Resource...

Perennial Lupine: *Lupinus perennis*

Weed Description: **A perennial herb with distinctively divided leaves and attractive flowers that may reach 2 feet in height. Perennial lupine and many other *Lupinus* species are usually very poisonous to livestock. This plant is usually found in the woods or along the edges of woods.**

Leaves: **Leaves are divided into 7 to 11 leaflets that arise from a central point (palmately divided). Individual leaflets may reach 2 inches in length and 12 mm wide.**

Flowers: **A long (8 inch) raceme with many blue or bluish-white flowers.**

Fruit: **A legume, 2 inches long by 10 mm wide.**

Identifying Characteristics: **The palmately divided leaves of this plant make it easy to distinguish from most other plants found in similar locations.**

Common Weed Names: M

Common Name	Scientific Name
Madder, Field	*Sherardia arvensis*
Mallow, Common	*Malva neglecta*
Mallow, Venice	*Hibiscus trionum*
Mandrake	*Podophyllum peltatum*
Marijuana	*Cannabis sativa*
Marsh Dayflower	*Murdannia keisak*
Marsh Pennywort	*Hydrocotyle umbellata*
Mary's Grass	*Microstegium vimineum*
Mayapple	*Podophyllum peltatum*
Maypop Passionflower	*Passiflora incarnata*
Mayweed Chamomile	*Anthemis cotula*
Mazus, White Flowered	*Mazus japonicus*
Mouseear Hawkweed	*Hieracium pilosella*
Microstegium	*Microstegium vimineum*
Milkweed, Butterfly	*Asclepias tuberosa*
Milkweed, Common	*Asclepias syriaca*
Milkweed, Honeyvine	*Ampelamus albidus*
Milkweed, Swamp	*Aslepias incarnata*
Millet, Browntop	*Brachiaria ramosa*
Millet, Wild-Proso	*Panicum miliaceum*
Mimosa	*Albizia julibrissin*

Mint, Perilla	*Perilla frutescens*
Morningglory, Bigroot	*Ipomoea pandurata*
Morningglory, Cotton	*Ipomoea cordatotriloba**
Morningglory, Cypressvine	*Ipomoea quamoclit*
Morningglory, Entireleaf	*Ipomoea hederacea* **
Morningglory, Ivyleaf	*Ipomoea hederacea*
Morningglory, Palmleaf	*Ipomoea wrightii*
Morningglory, Pitted	*Ipomoea lacunosa*
Morningglory, Red	*Ipomoea coccinea*
Morningglory, Smallflower	*Jacquemontia tamnifolia*
Morningglory, Tall	*Ipomoea purpurea*
Moss Pink	*Phlox subulata*
Mouse-ear Chickweed	*Cerastium vulgatum*
Mouse-ear Cress	*Arabidopsis thaliana*
Mouseear Hawkweed	*Hieracium pilosella*
Mugwort	*Artemisia vulgaris*
Mullein, Common	*Verbascum thapsus*
Mullein, Moth	*Verbascum blattaria*
Multiflora Rose	*Rosa multiflora*
Musk-grass	*Chara* spp.
Musk Thistle	*Carduus nutans*
Mustard, Garlic	*Allaria petiolata*
Mustard, Hedge	*Sisymbrium officinale*
Mustard, Wild	*Brassica kaber*

*** The full scientific name is *Ipomoea cordatotriloba* var. *torreyana***

**** The full scientific name is *Ipomoea hederacea* var. *integriuscula***

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Venice Mallow: *Hibiscus trionum*

Weed Description: **A summer annual with divided leaves and showy yellow and purple flowers. Venice mallow is primarily a weed of agronomic and nursery crops that is found throughout the eastern half of the United States.**

Seedling: **Cotyledons are round and occur on long hairy petioles. First true leaves are alternate and irregularly shaped with a toothed margins. All subsequent leaves are lobed at least 3 times.**

Leaves: **Alternately arranged along the stem and are approximately 3 inches wide and long. Leaves are divided into at least 3 distinct lobes, but may be divided into as many as 7 lobes. All lobes have margins that are toothed. All leaves occur on long petioles and are without hairs (glabrous) on the upper surface and have hairs on the lower surface.**

Stems: **Erect, hairy,**

and branching from the base.

Roots: A shallow taproot and a fibrous root system.

Flowers: Arise from the position between the stem and leaf petioles (leaf axils). Flowers consist of 5 petals that are pale yellow to white in color with a purple base. The 5 sepals resemble a membranous bladder with distinctive dark green veins.

Fruit: A round, hairy capsule that is surrounded by the sepals.

Identifying Characteristics: The lobed leaves, membranous sepals that resemble a bladder, and yellow and purple flowers are all characteristics that help in the identification of Venice mallow.

Mayapple or Mandrake: *Podophyllum peltatum*

Weed Description: **A perennial herb with large, umbrella-like leaves that primarily grows in woods and forests.**

Leaves: **Usually only 1 per erect stem, sometimes 2, approximately 4 to 14 inches in diameter. Leaves are circular in outline and divided into 5 to 9 segments that arise from a central point.**

Roots: **Rhizomes and a fibrous root system.**

Stems: **Erect, unbranching, 8 to 20 inches in height.**

Flowers: **A single white flower occurs on each plant, approximately 3/4 to 2 inches in width with 6 to 9 petals.**

Fruit: **A relatively**

large (1 1/4 to 2 inch long) yellow or red berry that resembles an apple.

Identifying Characteristics: The tendency of this plant to grow only in wooded areas, the large, umbrella-like leaves that are divided into 5 to 9 segments arising from a central point, and the characteristic apple-like berry are all characteristics that help in the identification of mayapple.

Marijuana: *Cannabis sativa*

Weed Description: **Annual weed with distinctive leaves and odor that may reach 10 feet in height. Found throughout the United States except in the southwest and northern Great Plains.**

Seedling: **Cotyledons egg-shaped, without hairs. First true leaves are opposite and have distinctly serrated margins.**

Leaves: **Lower leaves are opposite, upper ones are alternate. All leaves are divided into 5 to 9 leaflets that each arise from a common point (palmately divided). Individual leaflets have serrated margins and are hairy.**

Stem: **Rough to the touch, hairy, somewhat grooved, and branched. Hairs along the stem exude a sap that contributes to the distinctive smell of this plant.**

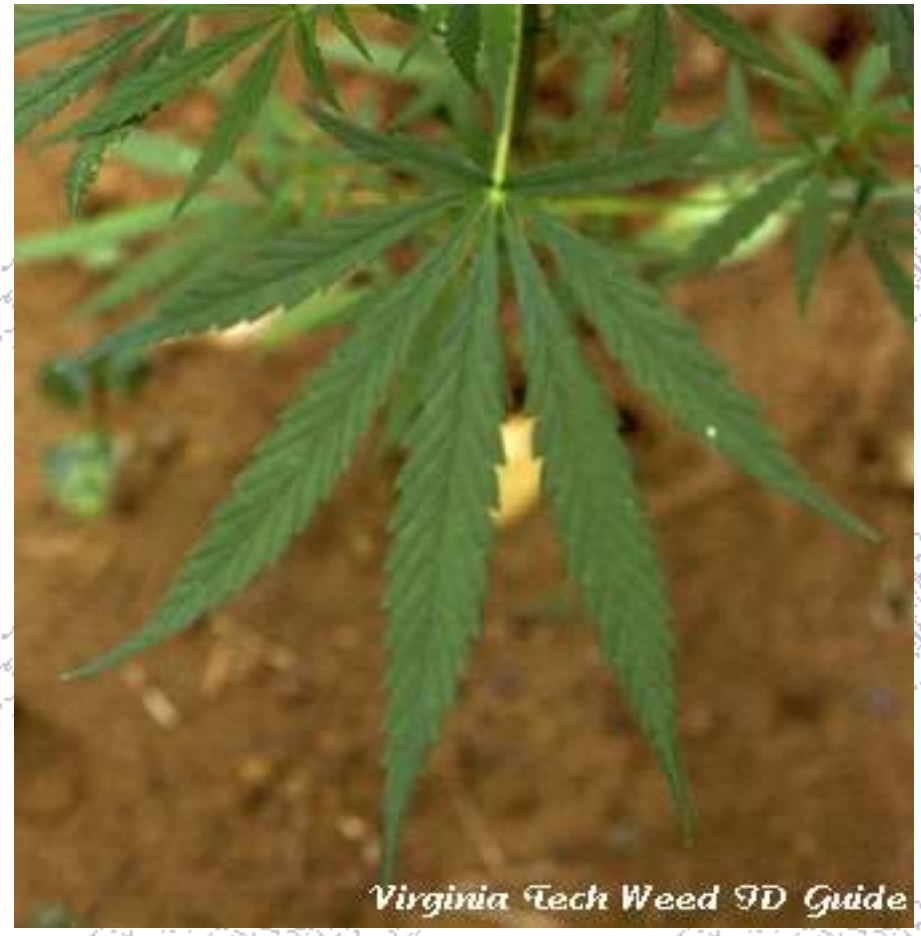
Roots: **Taproot.**

Flowers: **Male and female flowers are produced on separate**

plants (dioecious). Male flowers arise from the position between the stem and the leaf (leaf axils) and are elongated inflorescences in which each stalked flower arises from a central stem (racemes). Female flowers also arise from the leaf axils, but are spikelike clusters.

Fruit: An achene that is approximately 4 mm long, oval in shape, and yellow to brown in color.

Identifying Characteristics: The 5 to 9 distinctive leaflets with serrated margins that arise from a common point and the characteristic smell of marijuana help to distinguish this plant from most other weeds. The leaflets of some of the cinquefoils like Sulfur Cinquefoil (*Potentilla recta*) closely resemble



those of marijuana, however the individual leaflets of the cinquefoils are much shorter than those of marijuana, and these plants also have a prostrate growth habit unlike that of marijuana.

Virginia Tech Weed Identification Guide

Select a Resource...

Marsh Pennywort: *Hydrocotyle umbellata*

Weed Description: **A perennial aquatic weed that spreads out horizontally forming dense mats in shallow water, mud, or in marshes.**

Stems: **Stems are capable of rooting at the nodes but also may be floating. Stems are approximately 1/4 inch in diameter.**

Leaves: Alternately arranged, round in outline, smooth, and often shiny. Leaf margins have rounded teeth and each leaf occurs on a petiole that may reach 6 inches in length. Leaf blades may reach 2 inches in width and are bright green in color and have veins that originate from the central point of the leaf.

Flowers: Occur in clusters that form an umbrella-like head. Individual flowers are very small and consist of 5 white petals but many flowers occur together in a single cluster.

Identifying Characteristics: Aquatic perennial with round leaves that have 'scalloped' margins. Additionally, the umbrella-like heads of small white flowers helps to distinguish this plant from most others. Marsh pennywort is very

similar to water pennywort (*Hydrocotyle ranunculoides*), however water pennywort has a distinctive red spot in the center of the leaves unlike marsh pennywort.

Virginia Tech Weed Identification Guide

Select a Resource...

Maypop Passionflower: *Passiflora incarnata*

Weed Description: **A herbaceous perennial vine with distinctive 3-lobed leaves and attractive flowers that my reach 6 1/2 feet or more in length. Maypop passionflower is primarily found along the edges of woods and fields, but is becoming more noticeable in many of Virginia's agronomic crops, especially where conservation tillage is practiced. Maypop passionflower is found from southern Oklahoma east to Virginia, south to Florida and west to central Texas.**

Seedlings: **Cotyledons are oval, thick, and have a waxy appearance. The first true leaf is heart-shaped and also glossy. Subsequent leaves have lobes (usually 3) arising from a common**

point (palmately lobed leaves). Seedlings can occur but sprouts from the perennial rootstocks are much more common.

Roots: **Roots initially develop as a taproot but eventually develop a very deep perennial rootstock from which sprouts can emerge.**

Leaves: **Arranged alternately along the stem, usually only slightly hairy. Individual leaves are divided into 3 (only sometimes 5) lobes that arise from a common point (palmately lobed). Leaves are approximately 2 1/2 to 5 1/2 inches long and wide and occur on petioles. A pair of nectar-filled glands occurs at the base of the leaf blade and the junction of the petiole.**

Stems: **Stems can trail along the ground or climb on other vegetation. Stems or usually only slightly hairy and may reach 6**

1/2 feet in length.

Flowers:
Solitary flowers arise from the area between stem and leaf petioles. Flowers range from 2 to 4 inches in length and are very attractive and light purple to lavender in color.

Fruit: A relatively large (1 1/2 - 3 inches long) berry that is green or yellowish-green in color. Stepping on these berries when mature often causes a loud 'popping' sound, thus the name of this plant. Berries contain many dark brown 'dimpled' seed (reticulate seed).

Identifying Characteristics: The 3-lobed leaves, vining habit, deep rootstock, and attractive flower are all characteristics that help to distinguish maypop passionflower from other weeds.

Virginia Tech Weed Identification Guide

Select a Resource...

Swamp Milkweed: *Asclepias incarnata*

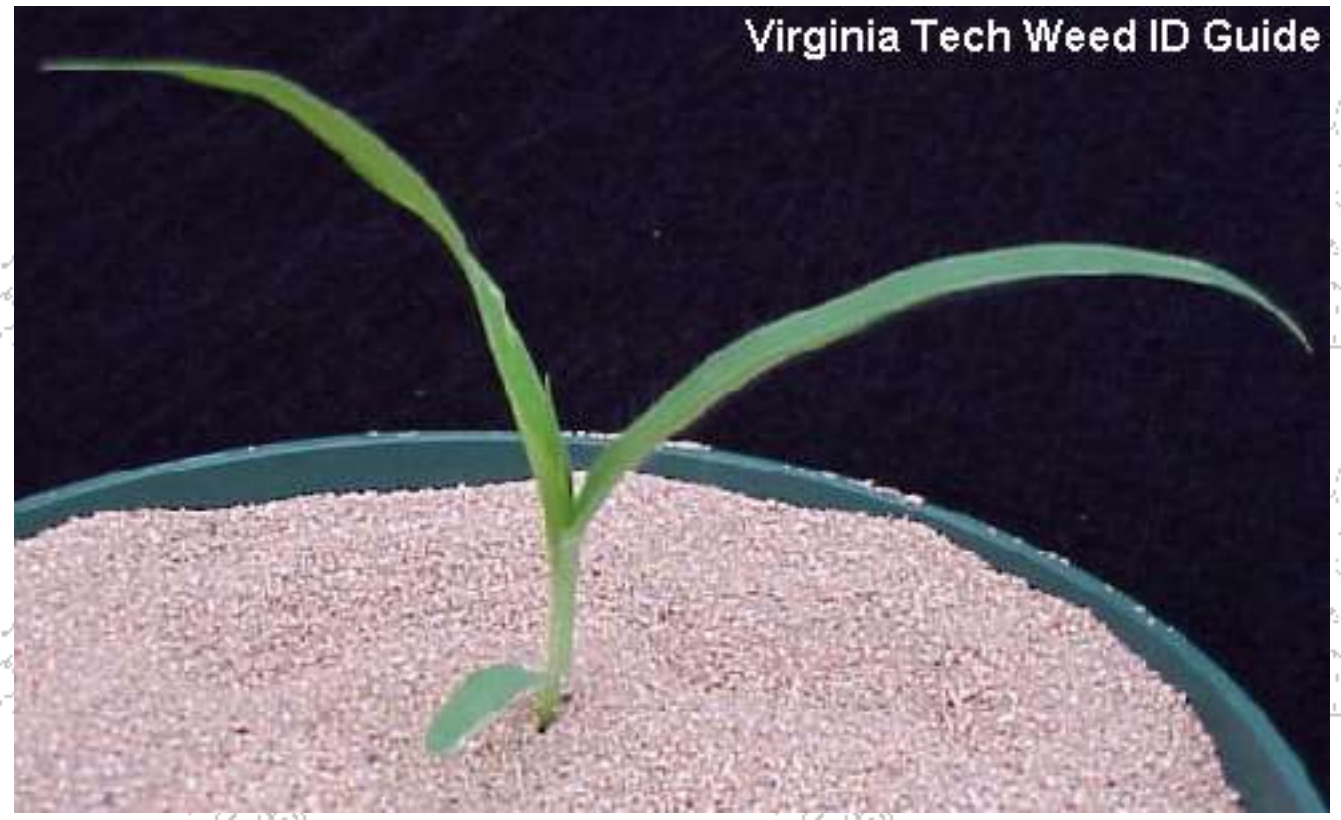

Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Wild-proso Millet: *Panicum miliaceum*




Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Red Morningglory: *Ipomoea coccinea*

Weed Description: **A twining and climbing annual vine with leaves that have several points along the basal margins. Red morningglory is a weed of agronomic crops, nurseries, landscapes, pastures, hayfields, and noncrop areas. Red morningglory is found from southern California east to Texas and north to Michigan.**

Seedling: **Stems below the cotyledons (hypocotyls) are often tinted maroon and are without hairs. Cotyledons are only somewhat indented or lobed, have rounded points, and are often tinted maroon, especially around the margin.**

Leaves: **Occur on petioles, arranged alternately along the stem, and are heart-shaped in outline. Leaves often have several points along the margins which helps to distinguish this weed from most other morningglories.**

Stems: **Trailing, twining, or climbing and may reach 6 1/2 feet in length.**

Flowers: **Dark orange to red in color, approximately 1 to 1 1/4 inches long.**

Fruit: **A round capsule.**

Identifying Characteristics: The red flowers and leaves with points along the margins are both characteristics that help to distinguish this weed from most other similar morningglories. When in the cotyledon stage, red morningglory may be confused with Ivyleaf Morningglory (*Ipomoea hederacea*) or Entireleaf Morningglory (*Ipomoea hederacea* var. *integriuscula*), however neither of these weeds should have a purplish tint along the margins, and the cotyledons of these weeds are generally more indented than those of red morningglory.

Virginia Tech Weed Identification Guide

Select a Resource...

Smallflower Morningglory: *Jacquemontia tamnifolia*

Weed Description: **A trailing or climbing summer annual with light blue flowers that may reach 6 1/2 feet in length. Smallflower morningglory is an isolated weed of agronomic crops, nurseries, and landscapes in the southeastern United States.**

Seedling: **Cotyledons are rounded with slight indentations and resemble those of a mustard. Cotyledons are without hairs.**

Roots: **Taproot.**

Leaves: **Occur on petioles that are alternately arranged along the stem. Leaves are approximately 1 1/4 to 4 1/2 inches long by 3/4 to 3 inches**

wide. Hairs occur on the margins and only occasionally on the leaf surfaces. Leaves are ovate to elliptic in outline.

Flowers: **Many light blue flowers occur in clusters with many bracts below. Individual flowers are approximately 1/2 to 3/4 inch in width.**

Fruit: **A capsule.**

Identifying Characteristics:
A trailing or climbing vine with ovate to elliptic leaves and many light blue flowers. These characteristics help to distinguish smallflower morningglory from most other weeds as well as other morningglories.

Virginia Tech Weed Identification Guide

Select a Resource...

Mugwort: *Artemisia vulgaris*

Weed Description: **Perennial weed with persistent rhizomes that may be spread or transported by cultivation equipment, or also in burlaped nursery stock infested with rhizomes. Found throughout the eastern United States.**

Seedling: **Viable seed are rarely produced in North America. Cotyledons egg-shaped, without petioles.**

Stems: **May reach 5 ft in height, often reddish-brown in color, and become woody with age.**

Leaves: Leaves are 2-4 inches long, 1-3 inches wide, simple, alternate, deeply lobed, and have a distinctive aroma. Leaves on the upper portions of the plant are more deeply lobed and may lack petioles. Leaf undersides are covered with soft, white to gray hairs, while upper leaf surfaces may be smooth to slightly hairy.

Flowers: Inconspicuous and occur in clusters at the top of the plants. Individual heads are 2.5-3 mm wide and on short stalks.

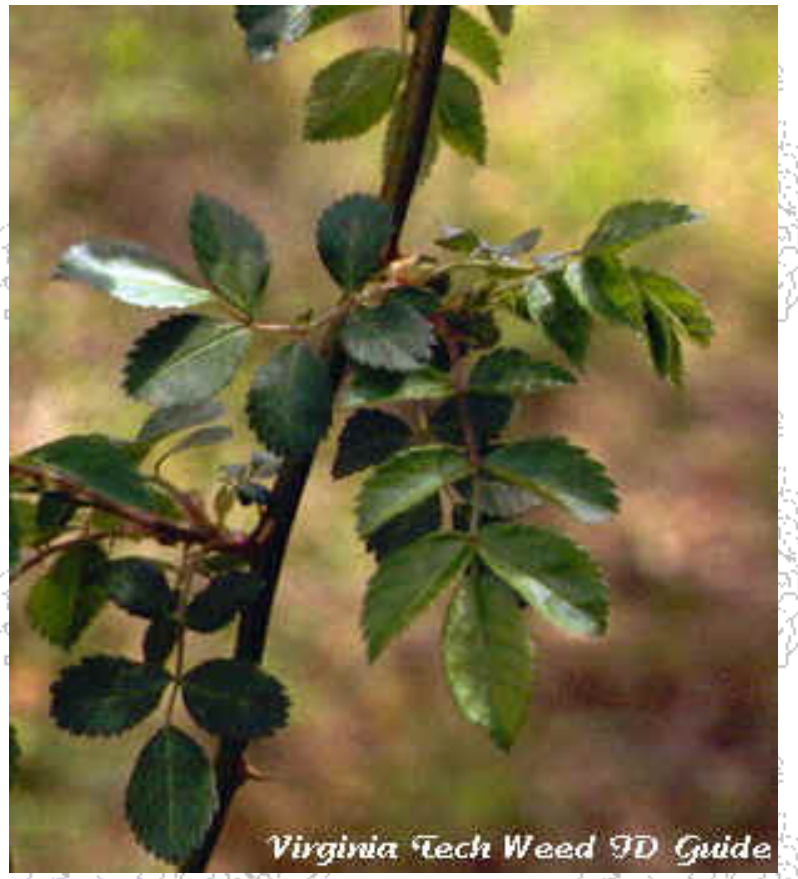
Fruit: An achene that encloses the seed. However, viable seeds are rarely produced in North America.

Roots: Rhizomes.

Identifying Characteristics: Mugwort is similar in appearance to the garden chrysanthemum commonly grown in flowerbeds and landscapes. Common Ragweed (*Ambrosia artemisiifolia*) seedlings are similar to mugwort, but have more deeply dissected leaves and lack the distinctive aroma typical of mugwort.

Mugwort

Multiflora Rose: *Rosa multiflora*



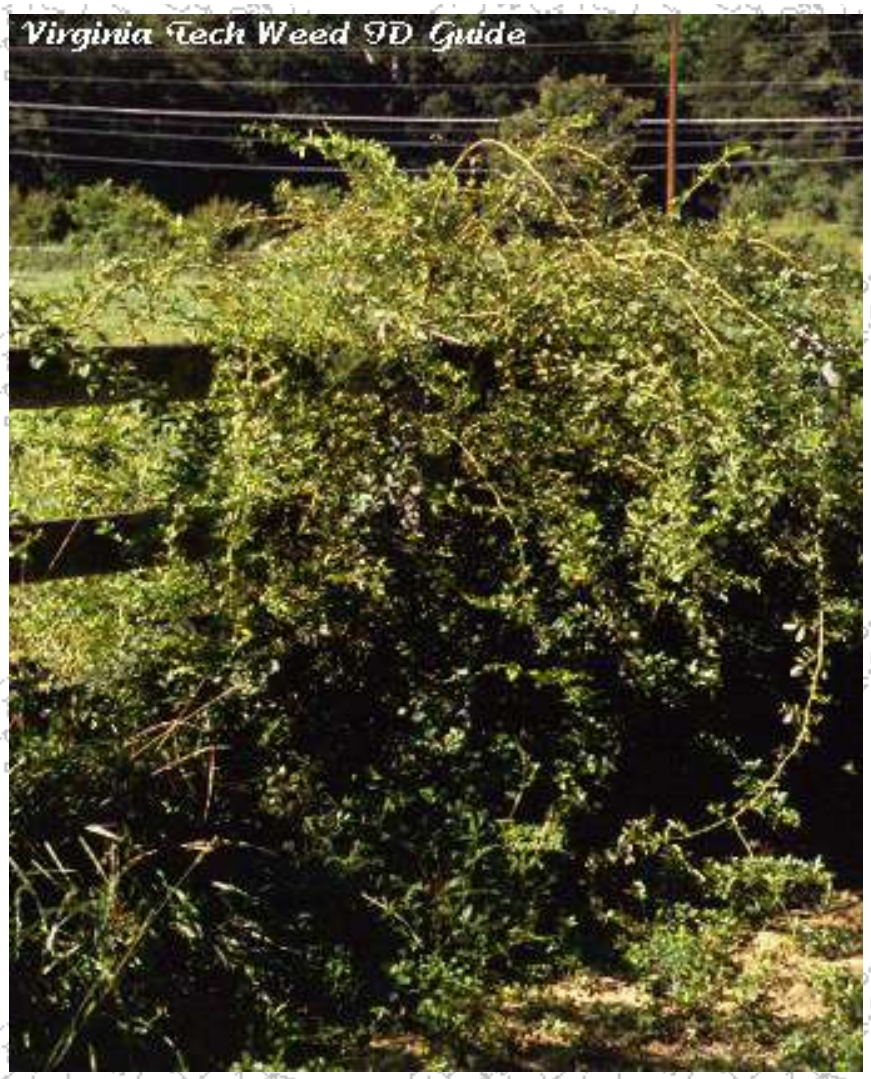
Weed Description: **An invasive bush that can form large thickets, especially along fencerows or in pastures and hay fields. Multiflora rose was introduced from eastern Asia in the 1800's as an ornamental shrub, and was later promoted for planting as a wildlife food and 'living fence' for cattle in the United States. Today, multiflora rose occurs throughout the United States and is especially troublesome in pastures, hay fields, and fencerows in the western half of Virginia.**

Leaves: **Petioled, arranged alternately along the stem, divided into 7 to 9 leaflets. Individual leaflets are without hairs (glabrous) above, usually hairy below. Leaflets are elliptic in outline, from 1/2 to 2 1/2 inches long and 1/4 to 1 1/4 inches wide. Leaflet margins are coarsely toothed or serrated. A distinctive fringe of stipules occurs at the base of the leaf**

petiole, which resemble many stiff hairs fused together.

Stems: **Erect, without hairs (glabrous), usually arching over other vegetation or objects. Stems may range from 3 to 10 feet in height and have many curved thorns throughout.**

Roots: **A fibrous root system and stems that are capable of producing roots and new plants when they come into contact with the ground.**



Flowers: **White in color, approximately 1 inch in diameter, usually with 5 petals. Multiflora rose typically blooms in June in Virginia.**

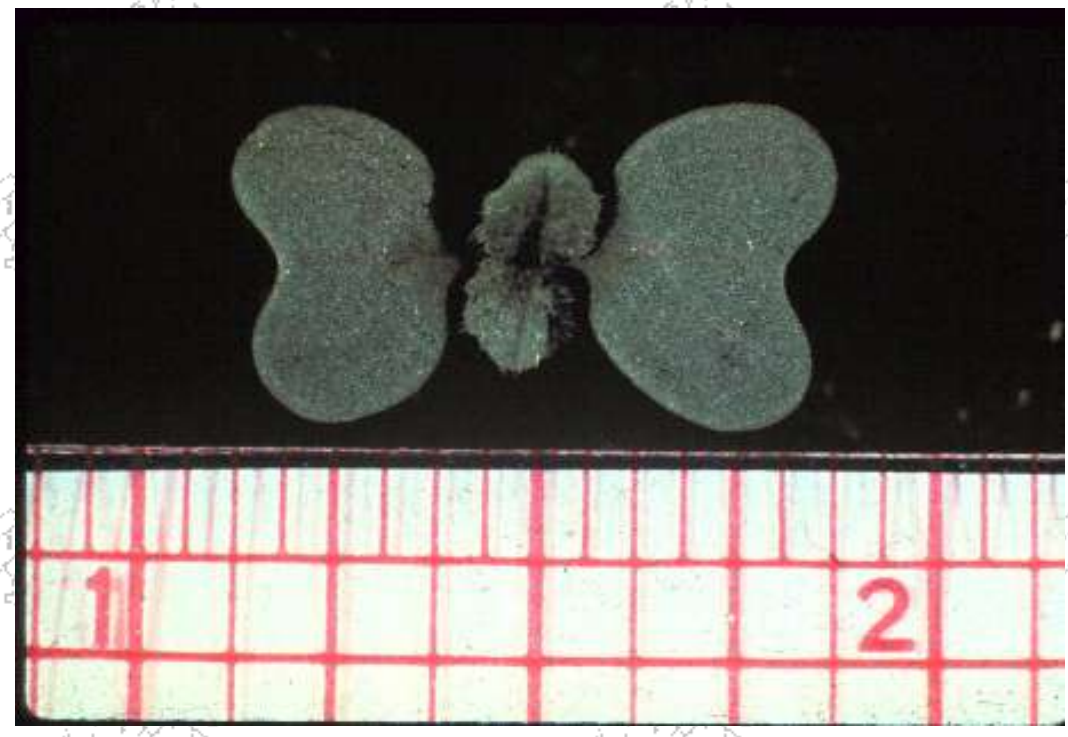
Fruit: **An achene that is red and densely covered with hairs.**

Identifying Characteristics:
The fringe of stipules at the leaf petiole bases and the erect, shrubby nature of this plant help to distinguish it from most other species. While multiflora rose is similar to many other *Rosa* species, it can easily be distinguished by the distinctive stipules that occur at the base of the leaf petiole.

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Mustard: *Brassica kaber*



Weed Description: **Most often a winter annual but sometimes a summer annual with characteristic yellow mustard flowers. This weed can be found throughout the United States primarily in nurseries and winter small grains.**

Seedling: **Cotyledons kidney- to heart shaped, approximately 5 mm long and 8 mm wide and have indentations at the apex. First true leaves are alternate, hairy, elliptic in outline and have wavy margins.**

Roots: **Taproot in combination with a fibrous root system.**

Leaves: **Alternate, egg-shaped to ovate in outline, approximately 2 to 8 inches long and 1 1/2 to 4 cm wide. Lower leaves occur as a rosette, are petiolated, and unevenly lobed with toothed margins. Upper leaves become progressively smaller up the stem, are not lobed, and either clasp the stem or have short petioles.**

Stems: **Erect, branched towards the top of the plant and usually have hairs at least at the base of the plant but hairs can also be absent.**

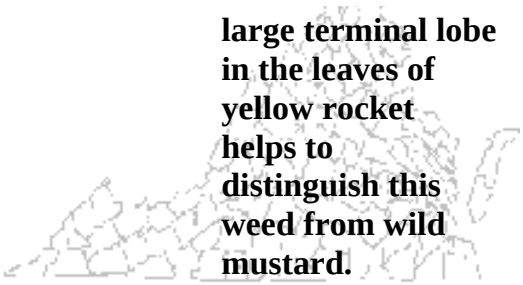
Flowers: **Produced in clusters at the ends of branches. Individual flowers consist of 4 yellow petals and are approximately 3/4 inch wide.**

Fruit: **A silique that is approximately 1 to 2 inches long and 2 to 3 mm wide. Siliques occur on flower stalks that are approximately 5 to 7 mm long and are rounded in**

cross-section but have a 4-angled flattened beak at the tip that is a little less than half as long as the pod.

Identifying Characteristics:
Generally a plant with a winter growth habit that has typical yellow mustard flowers and irregularly lobed leaves with wavy margins toward the base of the plant and much smaller, unlobed leaves at the top of the plant. At maturity the flowers of several mustard species, including Yellow Rocket (*Barbarea vulgaris*) and Wild Radish (*Raphanus raphanistrum*), resemble those of wild mustard. However, wild radish has leaves that are covered with stiff hairs unlike either wild mustard or yellow rocket. Additionally, the

large terminal lobe in the leaves of yellow rocket helps to distinguish this weed from wild mustard.





















Virginia Tech Weed Identification Guide

Select a Resource...

Yellow Rocket: *Barbarea vulgaris*

Weed Description: **A winter annual or biennial with shiny green foliage and bright yellow flowers that may reach as much as 3 feet in height. Primarily a weed of turfgrass, winter small grains, and pastures. Found primarily throughout the eastern and central United States, but also occurs to a lesser extent in the western states.**

Seedling: **Cotyledons are egg-shaped on long stalks and slightly notched at the tip. First true leaves are rounded, usually with wavy margins that become toothed with maturity. All subsequent leaves are alternate, however biennial plants take the form of a basal rosette during the first year of growth.**

Roots: **Taproot with a fibrous root system.**

Leaves: Dark green in color and shiny. Basal leaves are approximately 2 to 8 inches long and lobed with one large terminal lobe and 1 to 4 oppositely arranged lateral lobes. Terminal lobes have a heart-shaped base. Leaves become smaller and less lobed toward the top of the plant. All leaves are alternate and have margins that are wavy and toothed.

Stems: Biennial plants produce flowering stems during the second year of growth. Stems are erect, smooth, ridged, and branched at the top.

Flowers: Produced in elongated clusters at the ends of branches. Individual flowers are bright yellow in color and consist of 4 yellow petals.

Fruit: The fruit is a silique that is approximately 1.5 mm wide and 1 inch long. Siliques have 'beaks' at the tip and are squarish in cross-section. Each silique occurs on a stalk (pedicel) that is from 3 to 6 mm long.

Identifying Characteristics: Plants with bright yellow flowers and shiny green leaves with several smaller lobes and one large terminal lobe. At maturity the flowers of several mustard species, including Wild Mustard (*Brassica kaber*) and Wild Radish (*Raphanus raphanistrum*), resemble those of yellow rocket. However, wild radish has leaves that are covered with stiff hairs unlike either wild mustard or yellow rocket. Additionally, the large terminal lobe in the leaves of yellow rocket helps to distinguish this weed from wild mustard.

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Radish: *Raphanus raphanistrum*

Weed Description: **Usually a winter annual but occasionally a summer annual or even biennial weed of small grains, forages, nurseries, and horticultural crops. Wild radish is found throughout the United States.**

Seedlings: **Cotyledons or heart-shaped and occur on petioles. The first true leaves are hairy, lobed, and have toothed margins.**

Leaves: **Leaves initially develop as a basal rosette of highly lobed leaves. Basal leaves are elliptic in outline, approximately 8 inches long by 2 inches wide, and occur on petioles. Stem leaves are alternate, lanceolate in outline, without petioles, and with toothed margins. All leaves are covered with stiff hairs.**

Flowers: **Flowers occur in racemes at the ends of stems. Individual flowers are approximately 1/2 to 3/4 inch in diameter and consist of 4 light yellow petals. Flowers occur on flower stalks (pedicels) that range from 5 to 20 mm in length.**

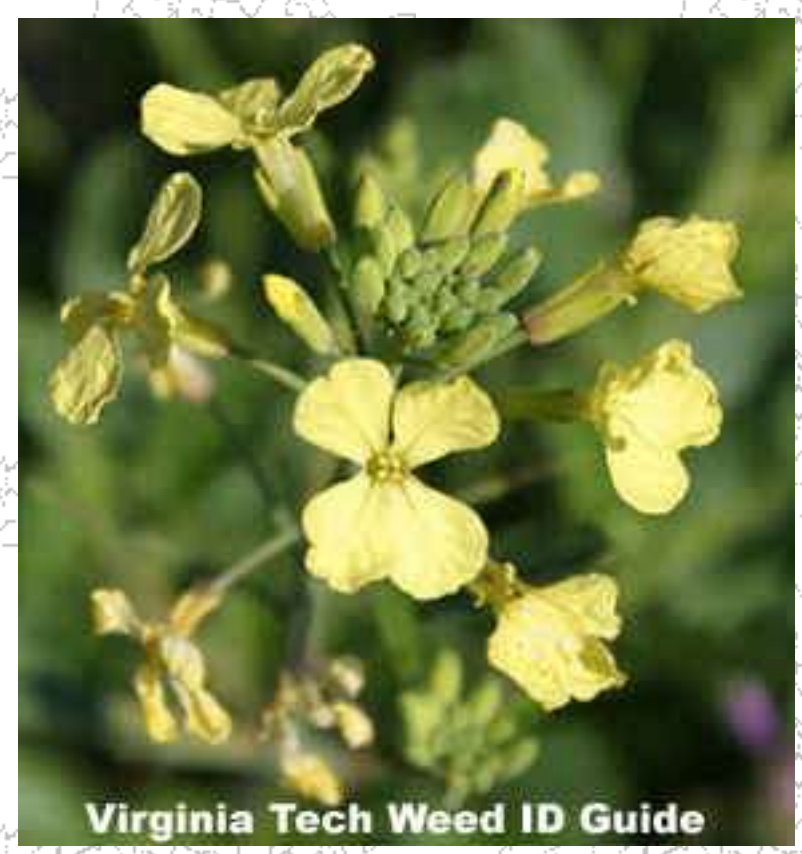
Roots: **A taproot somewhat like that of a radish with a distinctive radish odor and taste**

Stems: **Stems are erect, branching, ranging from 12 to 32 inches in height. Stems are covered with hairs.**

Fruit: **A segmented pod (silique) that is long (3/4 to 1 1/2 inch) and narrow with a distinctive 'beak' tip. At maturity, the fruit typically break into fragments rather than opening straight down the middle as in wild mustard.**

Identifying Characteristics:

Plants that are usually winter annuals with highly lobed leaves in a basal rosette and on the erect flowering stem. Wild Mustard (*Brassica kaber*) and Yellow Rocket (*Barbarea vulgaris*) are similar in both appearance and growth habit, however neither of these weeds are covered with stiff hairs as is wild radish. The leaves of wild radish are also more divided than either wild mustard or yellow rocket. The fruit of mild mustard also open straight down the middle to expose the seed while those of wild radish usually break into fragments.



Common Weed Names: N

Common Name	Scientific Name
Naiad, Brittleleaf	*Najas minor*
Nettle, Stinging	*Urtica dioica*
New York Ironweed	*Vernonia noveboracensis*
Nightshade, Bittersweet	*Solanum dulcamara*
Nightshade, Black	*Solanum nigrum*
Nightshade, Eastern Black	*Solanum ptycanthum*
Nightshade, Silverleaf	*Solanum eleagnifolium*
Nimblewill	*Muhlenbergia schreberi*
Nutsedge, Purple	*Cyperus rotundus*
Nutsedge, Yellow	*Cyperus esculentus*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Stinging Nettle: *Urtica dioica*

Weed Description: **A perennial weed that is perhaps most notably known for the skin irritation that this weed causes when contacted. The hairs and spines on the leaves and stems of this weed release formic acid when touched, which gives a burning or stinging sensation to humans. Stinging nettle is primarily a weed of landscapes, orchards, pastures, and roadsides. This weed reproduces by seed and rhizomes, which are underground stems that are capable or generating new plants. Stinging nettle is found throughout most of the United States.**

Leaves: **Arranged oppositely along the stem, occurring on petioles. Leaves are egg-shaped to lanceolate in outline with serrated or toothed leaf margins. Mature leaves are mostly without hairs, except for the long hairs capable of 'stinging' humans that occur on the lower leaf surface. Younger leaves usually have both short hairs and the longer 'stinging' hairs on the upper leaf surfaces. Long, pointed stipules occur in the area between the stems and leaf petioles.**

Stems: **Erect, reaching 6 1/2 feet in height, usually unbranched. Stems are angled and have long, 'stinging' hairs.**

Roots: **Rhizomes.**

Flowers: **Relatively inconspicuous and green to yellowish in color. Flowers**

occur in clusters that arise from the area between the stem and leaf petioles (leaf axils).

Fruit: An achene.

Identifying Characteristics: A perennial with rhizomes, lanceolate leaves with toothed margins, erect usually unbranched stems, and fairly long 'stinging' hairs. These characteristics help to distinguish it from most other weed species.

Virginia Tech Weed Identification Guide

Select a Resource...

Silverleaf Nightshade: *Solanum eleagnifolium*

Weed Description: **A perennial from rhizomes with distinctive silver or grayish leaves and purple to blue flowers. Silverleaf nightshade is primarily a weed of agronomic crops, pastures, hay fields, and roadsides that is distributed throughout the southeastern United States.**

Seedlings: **Cotyledons are linear and covered with hairs. Stems below the cotyledons (hypocotyls) are covered with hairs and often purple-tinged.**

Leaves:
Arranged alternately along the stem, linear to oblong in outline, ranging from 2 to 6 inches in length. Leaves are covered with star-shaped hairs and have a silver to grayish cast.

Stems:
Stems may reach as

much as 3 1/3 feet in height. Stems are branching and usually have spines. Stems also have a silver to grayish cast and are covered with star-shaped hairs.

Roots: Fibrous roots with rhizomes.

Flowers: Consist of purple to blue petals and a yellow center (anthers) that collectively resemble a star. Flowers occur in clusters at the ends of stems.

Fruit: A round berry, approximately 1/2 to 3/4 inch in diameter. Berries are green when immature and turn yellow to brown with maturity.

Identifying Characteristics: The grayish or silvery cast that is typical of the leaves and stems of silverleaf nightshade helps to distinguish this weed from most others.

Common Weed Names: O

Common Name	Scientific Name
Oatgrass, Bulbous Tall	*Arrhenatherum elatius* var. *bulbosa*
Olive, Autumn	*Elaeagnus umbellata*
Oxeye Daisy	*Chrysanthemum leucanthemum*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Common Weed Names: P

Common Name	Scientific Name
Paleseed Plantain	*Plantago virginica*
Palmer Amaranth	*Amaranthus palmeri*
Palmleaf Morningglory	*Ipomoea wrightii*
Panicum, Fall	*Panicum dichotomiflorum*
Pansy, Wild	*Viola arvensis*
Parsnip, Wild	*Pastinaca sativa*
Partridgepea	*Cassia fasciculata*
Passionflower, Maypop	*Passiflora incarnata*
Pear, Prickly	*Opuntia humifusa*
Pea, Sweet	*Lathyrus latifolius*
Pennsylvania Smartweed	*Polygonum pensylvanicum*
Pennycress, Field	*Thlaspi arvense*
Pennycress, Perfoliate	*Thlaspi perfoliatum*
Pennycress, Thoroughwort	*Thlaspi perfoliatum*
Pennywort, Marsh	*Hydrocotyle umbellata*
Pepperweed, Field	*Lepidium campestre*
Pepperweed, Virginia	*Lepidium virginicum*
Perennial Lupine	*Lupinus perennis*
Perfoliate Pennycress	*Thlaspi perfoliatum*
Perilla Mint	*Perilla frutescens*
Persian Speedwell	*Veronica persica*

Phlox, Creeping	*Phlox subulata*
Phyllanthus, Long-stalked	*Phyllanthus tenellus*
Pickerelweed	*Pontederia cordata*
Pigweed, Prostrate	*Amaranthus blitoides*
Pigweed, Redroot	*Amaranthus retroflexus*
Pigweed, Smooth	*Amaranthus hybridus*
Pigweed, Spiny	*Amaranthus spinosus*
Pineapple-weed	*Matricaria matricarioides*
Pitted Morningglory	*Ipomoea lacunosa*
Plantain, American Water	*Alisma subcordatum*
Plantain, Blackseed	*Plantago rugelii*
Plantain, Broadleaf	*Plantago major*
Plantain, Buckhorn	*Plantago lanceolata*
Plantain, Paleseed	*Plantago virginica*
Plumeless Thistle	*Carduus acanthoides*
Poinsettia, Wild	*Euphorbia dentata*
Poison Hemlock	*Conium maculatum*
Poison Ivy	*Toxicodendron radicans*
Pokeweed, Common	*Phytolacca americana*
Pondweed, Curlyleaf	*Potamogeton crispus*
Pondweed, Slender	*Potamogeton pusillus*
Pondweed, Variable-leaf	*Potamogeton diversifolius*
Poorjoe	*Diodia teres*
Poppy, Field	*Papaver dubium*

Potato Vine	*Dioscorea batatas*
Prickly Lettuce	*Lactuca serriola*
Prickly Pear	*Opuntia humifusa*
Prickly Sida	*Sida spinosa*
Primrose, Creeping	*Ludwigia palustris*
Prostrate Knotweed	*Polygonum aviculare*
Prostrate Amaranth	*Amaranthus blitoides*
Prostrate Pigweed	*Amaranthus blitoides*
Puncturevine	*Tribulus terrestris*
Purple Deadnettle	*Lamium purpureum*
Purple Cudweed	*Gnaphalium purpureum*
Purple Loosestrife	*Lythrum salicaria*
Purple Lovegrass	*Eragrostis spectabilis*
Purple Nutsedge	*Cyperus rotundus*
Purpletop	*Tridens flavus*
Purslane, Common	*Portulaca oleracea*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Wild Parsnip: *Pastinaca sativa*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Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Prickly Pear: *Opuntia humifusa*

Weed Description: **A prostrate perennial cactus that is native to Virginia and most of the United States. Prickly pear has many pads (called cladodes) with tufts of needle-like spines.**

Leaves: **No true leaves are present.**

Roots: **A thick rootstock. Also, pads are able to root and in this manner facilitate the spread of this species.**

Stems: **Each 'pad' (or cladode) is a stem that is succulent, thick, and contains many individual spines. Upon closer examination, you can see that some of the spines (less than 1/2 inch long) actually consists of many very small 'needles' that can very easily stick in skin, clothing, fur, etc. Pads also contain some spines that are approximately 1 inch long that do not divide in this manner. Pads that become detached from the parent plant have the ability to root and form new plants in almost any location.**

Fruit: **A capsule that is cone-shaped and widest at the top, tapering to the base. Individual fruit are approximately 1 to 1 1/2 inches long, fleshy, and turn red to maroon with maturity.**

Flowers: **Bright yellow in color, 2 to 3 inches wide, sometimes with a reddish center.**

Identifying Characteristics: A low-growing cactus with showy yellow flowers and cladodes that have many individual prickles that consist of tufts of needle-like spines. Many prickly pear species occur in the western United States, however *Opuntia humifusa* is the only species that is native to Virginia.

Virginia Tech Weed Identification Guide

Select a Resource...

Pickerelweed: *Pontederia cordata*

Weed Description: **An erect, emerged aquatic perennial with attractive purple flowers. Pickerelweed is a weed of ponds, lakes, ditches, and streams that is found throughout the southeastern United States.**

Roots: **Rhizomes and a fibrous root system.**

Leaves: **Leaves are variable in shape from lanceolate to lanceolate-ovate to triangular. Leaves have heart-shaped bases, are thick, have parallel veins, may reach 120 mm in width and range from 6 to 12 inches long. Leaves occur on long petioles.**

Flowers: **Flowers occur on the upper 2 to 6 inches of erect leafless stems. Individual flowers are blue to purple in color and somewhat hairy.**

Fruit: **An utricle, approximately 1/4 inch long.**

Identifying Characteristics: **The relatively narrow, lanceolate-ovate to triangular leaves and attractive purple flowers on the ends of erect stems helps to distinguish pickerelweed from most other aquatic plants. However, prior to flowering the leaves of pickerelweed may be mistaken for some of the arrowheads like Long-beaked Arrowhead (*Sagittaria australis*), but these weeds have leaves with lobes unlike**

the heart-shaped bases of pickerelweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Smooth pigweed: *Amaranthus hybridus*


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Virginia Tech Weed Identification Guide

Select a Resource...

Plumeless Thistle: *Carduus acanthoides*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Wild Poinsettia or Toothed Spurge: *Euphorbia dentata*

Weed Description: **Erect annual with lanceolate leaves that often have at least one dark red spot. All parts of the plant emit a milky sap when broken. Toothed spurge may reach 2 feet in height and is found from New York west to Arizona. Toothed spurge is primarily a weed of pastures, hayfields, roadsides, and other noncrop areas.**

Stems: **Stems are erect, branching oppositely from the base, and hairy. Broken stems**

emit a milky sap.

Leaves: Leaves are lanceolate in outline, approximately 1/2 to 3 inches long, with toothed margins. Leaves are oppositely arranged, usually have hairs, and often have at least one dark red spot on the upper surface, especially with age. Lower leaves may sometimes be alternately arranged. Leaves at the ends of stems near the flowers often appear whorled.

Flowers: Flowers occur in clusters at the ends of branches. Flowers are relatively inconspicuous and have no petals.

Fruit: **A capsule that is yellowish-green in color and smooth. Each capsule normally contains 3 seeds.**

Identifying Characteristics:
Opposite, lanceolate leaves with dark red markings and milky sap emitted by all parts of the plant.

Virginia Tech Weed Identification Guide

Select a Resource...

Slender or Small Pondweed: *Potamogeton pusillus*

Weed Description:
A submersed aquatic perennial weed with narrow, ribbon-like leaves that often forms thick mats, especially in shallow water. Slender pondweed is found in lakes and ponds throughout the southeastern United States.

Stems:
Root at the nodes when in contact with the ground.

Leaves: **Leaves are arranged alternately along the stem and are linear or ribbon-like in outline, approximately 1 to 2 inches long and only a few millimeters wide. A pair of glands occurs at the bases of the leaves, which are often difficult to see with the naked eye. The leaves also have stipules that are separate from the leaf bases and are approximately 1/3 to 2/3 inch long.**

Flowers: **Small flower spikes occur on short stalks (peduncles) that arise from the area between the leaf bases and the stems.**

Fruit: **An achene.**

Identifying Characteristics: **The alternately arranged narrow, ribbon-like leaves and stipules are both characteristics that help to distinguish this weed from other aquatic plants. Slender pondweed is often confused with southern**

naiad (*Najas guadalupensis*), however the leaves of this aquatic are arranged oppositely along the stem and have toothed margins unlike those of slender pondweed.

Virginia Tech Weed Identification Guide

Select a Resource...

Variable-leaf Pondweed or Waterthread Pondweed:

Potamogeton diversifolius

Weed Description: **A perennial with both floating and submersed leaves that are elliptic to oval in outline. This weed is a common aquatic weed of ponds, streams, and lakes that is found throughout the United States.**

Leaves: **Both floating and submersed leaves occur on the same plants. Floating leaves are elliptic to oval in outline, reaching 2 inches in length and ranging from 10 to 20 mm in width. Floating leaves usually have 7 to 11 distinct veins. Submersed leaves are arranged**

alternately along the stem and are usually smaller than the floating leaves. Submersed leaves have 3 veins, only 1 of which is usually noticeable. Submersed leaves have stipules at the base of the leaf petiole that forms a sheath around the stem.

Roots: **Small, thin, rhizomes and fibrous roots.**

Fruit: **An achene that is very small.**

Flowers: **Flowers are spikes that occur on short flower stalks (peduncles) and arise just above the water surface.**

Identifying Characteristics: **The relatively small elliptical floating and submersed leaves and distinctively veined leaves of this plant helps to distinguish it from most other pondweeds.**

Virginia Tech Weed Identification Guide

Select a Resource...

Puncturevine: *Tribulus terrestris*

Purpletop: *Tridens flavus*

Weed Description:
A perennial with short, thick rhizomes that is most noticeable from August through October when these plants reach 4 or 5 feet in height and produce dark purple panicles. Purpletop is primarily a weed of hay fields, pastures, abandoned fields, and roadsides that is found from New Hampshire south to Florida.

Leaves: **Leaves are somewhat flattened and appear folded in the sheath and have a relatively prominent white midvein. Leaves are 8 to 17 mm wide, usually hairy except near the bases, lacking auricles, and with a ligule that is a fringe of hairs less than 1 mm in length.**

Stems: **Sheaths are round and usually hairy only near the top. Plants may reach 4 to 5 feet in height when mature.**

Flowers: **The seedhead is an open panicle that is dark purple in color. Individual spikelets are 6 to 8 mm long, 1 to 2 mm wide, and purple in color.**

Roots: **Short, thick rhizomes occur along with a fibrous root system.**

Identifying Characteristics: **A grass with relatively wide leaves that have a very small ligule that is a fringe of hairs. Additionally, the short, thick rhizomes and purple seedhead are characteristics that help in the identification of this weed.**

Common Weed Names: Q

Common Name	Scientific Name
Quackgrass	*Elytrigia repens*
Queen Anne's Lace	*Daucus carota*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Quackgrass: *Elytrigia repens*

Weed Description:
A perennial grass weed from rhizomes that may reach 3 1/2 feet in height. Quackgrass is a common weed of agronomic crops, turfgrass, lawns, nurseries, and landscapes that may be found in the northern United States from North Carolina to California.

Seedling: **First leaf is very long and wide and may have hairs or be hairless (glabrous) on the upper surface but are without hairs on the lower surface. Leaves are rolled in the bud and have membranous ligules that are very short (0.4 mm long). Seedlings have auricles but are often difficult to see on very young seedlings.**

Stems: **Leaf sheaths are rounded and may have short hairs but hairs typically can be found only near the base of the plant. Stems often bend out and up from the base of the plant.**

Leaves: **Leaves are rolled in the bud and are approximately 1 1/2 to 12 inches long and usually 2 to 3 mm wide but may reach 12 mm in width. Leaves may or may not have hairs on the upper surfaces, but lower leaf surfaces are without hairs. Leaves have membranous ligules that are less than 1 mm long and also have narrow auricles that clasp the sheath.**

Roots: **Rhizomes and a fibrous root system.**

Flowers: **Seedhead a long, narrow spike consisting of many individual spikelets arranged in 2 rows along the stem. Spikes range from 2 to 8 inches in length while individual spikelets are approximately 11 to 18 mm long with awns.**

Identifying Characteristics: **A perennial grass weed with auricles that clasp the stem, rhizomes, and a long, narrow spike for a seedhead. The auricles of this weed helps to immediately distinguish it from most other grass weeds, however tall fescue (*Festuca arundinacea*), Annual Ryegrass (*Lolium multiflorum*), and**

perennial ryegrass (*Lolium perenne*) are similar grass weeds that also have auricles. However, none of these grass weeds have rhizomes like quackgrass.

Common Weed Names: R

Common Name	Scientific Name
Rabbitfoot Clover	*Trifolium arvense*
Radish, Wild	*Raphanus raphanistrum*
Ragweed, Common	*Ambrosia artemisiifolia*
Ragweed, Giant	*Ambrosia trifida*
Ragwort, Wooly	*Senecio tomentosus*
Rattlesnake Weed	*Stachys floridana*
Red Clover	*Trifolium pratense*
Red Deadnettle	*Lamium purpureum*
Red Morningglory	*Ipomoea coccinea*
Red Rice	*Oryza sativa*
Redroot Pigweed	*Amaranthus retroflexus*
Red Sorrel	*Rumex acetosella*
Redstem Filaree	*Erodium cicutarium*
Redvine	*Brunnichia ovata*
Reed, Common	*Phragmites australis*
Rice Flatsedge	*Cyperus iria*
Rose, Multiflora	*Rosa multiflora*
Roughstalk Bluegrass	*Poa trivialis*
Rush, Creeping	*Juncus repens*

Ryegrass, Annual *Lolium multiflorum*

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Virginia Tech Weed Identification Guide

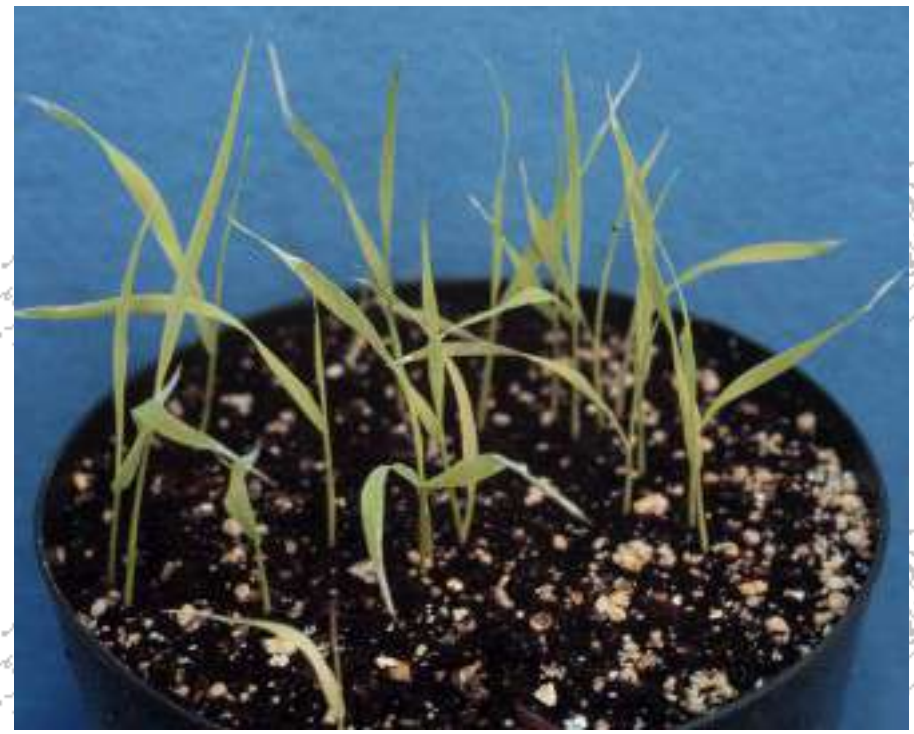
Select a Resource...

Wooly Ragwort: *Senecio tomentosus*

Virginia Tech Weed Identification Guide

Select a Resource...

Red Rice: *Oryza Sativa*



Weed Description: **An erect summer annual that may reach 32 inches in height. Red Rice is primarily a weed of rice and occurs in parts of Texas, Louisiana, Arkansas, and Mississippi where rice is grown.**

Roots: **A fibrous root system.**

Leaves: **Mature leaf blades are from 12 to 24 inches long and 7 to 20 mm wide. Leaves have auricles and also have a long (15 mm) membranous ligule that is triangular in outline. Some hairs occur in the collar regions.**

Stems: **Sheaths are tufted and without hairs except in the collar regions.**

Flowers: **Seedhead is a loose panicle, often somewhat drooping, reaching a maximum length of 8 inches. Panicles consist of many spikelets that are 7 to 10 mm long and 2 to 2 1/2 mm wide.**

Identifying Characteristics: **The presence of auricles and tall membranous ligule are both characteristics that help in the identification of red rice.**

Virginia Tech Weed Identification Guide

Select a Resource...

Red Sorrel: *Rumex acetosella*

Weed Description: **A perennial from rhizomes with distinctive arrowhead-shaped leaves and red flowering stems. Red sorrel is primarily a weed of turfgrass, lawns, roadsides, landscapes, and some nursery crops. It is found throughout the United States.**

Seedlings:
Cotyledons are oblong, without hairs, reaching 10 mm in length. Cotyledons and young leaves usually have a 'mealy' cast on the leaf surfaces. The first true leaf is egg-shaped in outline and occurs on a short petiole. The distinctive arrowhead-shaped leaves develop later.

Roots: **A taproot and rhizomes.**

Stems: **Flowering stems are erect, reaching18 inches in height, branching in the upper portions only. Stems are ridged and often maroon-tinted.**

Flowers: **Occur in clusters on the flowering stems. Flowers can be either yellowish-green in color (male) or red to maroon in color (female).**

Fruit: **An achene that is also red to maroon in color.**

Leaves: **Distinctively arrowhead-shaped due to 2 lobes that occur at the base of the leaves. Most leaves occur in the basal rosette, however some stem leaves occur also. Basal leaves are approximately 1 to 3 inches long, without hairs (glabrous), and occur on petioles. Leaves on the flowering stem are arranged alternately and are usually linear in outline (not usually arrowhead-shaped), without distinctive petioles. All leaves have a thin membranous sheath (ocrea) surrounding the stem at the point of the leaf petiole attachment.**

Identifying Characteristics: **The arrowhead-shaped leaves that develop in a basal rosette and the red to**

maroon-tinged flowering stems are both characteristics that distinguish red sorrel from most other species.

Virginia Tech Weed Identification Guide

Select a Resource...

Redstem Filaree: *Erodium cicutarium*

Weed Description:
A winter annual with showy pink to purple flowers that ranges from 4 to 20 inches in height. Redstem filaree is primarily a weed of turfgrass and landscapes that is found throughout the United States.

Seedling:
Cotyledons and first true leaves are deeply lobed and occur on long petioles that are hairy.

Roots:
Small taproot and fibrous root system.

Leaves:

Plants develop as a basal rosette. Rosette leaves occur on petioles and are hairy. Individual leaves are divided into 3 to 9 individual leaflets that are arranged oppositely from one another. Individual leaflets are lanceolate in outline and range from 1 1/4 to 8 inches long. Leaflets are deeply lobed and do not have petioles (sessile).

Stems: Growing along the ground or also may be ascending, with hairs, branched, often tinted red in color.

Flowers: Clusters of 2 to 8 flowers occur with each individual flower occurring on a relatively long flower stalk (pedicel). Individual flowers are approximately 1/2 inch wide and consist of 5 bright pink to purple petals.

Fruit: Resembles a bird's beak and is approximately 1/2 to 3/4 inch long.

Identifying Characteristics: The finely divided leaves, rosette growth habit, and opposite leaflets helps to distinguish this weed from most other winter annual weeds that are normally found in lawns and turfgrass. Additionally, the distinctive fruit and showy purple flowers are good identifying characters of redstem filaree.

Redvine: *Brunnichia ovata*

Weed Description: **Perennial, shrubby vine that becomes woody with maturity. Found most often along roadsides, riverbanks, and in swamps, however this plant can occur as a weed of many agronomic crops of the southern United States. Occurs from southern Illinois and Missouri east to South Carolina and south to Florida and Texas.**

Leaves: **Alternate, ovate in outline, 2 to 6 inches long, and have distinct veins.**

Stems: **Climbing and become woody with age. Stems have tendrils that result in short lateral branches.**

Roots: **Deep-rooted rootstock that serves as the perennating organ.**

Flowers: **Occur in panicles at the ends of branches. Flowers are greenish to white in color.**

Fruit: **A nutlet that occurs within the collective sepals of the flower (a calyx). The calyxs are approximately 1 inch long and white to pink in color.**

Identifying Characteristics:

Perennial vine with tendrils and leaf and stems that often have a reddish tint. These characteristics help to distinguish redvine from most weeds, however Wild Buckwheat (*Polygonum convolvulus*), Field Bindweed (*Convolvulus arvensis*), and Hedge Bindweed (*Calystegia sepium*) are all weeds that may be confused with redvine. Redvine has a deep perennating rootstock unlike wild buckwheat or hedge bindweed. Additionally, the leaves of hedge bindweed are cut off squarely across the top (truncate) unlike those of redvine, field bindweed, or wild buckwheat. The basal lobes of redvine are also much more rounded than those of field bindweed. Lastly, wild buckwheat

can be distinguished from either of these weeds due to the ocrea that occurs at the base of the leaf petioles.

Common Weed Names: S

Common Name	Scientific Name
Salsify, Western	*Tragopogon dubius*
Sandbur, Longspine	*Cenchrus longispinus*
Scarlet Pimpernel	*Anagallis arvensis*
Sericea Lespedeza	*Lespedeza cuneata*
Shepherd's-purse	*Capsella bursa-pastoris*
Showy Crotalaria	*Crotalaria spectabilis*
Sicklepod	*Cassia obtusifolius*
Signalgrass, Broadleaf	*Brachiaria platyphylla*
Silverleaf Nightshade	*Solanum eleagnifolium*
Slender Naiad	*Najas minor*
Slender Pondweed	*Potamogeton pusillus*
Smallflower Morningglory	*Jacquemontia tamnifolia*
Small-flowered Crowfoot	*Ranunculus abortivus*
Smartweed, Pennsylvania	*Polygonum pensylvanicum*
Smartweed, Swamp	*Polygonum coccineum*
Smooth Bedstraw	*Galium mollugo*
Smooth Crabgrass	*Digitaria ischaemum*
Smooth Hawksbeard	*Crepis capillaris*
Smooth Pigweed	*Amaranthus hybridus*
Smooth Vetch	*Vicia dasycarpa*
Soapwort	*Saponaria officinalis*

Sowthistle, Annual	*Sonchus oleraceus*
Sowthistle, Spiny	*Sonchus asper*
Spanishneedles	*Bidens bipinnata*
Speedwell, American	*Veronica americana*
Speedwell, Persian	*Veronica persica*
Spiderwort, Asian	*Murdannia keisak*
Spiny Amaranth	*Amaranthus spinosus*
Spiny Cocklebur	*Xanthium spinosum*
Spiny Sowthistle	*Sonchus asper*
Spotted Knapweed	*Centaurea maculosa*
Spotted Spurge	*Euphorbia maculata*
Spurge, Caper	*Euphorbia lathyris*
Spurge, Cypress	*Euphorbia cyparissias*
Spurge, Spotted	*Euphobia maculata*
Spurge, Sun	*Euphorbia helioscopia*
Spurge, Toothed	*Euphorbia dentata*
Spurred Anoda	*Anoda cristata*
Spurry, Corn	*Spergula arvensis*
Starch Grapehyacinth	*Muscari racemosum*
Star-of-Bethlehem	*Ornithogalum umbellatum*
Star Thistle	*Centaurea maculosa*
Starwort, Water	*Callitriche heterophylla*
Stick-tights	*Bidens frondosa*
Stickweed	*Verbesina occidentalis*

Stinging Nettle	*Urtica dioica*
Stinkgrass	*Eragrostris cilianensis*
St. Johnswort	*Hypericum perforatum*
Stonewort	*Chara* spp.
Sulfur Cinquefoil	*Potentilla recta*
Sun Spurge	*Euphorbia helioscopia*
Swamp Milkweed	*Aslepias incarnata*
Swamp Smartweed	*Polygonum coccineum*
Sweet Pea	*Lathyrus latifolius*
Sweet Vernalgrass	*Anthoxanthum odoratum*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Scarlet Pimpernel: *Anagallis arvensis*

Weed Description: **A low-growing annual that resembles chickweed but has showy reddish-orange flowers. Primarily a weed of turfgrass and landscapes that is now distributed throughout the United States.**

Seedling:
Cotyledons triangular in outline, dark green in color, shiny, with tiny hairs. Young leaves are opposite and resemble those of the mature plant.

Leaves:
Opposite, oval to elliptic in outline, reaching 1 inch in length, without petioles. Lower leaf surfaces have small dark purple spots.

Leaves may have tiny hairs and sometimes may occur in whorls of three.

Stems: Square, branching at the base, and may reach 10 inches in length.

Fruit: A round capsule that contains many small (1.3 mm long), brown seeds.

Flowers: Solitary flowers arise from the area between the stem and leaves (leaf axils) and occur on relatively long stalks (pedicels). Individual flowers have 5 petals that are orange to red in color with tiny hairs along the margins. Flowering usually occurs from June to August.

Identifying Characteristics: A low-growing annual with opposite leaves that have spots on the lower surfaces. This weed is often mistakenly identified as Common Chickweed (*Stellaria media*), however scarlet pimpernel has square stems and reddish-orange

flowers while common chickweed has round stems and white flowers. Additionally, the purple spots on the lower leaf surfaces of scarlet pimpernel help to distinguish this weed from other similar weed species.

Virginia Tech Weed Identification Guide

Select a Resource...

Shepherd's-purse: *Capsella bursa-pastoris*


Virginia Tech Weed ID Guide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Select a Resource...

Showy Crotalaria: *Crotalaria spectabilis*

Weed Description: **A summer annual weed with relatively showy yellow flowers and distinctive seedpods. Showy crotalaria is primarily a weed of agronomic crops and may be found from Virginia to Missouri and southward.**

Stems: **Erect, reaching 6 ½ feet in height, stout, and green or purplish in color. Stems become waxy and somewhat angled with age.**

Seedling: Stems below the cotyledons (hypocotyls) become maroon with age and are covered with short hairs that lie flat against the hypocotyls (appressed). Cotyledons are bean-shaped, thick, dark green above and light green below. First true leaves are alternate and widest at the apex and tapering to the base. Leaves are without hairs on the upper surface and covered with appressed hairs on the lower surface.

Roots: Taproot.

Leaves: Alternate, approximately 2 to 6 inches long, widest at the apex and tapering to the base. Leaves are without hairs on the upper surface and covered with appressed hairs on the lower surface. Leaves occur on short petioles. Stipules also occur at the base of the petioles but usually persist only for a short time.

Flowers: Individual flowers occur on elongated inflorescences (racemes) and are stalked from a central axis, large, showy, and bright yellow in color. Flower stalks have a distinctive bract at their base that is approximately 7 to 12 mm long and 5 to 9 mm wide.

Fruit: **A legume that is 1 to 2 inches in length and takes on the appearance of an inflated cylindrical pod. Fruit turn brown to black when mature and the seed within the fruit often become unattached resulting in a 'rattlebox' sound when shaken.**

Identifying Characteristics: **Leaves that are widest at the apex and taper to the base. Also the bright yellow flowers and distinctive seedpods help to distinguish this weed from most others.**

Virginia Tech Weed Identification Guide

Select a Resource...

Swamp Smartweed: *Polygonum coccineum*

Virginia Tech Weed Identification Guide

Select a Resource...

Smooth Vetch: *Vicia dasycarpa*

Virginia Tech Weed Identification Guide

Select a Resource...

Sun Spurge: *Euphorbia helioscopia*

Weed Description: **A winter annual that grows prostrate along the ground with tips and upper stem portions ascending (decumbent growth habit). All parts of the plant emit a milky sap when cut. Sun spurge is a somewhat rare weed of pastures, hayfields, and winter small grains in Virginia.**

Stems: **Stout, growing prostrate along the ground with tips ascending. Stems are distinctly red-tinged and emit a milky sap when cut. Stems radiate outward from a central point. Stems may be sparsely**

hairy, especially in the upper portions.

Leaves: The leaves of the upper stem appear whorled but usually occur in groups of 2 or occasionally 3. Leaves are oppositely arranged along the stem. Leaves are widest at the apex and taper to the base (oblanceolate). Leaf apexes are are very finely toothed or serrated. All leaves generally attach directly to the stem and do not

occur on petioles (sessile).

Flowers: Inconspicuous, light green to pale yellow in color. inflorescences (cyathias) occur at the ends of stems and are 4-lobed. Each lobe has a round yellowish gland.

Fruit: A very distinctive 3-parted capsule (3-4 mm long) that contains a single, 2 mm long dark brown seed.

Identifying Characteristics: The distinctive red stems, leaves with finely toothed leaf apexes, and milky sap are all characteristics that help in the identification of sun spurge. From a distance, this plant might be confused with Cypress Spurge (*Euphorbia cyparissias*), which has very similar flowers. However, the leaves of cypress spurge are much more linear than those of sun spurge and

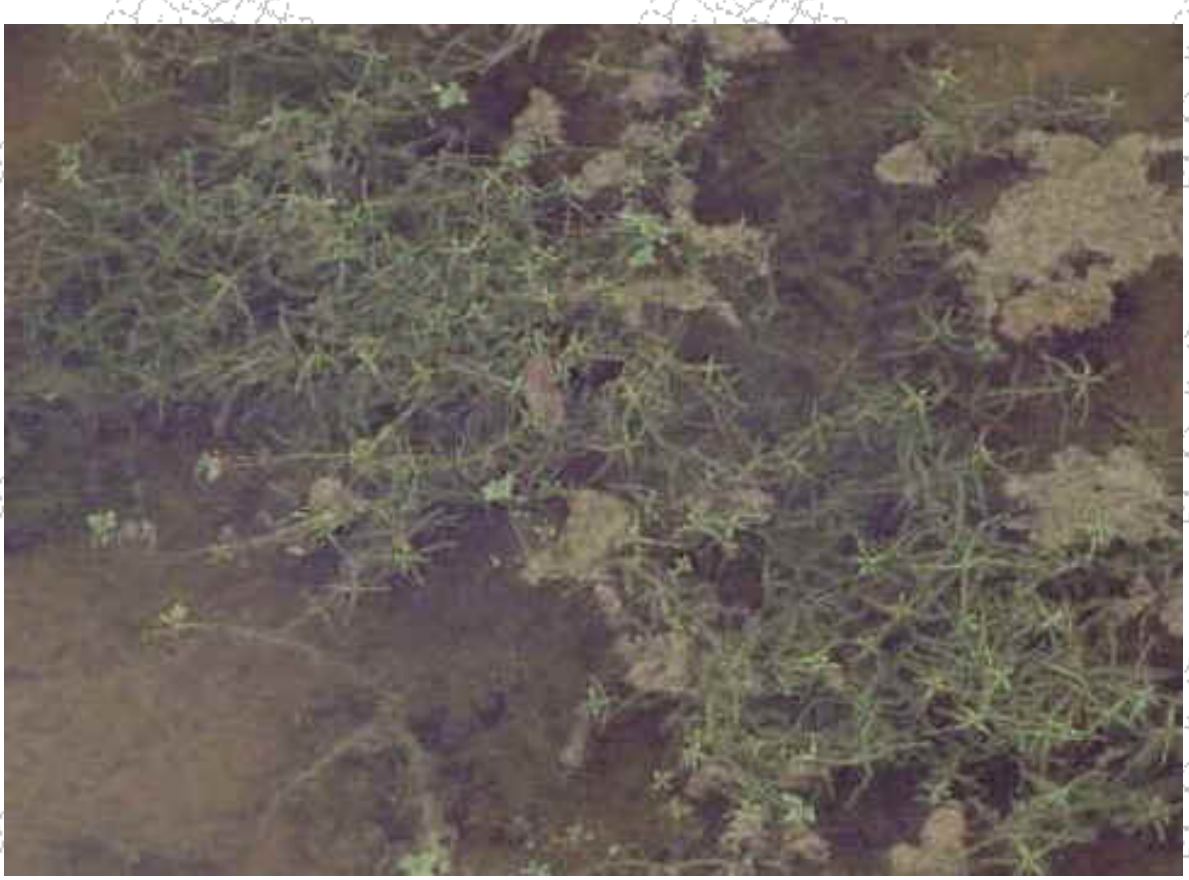
upon closer examination distinguishing between the two species is relatively easy.

Water-starwort: *Callitriche heterophylla*

Weed Description: **Annual aquatic weeds that are primarily submersed but have some floating and emersed leaves. These weeds primarily occur where there is little to no movement of water as in ditches, swamps, streams, and lakes. All parts of these plants are eaten by ducks.**

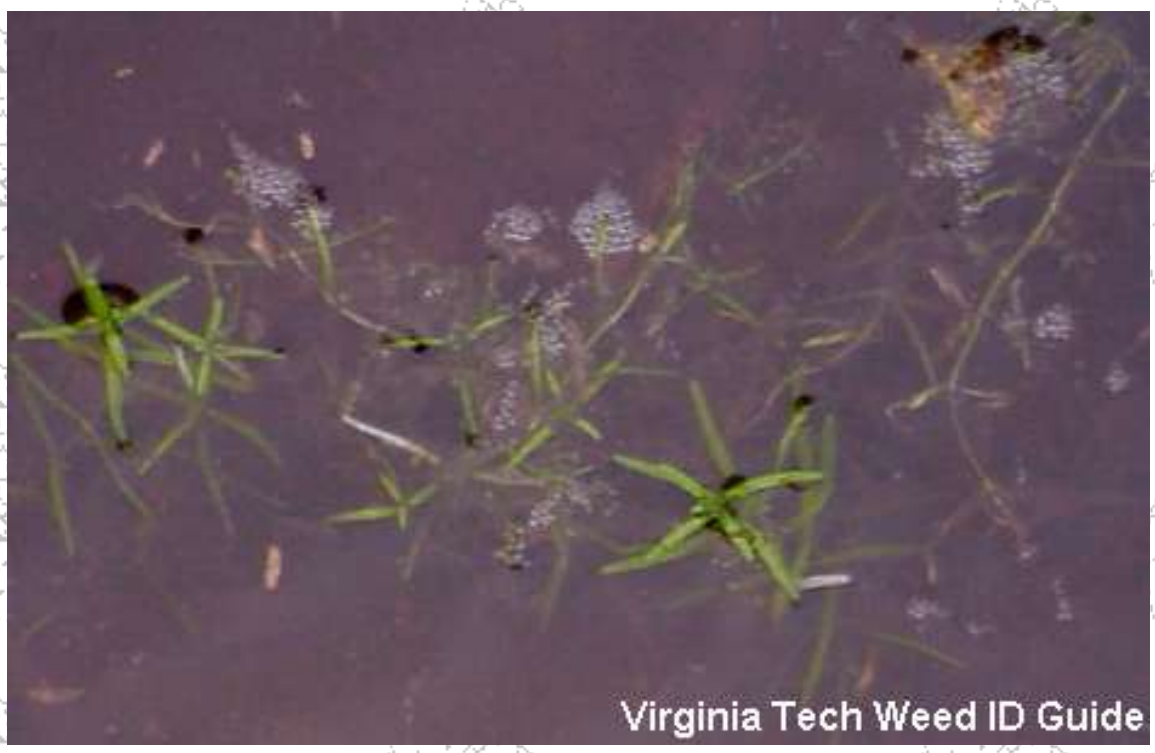
Leaves:
Submersed leaves are linear in outline and approximately 6 mm wide and ½ to 1 inch long. The submersed leaves are much different from either the floating or

emersed leaves. Floating and emersed leaves are either crowded in a rosette-type growth habit or arranged oppositely from one another. Floating and emersed leaves are approximately ¼ to ½ inch long.



Fruit:
Heart-shaped, approximately 1 mm wide, and splitting into 4 nutlets with maturity.

Flowers: **Occur in the areas between the leaves and the stem (leaf axils). Flowers are very small and inconspicuous, with no sepals or petals.**



Identifying Characteristics: **Annual aquatic weed that can occur with three different leaf forms: submersed, floating, and emersed. The opposite, floating leaves of this plant may resemble some other small aquatic weeds like Creeping Primrose (*Ludwigia palustris*), but the lack of evident flowers on water-starwort helps to distinguish this plant from almost all other aquatic weeds.**

Virginia Tech Weed Identification Guide

Select a Resource...

Stinkgrass: *Eragrostis cilianensis*

Weed Description: **A summer annual grass weed that emits a distinctive odor. Stinkgrass is a common grass weed of many agronomic crops, pastures, hayfields, and noncrop areas.**

Seedling: **Seedlings develop into tufted plants relatively quickly. Leaves are without auricles and have ligules that are less than 1 mm long and a fringe of hairs.**

Leaves: **Leaves are rolled in the bud and are approximately 5 to 10 mm wide. Leaves are smooth and glossy below while upper leaf surfaces are rough and may have hairs along the margins. Auricles are absent and the ligule is a fringe of hairs that is usually less than 1 mm long.**

Stems: **Sheaths are round to slightly flattened, without hairs except occasionally where the leaf joins to the sheath.**

Roots: **A fibrous root system.**

Flowers: **Seedhead a triangular panicle that has a grayish green cast. Panicles may reach 8 inches in length and consist of spikelets that are approximately 3/4 inch long. Individual spikelets are gray to silver in color.**

Identifying Characteristics: **Annual grass that emits an unpleasant odor and has ligules that are less than 1 mm long and are a fringe of hairs. The distinctive grayish-green panicle also helps to distinguish this weed from other similar grasses.**

Virginia Tech Weed Identification Guide

Select a Resource...

Common St. Johnswort: *Hypericum perforatum*


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Sweet Vernalgrass: *Anthoxanthum odoratum*

Weed Description:

A perennial or winter annual grass that often produces a noticeable seedhead by April or May in many of Virginia's hay fields. Sweet vernalgrass gives off a distinctive, sweet-smelling odor when mature. This plant is most commonly a weed of pastures, hay fields, roadsides, and ditch banks that is found throughout the southeastern United States and into Kentucky and West Virginia.

Leaves: **Leaves are rolled in the sheath and may reach 10 mm in width. Upper and lower leaf surfaces, as well as the leaf margins, usually have short hairs. Leaves are without auricles and have a membranous, sometimes toothed, ligule. Ligules are generally 3-6 mm in length.**

Stems: **Sheaths are round and generally without hairs except near the top. Sheaths are split and have overlapping margins that are essentially transparent (hyaline). Plants may reach 2 feet in height.**

Roots: **A fibrous root system.**

Flowers: **A brownish-yellow spike that is approximately 3/4 to 2 3/4 inches long and 1/2 to3/4 inch wide. Each spike contains many spikelets that are approximately 6 1/2 to 8 1/2 mm long.**

Identifying Characteristics: **Plants with brownish-yellow spikes and distinctive sweet smell. Additionally, the relatively early appearance of this grass in Virginia helps in its identification.**

Common Weed Names: T

Common Name	Scientific Name
Tall Morningglory	*Ipomoea purpurea*
Tall Oatgrass (Bulbous)	*Arrhenatherum elatius* var. *bulbosa*
Tall Thistle	*Cirsium altissimum*
Tearthumb, Arrow-leaved	*Polygonum sagittatum*
Tearthumb	*Polygonum arifolium*
Teasel, Common	*Dipsacus fullonum*
Teaweed	*Sida spinosa*
Texas Panicum	*Panicum texanum*
Thistle, Bull	*Cirsium vulgare*
Thistle, Canada	*Cirsium arvense*
Thistle, Musk	*Carduus nutans*
Thistle, Plumeless	*Carduus acanthoides*
Thistle, Star	*Centaurea maculosa*
Thistle, Tall	*Cirsium altissimum*
Thoroughwort Pennycress	*Thlaspi perfoliatum*
Tick Trefoil	*Desmodium viridiflorum*
Toadflax, Common	*Linaria canadensis*
Toothed Spurge	*Euphorbia dentata*
Touch-me-not	*Impatiens capensis*

Trailing Crownvetch	*Coronilla varia*
Tree-of-Heaven	*Ailanthus altissima*
Tropic Croton	*Croton glandulosus*
Trumpetcreeper	*Campsis radicans*
Tufted Knotweed	*Polygonum caespitosum* var. *longisetum*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Tall Thistle: *Cirsium altissimum*

Weed Description: **A biennial thistle with distinctive pink flower heads, hairy stems, and densely white pubescent (tomentose) leaf undersides. These plants may reach as much as 9 1/2 feet in some areas and typically flower from July to October. Tall thistle is found as a weed of pastures, hay fields, roadsides, railroads, and other non-crop areas.**

Leaves: **Arranged alternately along the flowering stems. Leaves are mostly without hairs above (glabrous) and are densely white pubescent (tomentose) beneath. Leaf margins are usually not lobed (entire) but spines occur along the leaf margins. Leaves typically occur without petioles and are attached directly to the stem (sessile), or some may occur on short petioles. Leaves may reach as much as 12 inches in length and 4 inches in width.**

Stems: Stems are erect, branching, with many hairs. Stems may reach heights of 9 1/2 feet or more in certain areas.

Roots: A taproot.

Fruit: An achene 6 mm long and 2 mm wide.

Flowers: Single flower heads occur at the ends of the flowering stems. Each flower may reach as much as 1 1/3 inches in height and width. Subtending bracts occur below the flower head. Flowers are pink to purplish in color.

Identifying Characteristics: The distinctive bulbous-like base below the pink to purplish flowers helps to identify this plant as one of the *Cirsium* species. The mostly entire leaves with spiny margins and tomentose leaf undersides are also characteristics that help to distinguish this plant from Canada Thistle

(*Cirsium arvense*), Bull Thistle (*Cirsium vulgare*), or Musk Thistle (*Carduus nutans*).

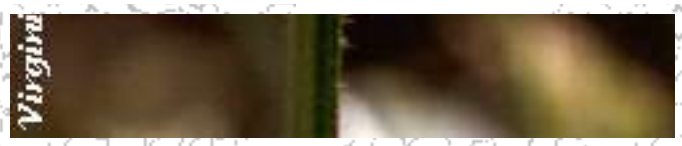
Virginia Tech Weed Identification Guide

Select a Resource...

Tick Trefoil: *Desmodium viridiflorum*

Weed Description: **Erect perennial with trifoliate leaves that may reach 6 1/2 feet in height. Primarily a weed of pastures, roadsides, and noncroplands that is found throughout the southeastern United States and as far North as eastern Pennsylvania and southern New York.**

Leaves: **Occur in clusters of 3 (trifoliate leaves). Individual leaflets are ovate in outline, approximately 1 to 3 1/2 inches long, roughly hairy above and densely velvet hairy below. Distinctive lance-shaped stipules also occur at the base of the leaf petioles where they meet the stem.**



Stems: **Erect, branching, hairy, reaching 6 1/2 feet in height.**

Flowers: **Occur in elongated inflorescences where each flower arises from a central stalk (racemes). Individual flowers occur on flower stalks (pedicels) that are from 2 1/2 to 8 mm long. Flowers are pink to purplish in color and are approximately 5 to 9 mm long.**

Fruit: **A loment of 2 to 6 segments that are each triangular in outline.**

Identifying Characteristics: **A large, erect perennial with trifoliate leaves, stipules, and relatively small pink or purple flowers. There are many different 'tick trefoil' species and their primary identifying characteristics are trifoliate leaves, presence of stipules, and loments.**

Virginia Tech Weed Identification Guide

Select a Resource...

Tree-of-Heaven: *Ailanthus altissima*

Weed Description: A weedy tree that may reach 60 feet in height. This tree has developed into a problem along roadsides, in rights-of-way, in urban areas, and even in certain agricultural fields. Found throughout the United States.

Seedling: Trees can arise from seed or colonies of this tree are often found due to saplings arising from underground roots. Seedlings resemble mature trees and have alternate and compound leaves.

Roots:
Underground roots may produce new saplings as far as 10 feet away from the central plant.

Leaves:
Individual leaves are arranged alternately along the stem and consist of 15-27 individual leaflets per leaf. Leaflets are lanceolate in shape with entire margins except for 1-5 teeth near the base of each leaflet. The foliage emits a distinctive, often considered unpleasant, odor.

Stems: **Woody, light brown to tan in color, and stout.**

Flowers: **Produced in large terminal panicles. Individual flowers are relatively inconspicuous and consist of 5 green petals that are approximately 1.5 to 2.5 mm long.**

Fruit: **A winged samara that is approximately 1.5 inches long and contains only one seed. Clusters of about 2 to 5 samaras occur at a time.**

Identifying Characteristics: **Weedy, colonizing trees with alternate and compound leaves and foliage that emits an**

unpleasant odor.

Common Weed Names: V

Common Name	Scientific Name
Variable-leaf Pondweed	*Potamogeton diversifolius*
Velvetleaf	*Abutilon theophrasti*
Venice Mallow	*Hibiscus trionum*
Venus' Looking-glass	*Triodanis perfoliata*
Vernalgrass, Sweet	*Anthoxanthum odoratum*
Vetch, Common	*Vicia sativa*
Vetch, Smooth	*Vicia dasycarpa*
Vine, Cinnamon	*Dioscorea batatas*
Violet, Common Blue	*Viola papilionacea*
Violet, Field	*Viola arvensis*
Viper's Bugloss	*Echium vulgare*
Virginia Buttonweed	*Diodia virginiana*
Virginia Copperleaf	*Acalypha virginica*
Virginia Creeper	*Parthenocissus quinquefolia*
Virginia Knotweed	*Polygonum virginianum*
Virginia Pepperweed	*Lepidium virginicum*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Common Weed Names: W

Common Name	Scientific Name
Water Hyacinth	*Eichhornia crassipes*
Waterlilies	*Nymphaea* spp.
Watermeal	*Wolffia* spp.
Watermilfoil, Eurasian	*Myriophyllum spicatum*
Water Plantain, American	*Alisma subcordatum*
Waterpurslane	*Ludwigia palustris*
Watershield	*Brasenia schreberi*
Water-starwort	*Callitriche heterophylla*
Waterthread Pondweed	*Potamogeton diversifolius*
Water Willow	*Justicia americana*
Western Salsify	*Tragopogon dubius*
White Avens	*Geum canadense*
White Campion	*Silene alba*
White Clover	*Trifolium repens*
White Flowered Mazus	*Mazus japonicus*
White Heath Aster	*Aster pilosus*
White Horehound	*Marrubium vulgare*
White Sweet Clover	*Melilotus alba*
Wild Basil	*Satureja vulgaris*
Wild Bergamot	*Monarda fistulosa*
Wild Buckwheat	*Polygonum convolvulus*

Wild Carrot	*Daucus carota*
Wild Chrysanthemum	*Artemisia vulgaris*
Wild Four-O' Clock	*Mirablis nyctaginea*
Wild Garlic	*Allium canadense*
Wild Grape	*Vitis* spp.
Wild Mustard	*Brassica kaber*
Wild Pansy	*Viola arvensis*
Wild Parsnip	*Pastinaca sativa*
Wild Poinsettia	*Euphorbia dentata*
Wild-proso Millet	*Panicum miliaceum*
Wild Radish	*Raphanus raphanistrum*
Wingstem	*Verbesina alternifolia*
Wire Grass	*Cynodon dactylon*
Witchgrass	*Panicum capillare*
Woodrush	*Luzula bulbosa*
Woodsorrel, Creeping	*Oxalis corniculata*
Woodsorrel, Yellow	*Oxalis stricta*
Wooly Ragwort	*Senecio tomentosus*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Virginia Tech Weed Identification Guide

Select a Resource...

Water Hyacinth: *Eichhornia crassipes*

Weed Description: **A floating, aquatic weed with attractive light purple flowers. Water hyacinth is capable of reproducing very rapidly through either runners or stolons and can form dense mats where these plants have been introduced. Water hyacinth occurs primarily along the coastal plains of the southeastern United States.**

Leaves:
Leaves are tough and leathery and elliptical or ovate in outline. Leaf blades have parallel veins and may range from 1/2 to 8 inches in length. Leaves occur on petioles that have an inflated appearance, especially towards the base.

Roots:
Floating roots are fibrous and have a purplish tint. Vegetative reproduction occurs through runners or stolons.

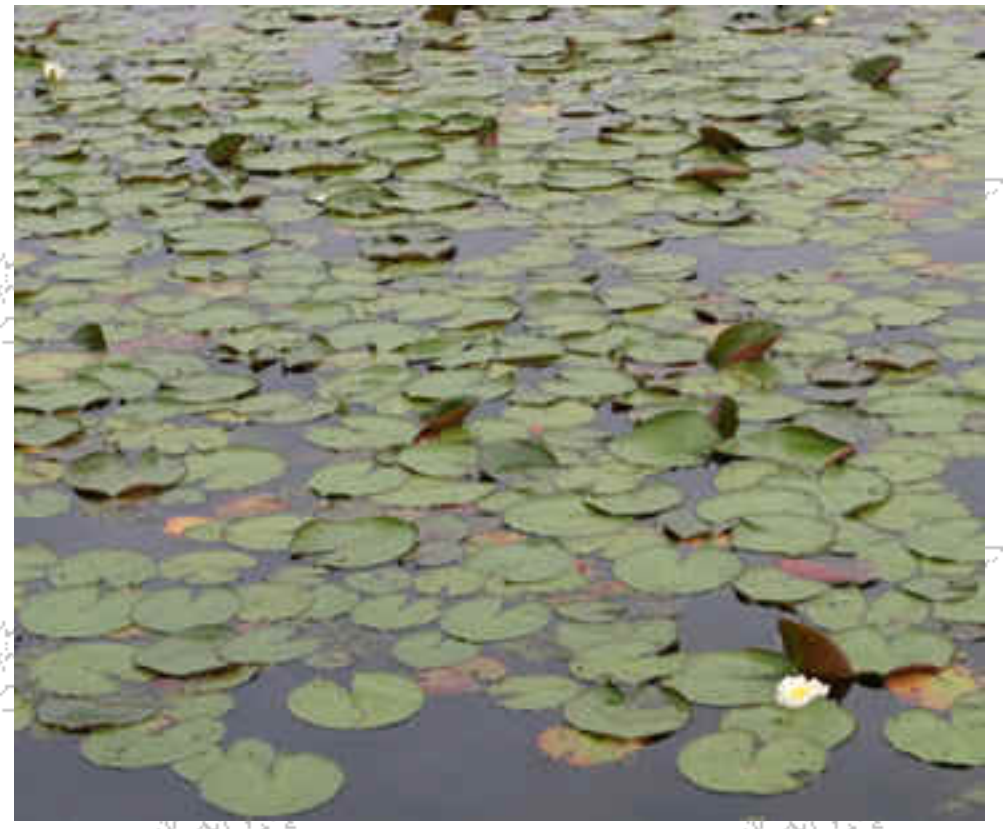
Flowers:
Individual flowers occur in groups of 5 to 20 on spikes. Flowers are light purple to blue in color and the upper petal always has a distinctive yellow spot.

Fruit: **A capsule that**

contains many seeds.

Identifying Characteristics:
Free-floating plants with leathery leaves, bulbous petioles, and attractive light purple flowers with a distinctive yellow mark on one of the petioles.

Waterlilies: *Nymphaea* spp.



Weed Description: **Aquatic perennials with floating leaves and showy flowers. Waterlilies occur in ponds, lakes, and marshes, and are often cultivated and sold for ornamental uses in home ponds.**

Leaves: **The leaves are floating, circular in outline, approximately 6 to 12 inches wide. The leaves are usually green above and purple-tinged below, with one central cleft that cut to the center of the leaf where the**

petiole attaches to the leaf. The lobes of this cleft are pointed. Leaves occur on petioles that may reach 6 feet in length.

Roots: **Stout rhizomes are rooted below.**

Flowers: **Individual flowers are floating and showy, usually white and yellow in color, but other cultivated forms have pink or purple flowers. Each flower may be from 3 to 5 inches wide.**

**Identifying Characteristics: Aquatic perennials with large floating leaves that are circular in outline with a central cleft and pointed lobes. Additionally, the large, showy flowers helps to distinguish these species from most other aquatic plants. The waterlilies are somewhat similar to Watershield (*Brasenia*

***schreberi*) in appearance, however watershield is generally smaller and does not have a distinctive cleft like the waterlilies. The waterlilies may also be confused with the floating-hearts (*Nymphoides* spp.), however the floating-hearts have rounded lobes and much smaller, less showy flowers.**

Virginia Tech Weed Identification Guide

Select a Resource...

Watershield: *Brasenia schreberi*

Weed Description:
Aquatic floating perennial from rhizomes with distinctive purple stems and leaf undersurfaces. All submerged portions of the plant are also covered in a jelly-like substance. Primarily a weed of poorly-managed lakes or ponds that most commonly occurs in water up to about 5 feet deep. Watershield is found in the eastern United States from Florida to Canada, and also in Oregon and California.

Leaves: Alternate, floating, oval to elliptic in outline, and approximately 4 1/2 inches long and 2 1/2 inches wide. Leaves are green and shiny on the upper surface and purple on the lower surface. The undersides of the leaves are covered with a thick, jelly-like substance. Leaves occur on petioles that range from 4 to 12 inches in length.

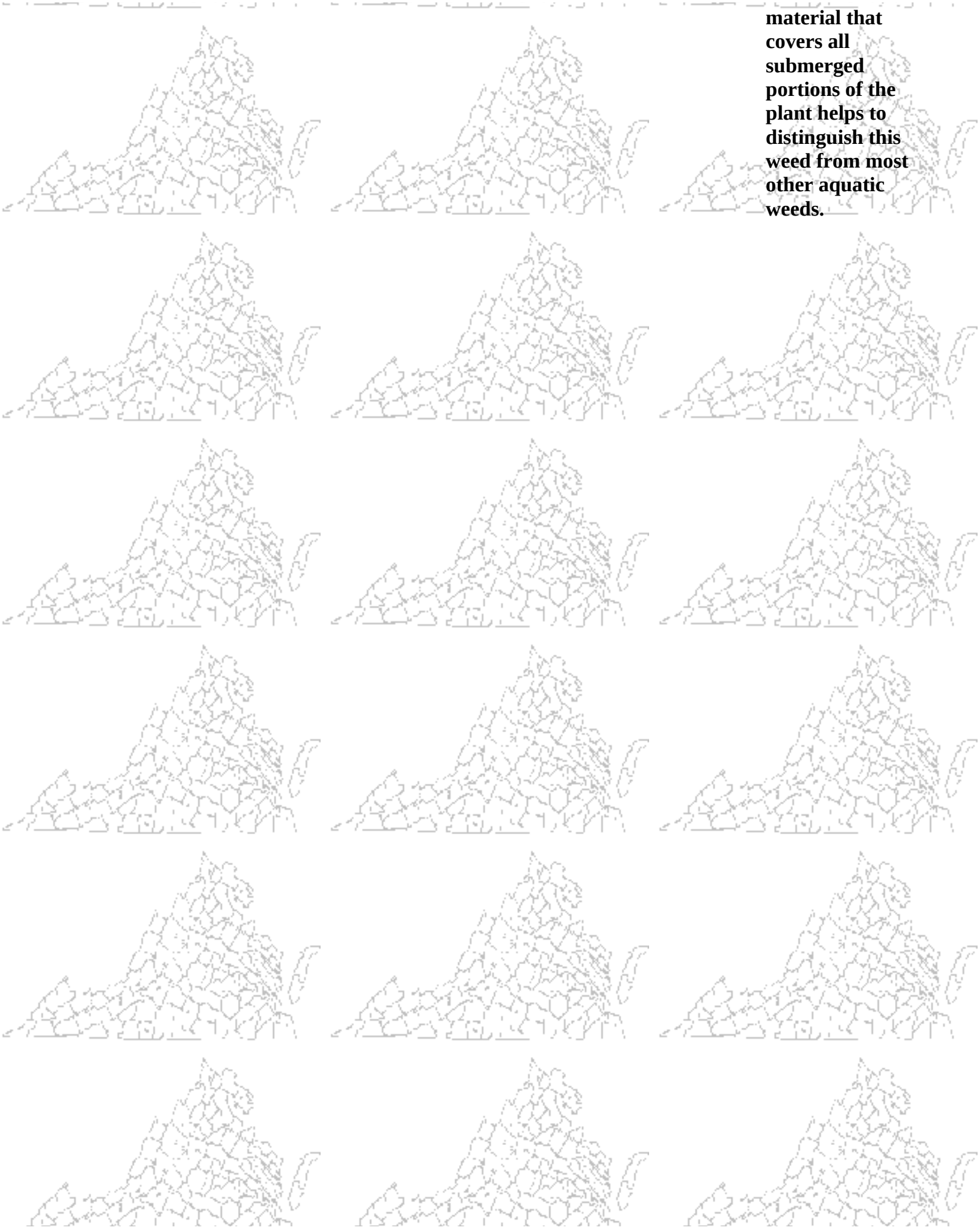
Stems: Purple, branched, and may reach 6 feet in length. All submerged stems are covered with a jelly-like substance.

Roots: Horizontal rhizomes that are rooted in the soil below.

Fruit: Club-shaped, leathery, and containing 1 or 2 seeds.

Flowers: Small (10 to 15 mm in diameter), emersed, purple, and occur on single stalks that open at the water surface. Flowers consist of 3 to 4 sepals and petals and 12 to 36 stamens.

Identifying Characteristics: Rooted, floating plants with oval leaves that are green on the upper surface and purple on the lower surface. Additionally, the jelly-like



material that covers all submerged portions of the plant helps to distinguish this weed from most other aquatic weeds.

Virginia Tech Weed Identification Guide

Select a Resource...

White Avens: *Geum canadense*

Weed Description:
A perennial weed primarily of damp and shaded areas that occasionally occurs as a weed in lawns and turfgrass. Found throughout the southeastern United States.

Leaves:
Rosette leaves occur on long petioles and are highly variable in shape. Leaves are usually distinctly lobed but may also be unlobed. Stem leaves become progressively smaller and

more unlobed up the stem. Leaf margins have rounded teeth. Leaves have distinct white veins on the upper surface and are slightly purple-tinged on the lower surface.

Stems: May reach 20 inches in height and often have hairs that lie flat against the stem (appressed), especially near the base of the plant.

Flowers: Occur on long flower stalks (pedicels) that arise from the position between the leaves and the stems (leaf

axils). Individual flowers ave 5 white petals.

Fruit: An achene that is approximately 3 mm long with an additional beak that is from 4 to 6 mm long.

Identifying Characteristics: Plants with a rosette growth habit, lobed leaves, distinct white veins on the upper leaf surfaces, and a purplish cast on the lower leaf surfaces.

Virginia Tech Weed Identification Guide

Select a Resource...

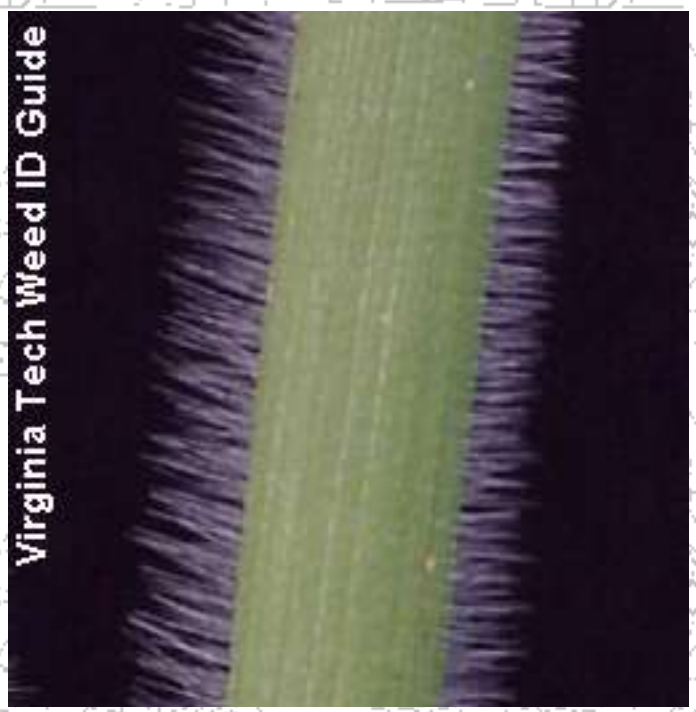
Witchgrass: *Panicum capillare*

Weed Description: **A densely hairy erect summer annual grass that may reach as much as 32 inches in height. Witchgrass is primarily a weed of agronomic crops, gardens, and landscapes. It is found throughout the United States.**

Seedlings: **The leaf blades and sheaths are covered with hairs. Leaves are rolled in the bud and lack auricles. The ligule is a fringe of hairs that is approximately 1 to 2 mm long.**

Leaves: **Leaves are covered with hairs on both surfaces. Leaves are rolled in the bud, lack auricles, and have a ligule that is a fringe of hairs often fused at the base. Ligules are usually 1 but may reach 2 mm in length. Leaf blades have a conspicuous white midvein and are from 4 to 10 inches long, 5 to 15 mm wide.**

Stems: **Sheaths are erect, reaching 32 inches in height, somewhat flattened, and covered with hairs. Sheaths have split margins that are overlapping.**



Roots: **A fibrous root system.**

Flowers: **The seedhead is a dense panicle that eventually becomes open and may range from 8 to 16 inches in length. Panicles may account for as much as half of the entire height of the plants.**

Identifying Characteristics: **A grass that is densely covered with hairs, has a ligule that is a fringe of hairs, and an open panicle that may account for as much as half of the height of the entire plant. These characteristics help to distinguish fall panicum from most other grasses.**

Virginia Tech Weed Identification Guide

Select a Resource...

Woodrush: *Luzula bulbosa*


Virginia Tech Weed ID Guide

Common Weed Names: Y

Common Name	Scientific Name
Yam, Chinese	*Dioscorea batatas*
Yarrow, common	*Achillea millefolium*
Yellow Crownbeard	*Verbesina occidentalis*
Yellow-flowered Leaf-cup	*Smallanthus uvedalia*
Yellow Foxtail	*Setaria glauca*
Yellow Rocket	*Barbarea vulgaris*
Yellow Nutsedge	*Cyperus esculentus*
Yellow Woodsorrel	*Oxalis stricta*
Yucca	*Yucca filamentosa*

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Department of Plant Pathology, Physiology & Weed Science

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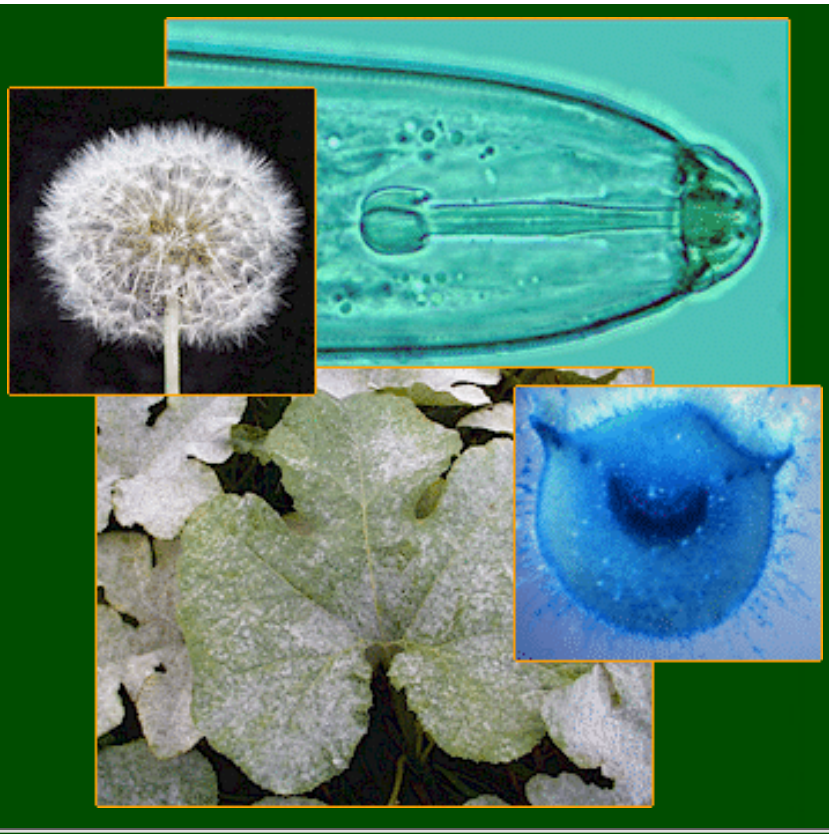

Dr. Craig Nessler named as Associate Dean for Research in Virginia Tech's College of Agriculture and Life Sciences and Director of the Virginia Agricultural Experiment Station
Virginia Tech news 4/22/04

Dr. Erik Stromberg named as Interim Head of the Department of Plant Pathology, Physiology, and Weed Science

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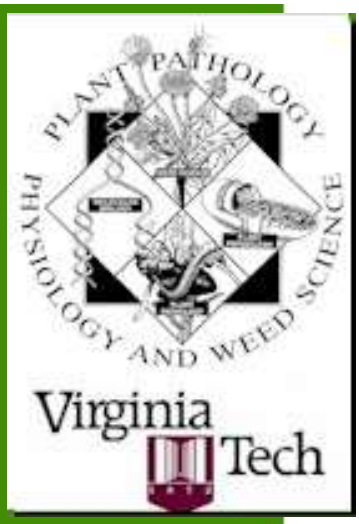

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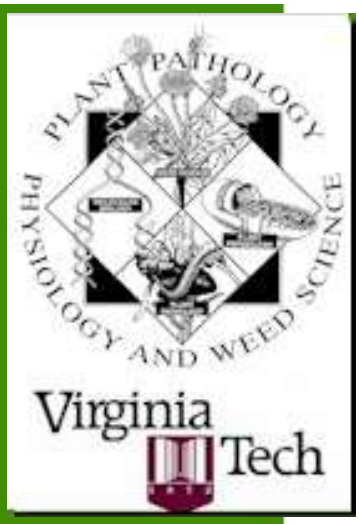

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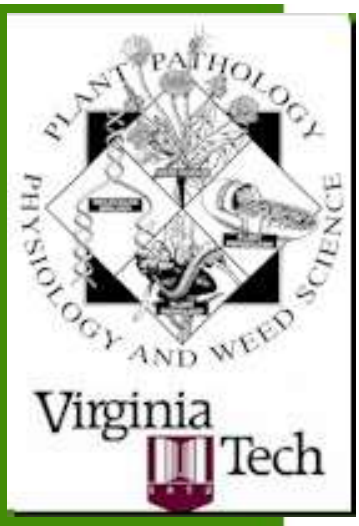

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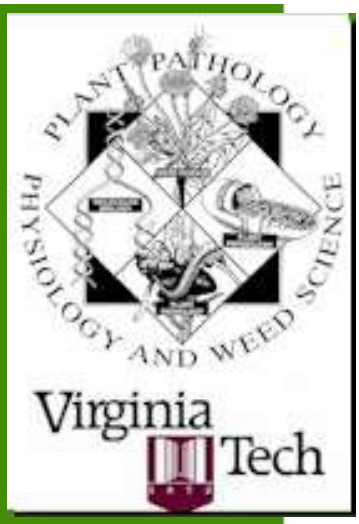

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Extension Plant Pathology

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- Weed Management in Horticultural Crops and Home Grounds

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Kriton K. Hatzios
August 6, 1949 - February 20, 2003

Respected researcher succumbs to cancer

News Archive:

Summer 1999 - The Weedy Physiopath
Newsletter of Plant Pathology, Physiology & Weed Science

March 18, 1999 - **Hatzios to Head VAES**
click here for Spectrum article

Research Workshop "Plant Sciences: Perspectives beyond 2000"
Program of Scheduled Activities

May 21, 1998 - Warsaw, VA -New Soft Red Winter Wheat Variety Named for Virginia Tech Professor Emeritus, Dr. Curtis W. Roane
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August 4, 1998 - Georgetown, DE -VIRGINIA TECH GRADUATE STUDENTS EXCEL IN REGIONAL WEED SCIENCE CONTEST
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Comments to: Peter Sforza
Last Updated January 06, 2004
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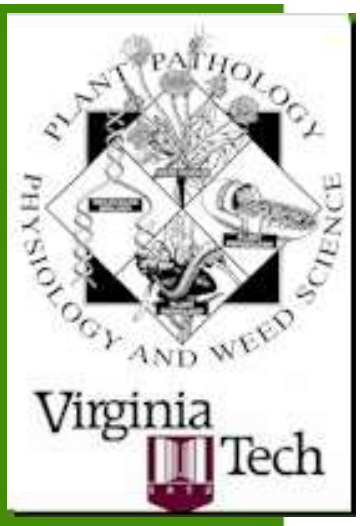

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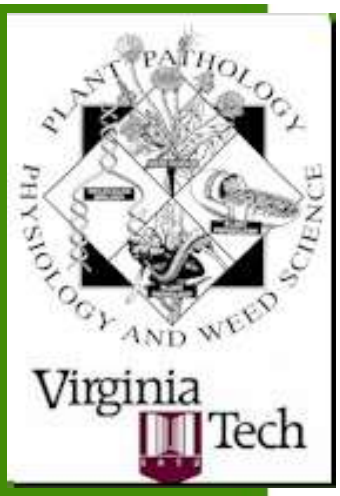

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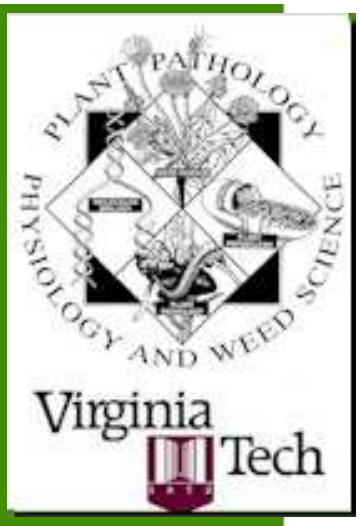

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Links

- Virginia Tech Homepage
- Virginia Tech Campus Maps
- U.S. National Weather Service - Interactive Weather Information Network

Plant Pathology

- American Chestnut Blight
- American Phytopathological Society
- Plant Pathology Internet Guidebook
- International Society for Plant Pathology
- Plant Parasitic Nematodes
- Canadian Phytopathological Society
- The British Society for Plant Pathology
- The WWW Virtual Library: Mycology

Plant Physiology

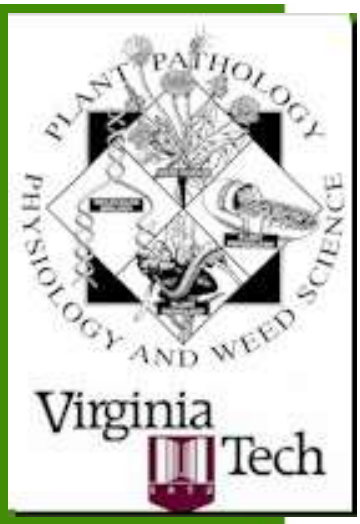
- American Society of Plant Physiologists

Weed Science

- Weed Science Society of America
- International Parasitic Plant Society

Agriculture

- USDA
- APHIS (Animal and Plant Health Inspection Service)
- National IPM Network
- Internet Resources in Agriculture - USDA National Agricultural Library



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Research Scientists and Research Associates

Visiting scholars

Staff

Students

Faculty

| Plant Pathology | Plant Physiology | Weed Science | Emeriti Faculty |

Faculty Programs in Plant Pathology (* Off Campus)

- Baudoin, A.B.A. -Associate Professor (abaudoin@vt.edu)- Epidemiology; integrated pest management; biological control of weeds
- Eisenback, J.D. - Professor (jon@vt.edu)- Plant Nematology
- Hansen, M.A. - Instructor (maryannh@vt.edu)- Diseases of ornamentals; Plant Clinic Manager
- Hong, Chuan* - Assistant Professor (chhong2@vt.edu) - Environmental plant pathology
- Johnson, C.S.* - Professor (spcdis@vt.edu)- Epidemiology; crop loss assessment; tobacco diseases
- McDowell, J.M. - Assistant Professor (johnmcd@vt.edu)- Molecular mechanisms of disease resistance
- Phipps, P.M.* - Professor (pmphipps@vt.edu)- Peanut and soybean diseases; nematology; epidemiology
- Shokes, F.M.* - Director, Tidewater AREC (fshokes@vt.edu)
- Stromberg, E.L. - Professor and Interim Head (elstrom@vt.edu)- Field crop pathology; chemical, biological and cultural disease control
- Tolin, S.A. - Professor (stolin@vt.edu)- Plant virology; biotechnology policy
- Tyler, B.M. - Professor, Virginia Bioinformatics Institute (brtyler@vt.edu)- Application of genomics and bioinformatics to plant-microbe interactions
- Yoder, K.S.* - Professor (ksyoder@vt.edu)- Tree fruit pathology; mode of action and resistance to fungicides

Faculty Programs in Plant Physiology

- Chevone, B.I. - Associate Professor (bchevone@vt.edu)- Plant stress physiology; air pollution
- Cramer, C.L. - Professor (ccramer@vt.edu)- Molecular and genetic bases of resistance; biotic and abiotic plant stress; pharmaceuticals in transgenic plants
- Denbow, C.J. - Research Scientist (cdenbow@vt.edu)- Plant molecular and cellular biology
- Grabau, E.A. - Associate Professor (egrabau@vt.edu)- Molecular biology of soybean improvement; transgenic plants

- Grayson, R.L. - Professor (ragrayso@vt.edu)- Director of CALS Minority Academic Opportunity Program
- Grene, R. - Professor (grene@vt.edu)- Air Pollution and other abiotic stresses; plant metabolism; plant gene expression and regulation
- Jelesko, J.G. - Assistant Professor - Molecular genetics of plant DNA recombination; molecular biology of alkaloid biosynthesis in tobacco
- Medina-Bolivar, F. - Research Assistant Professor (fmb2@vt.edu)-Transgenic plants for production of human vaccines. Production of natural products and recombinant proteins in hairy root cultures.
- Nessler, C.L. - Professor, Associate Dean for Research in the College of Agriculture and Life Sciences, and Director of the Virginia Agricultural Experiment Station (cnessler@vt.edu)- Metabolic engineering of primary and secondary products
- Sobral, B.W.M. - Professor and Director of the Virginia Bioinformatics Institute- (sobral@vt.edu) Application of genomics and bioinformatics to predicting phenotypic performance

Faculty Programs in Weed Science (* Off Campus)

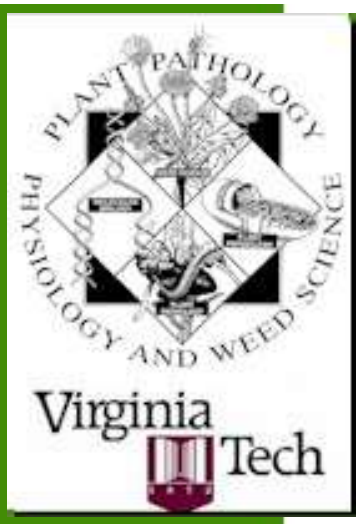
- Askew, S.D. - Assistant Professor (saskew@vt.edu)- Turf Weed Extension
- Derr, J.F.* - Professor (jderr@vt.edu)- Weed identification and control in ornamentals, turf, tree fruit, small fruit
- Hagood, E.S. - Professor (shagood@vt.edu)- Weed control in agronomic crops; low-input sustainable agriculture; integrated weed management
- Hipkins, P.L. - Extension Weed Scientist/Senior Research Associate (lhipkins@vt.edu)- Right-of-way vegetation management and turf weed control
- Westwood, J.H. - Assistant Professor (westwood@vt.edu)- Parasitic weed biology and control
- Wilson, H.P.* - Professor (hwilson@vt.edu)- Weed management in vegetable and agronomic crops

RETIRED FACULTY

- Alexander, S.A. - (salex@vt.edu)
- Bingham, S.W.
- Couch, H.B. - (hcouch@vt.edu)
- Foy, C.L. - (cfoy@vt.edu)
- Griffin, G.J. - (gagriffi@vt.edu)
- Lacy, G.H. - (lacygh@vt.edu)
- Moore, L.D. - (larrydm@vt.edu)
- Orcutt, D.M. - (dmorcutt@vt.edu)
- Roane, C.W.
- Stipes, R.J. - (treedr@vt.edu)

- Warren, H.L. - (hwarren@vt.edu)

Last Updated May 11, 2004.



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Faculty

Visiting scholars

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Students

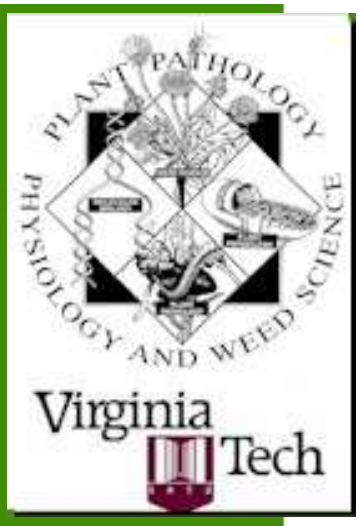
Research Scientists & Research Associates

RESEARCH SCIENTISTS

- Denbow, C.J. - Research Scientist (cdenbow@vt.edu)- Plant molecular and cellular biology
- Deng, Fan - Research Scientist (fandeng@vt.edu)
- Livingstone, D.M. - (dlivings@vt.edu)

RESEARCH ASSOCIATES

- Chiera, Joseph M.
- Cuzick, Alayne - (acuzick@vt.edu)
- Lorence, A. - (alorence@vt.edu)
- Sforza, Peter - Extension Research Associate (sforza@vt.edu)
- Watkinson, J. - (jowatki2@vt.edu)
- Woffenden, Bonnie - Postdoctoral Research Associate (bwoffend@vt.edu)
- Wright, Rhonda - Research Associate (wrightrh@vt.edu)



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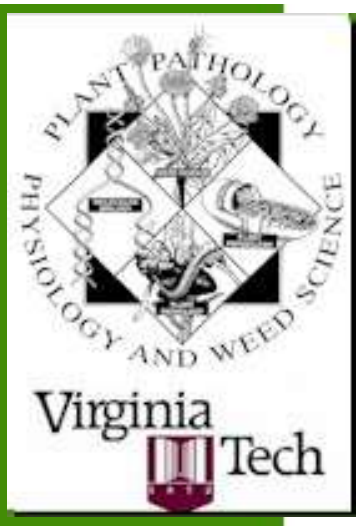
- None currently listed



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Staff

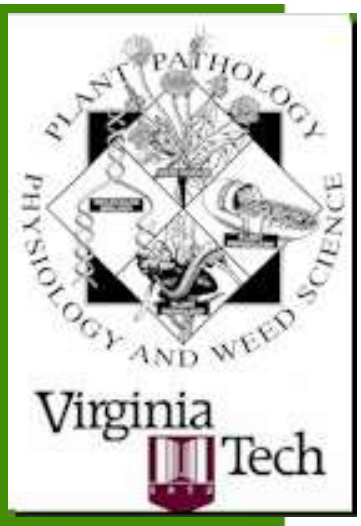
Clerical Staff

- Boyd, Arleta - Executive Secretary Sr.
- Fielder, Judy - Program Support Technician
- Neice, Patsy - Program Support Technician Sr.

Technical Staff

- Fagg, Christy - Laboratory Technician
- Feizabadi, Shahrooz - Program Analyst
- Gilbert, Crystal - Laboratory Specialist Senior
- Hampton, Jaime - Laboratory Specialist Senior
- Keating, Phil - Laboratory Specialist Senior
- Kenley, Claude - Research Specialist Senior
- Reaver, Diane - Laboratory Specialist Advanced
- Russell, Melissa - Laboratory Specialist Senior
- Stromberg, Verlyn - Laboratory Specialist Senior
- Tucker, Elizabeth - Laboratory Technician
- Vance, Amy - Laboratory Specialist

Last Updated July 30, 2003.



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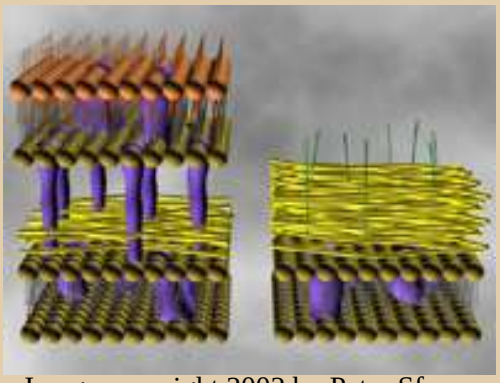
Students

2002-2003 GRADUATE STUDENTS

NAME	University/College Conferring Last Degree	Degree	Curriculum	Advisor
Barker, Whitnee	U. of Kentucky, Lexington	MS	WS	Askew
Beam, Josh	North Carolina State U.	Ph.D.	WS	Askew
Bennett, Selester	Virginia Tech	Ph.D.	Phys	Cramer
Fayad, Amer	American University, Beirut	Ph.D.	Path	Tolin
Kaufman, Nichole		MS	WS	Askew
Hamamouch, Noureddine	Med. Agronomy Inst., Chanra	Ph.D.	WS	Westwood
Heim, William	George Mason U.	MS	Phys	Jelesko
Hoff, Troy	Virginia Tech	Ph.D.	Path	McDowell
Hogan, Eric	James Madison U.	Ph.D.	Path	Griffin
Hurtado, Oscar	U. Nacional Agraria LaMolina	MS	WS	Westwood
Liu, Juanyun	Lanzhou U., China	Ph.D.	Phys	Cramer
Mackasmiel, Lucas	Virginia Tech	Ph.D.	Path	Tolin
Mane, Shrinivasrao		Ph.D.	Phys	Grene
Marvel, Josh	U. of Delaware	MS	Path	Alexander
McCall, David	Radford U.	MS	Path	Couch
Morozov, Ivan	Virginia Tech	Ph.D.	WS	Hagood/ Hipkins
Raymond, Michelle	U. of Delaware	MS	WS	Westwood/ Nessler
Reidy, Michael	Virginia Tech	Ph.D.	Phys	Cramer
Sforza, Peter	Virginia Tech	MS	Path	Hagood/ Stromberg
Simon, Stacey	Delaware State U.	Ph.D.	Path	McDowell

Stiles, Amanda	Virginia Tech	MS	Mol Bio	Grabau
Sun, Jian		Ph.D.	Mol Bio	Jelesko
Vasquez, Cecilia	U. Nacional Agraria LaMolina	Ph.D.	Phys	Grene
Whaley, Cory	Clemson U.	Ph.D.	WS	Wilson
Yun, Myoung-Hwi	Myoung J. U., Korea	Ph.D.	Phys	Chevone
Zhang, Wenyan	South China Agricultural U.	Ph.D.	Mol Bio	Chevone

Last Updated July 30, 2003.



Comparison of Gram-negative (left) and Gram-positive (right) cell walls

Key:

Peptidoglycan layer (yellow)
Protein (purple)
Teichoic acid (green)
Phospholipid (brown)
Lipopolysaccharide (orange)

Peter M. Sforza

Extension Research Associate,
Integrated Pest Management
and M.S. Student in Plant Pathology
418-C Price Hall
Department of Plant Pathology, Physiology, and Weed Science

Virginia Cooperative Extension

Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0331

Phone: (540) 231-1867
Fax: (540) 231-7477
E-mail: psforza@vt.edu

- Extension / Outreach
  - Weed collection - Images of 41 common weeds
  - 3-D and Virtual Reality
    - Weeds: Dandelion, Virtual Agroecosystem
    - Bacteria: Gram-positive and Gram-negative cell walls, Agrobacterium
    - Nematodes: Root-knot
    - Viruses: TMV, luteovirus, geminivirus, aphid transmission of BYDVs
    - Fungi: *Cercospora*
    - Serology: Detection of pathogens using DAS-ELISA
- Research
  - Survey of Virginia wheat fields
  - Management and epidemiology of Barley Yellow Dwarf Viruses
  - GIS for agricultural pest management
  - Weather and Degree-Days for IPM
  - Virginia climate | Virginia PET and PET-P | Station Graphs
- Virginia STATSGO maps
- Double-cropped corn in Virginia
- Statistics
- Virginia. Climate (IMS under construction).
- Presentations (barley yellow dwarf, degree-day calculator, double-cropped corn)
- Resume

- Internet documents and sites
- WWW links

Peter Sforza
Last updated February 20, 2004

Arleta L. Boyd
Executive Secretary, Senior
Department of Plant Pathology,
Physiology and Weed Science
413 Price Hall
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E-mail: boydal@vt.edu

General Introduction

Arleta has an Associate Degree in Business Management from New River Community College and is the secretary to the Department Head of PPWS. She is also a Certified Professional Secretary.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated May 07, 2001

Judy H. Fielder

Program Support Technician
412 Price Hall
Department of Plant Pathology, Physiology and Weed Science
Virginia Tech
Air Pollution Laboratory
Blacksburg, VA 24061-0330

Phone: 540-231-7876
Fax: 540-231-7477
E-mail: jfielder@vt.edu

General Introduction

Effective service date December 16, 1978. Judy graduated from Northside High School in June of 1978 and has received a Secretarial Development Certificate as well as Principles of Supervision I both from New River Community College. At the present time, she is attending Virginia Western Community College and will receive a course credit in the class Designing with Perennials (future classes in the Horticultural field are pending). Judy's office is located in 412 Price Hall. She provides assistance to faculty, staff, and students by means of assigning purchase orders, payment of invoices, filing travel reimbursement vouchers, distributing mail, inventory/surplus of items in the department, submission of the monthly leave reports. Judy handles the accounts for the faculty through the Virginia Tech Foundation, Inc. For the past 9 years Judy has been responsible for the departmental monthly newsletter 'PPWS News' and she compiles/distributes the departmental directory in the fall semester. Judy is married to Larry and she enjoys bowling, planting flowers, landscaping, and working outdoors.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated July 22, 2002

Patsy J. Neice

Fiscal Technician
412 Price Hall
Department of Plant Pathology,
Physiology and Weed Science
Virginia Tech
Blacksburg, VA 24061-0330

Phone: (540)231-7475
Fax: (540)231-7477
E-mail: pneice@vt.edu

General Introduction

Effective Service Date June 24, 1974. Patsy serves the department as bookkeeper.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated February 17, 1999

Philip J. Keating

Laboratory Specialist Senior
Department of Plant Pathology,
Physiology and Weed Science
Virginia Tech
Blacksburg, VA 24061-0331

Phone: (540)231-9598
Fax: (540)231-7477
E-mail: pkeating@vt.edu

General Introduction

Effective Service Date April 1, 1976. Phil works in the Turfgrass Disease Laboratory with Dr. H. B. Couch. He is married, has two daughters, and enjoys hunting, hiking, fishing, travel and golf.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated February 17, 1999

Claude C. Kenley

Laboratory Specialist Senior
Department of Plant Pathology,
Physiology and Weed Science
Virginia Tech
Blacksburg, VA 24061-0331

Phone: (540)231-7176
Fax: (540)231-7477
E-mail: cckweeds@vt.edu

General Introduction

Effective Service Date July 5, 1976. Claude is married and has two children Cameron and Sarah Grace. He is in charge of the Weed Identification Clinic and field research responsibilities for Dr. E. S. Hagood, Weed Science. He enjoys all sports, especially hunting and fishing.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated February 17, 1999

Diane M. Reaver

Laboratory Specialist Senior
Department of Plant Pathology,
Physiology and Weed Science
Virginia Tech
Blacksburg, VA 24061-0331

Phone: (540)231-5099
Fax: (540)231-7477
E-mail: dianer@vt.edu

General Introduction

Diane has a B. S. degree from the University of Michigan (1968). She spent several years in production of agriculture before earning her M.S. degree in Plant Pathology from Virginia Tech (1989). She has 13 years experience as in plant disease diagnostics, plant-parasitic nematode extraction and identification, and database management. She has given Extension educational talks to growers and Extension Agents. She has regularly attended the biennial Ornamental Workshop in Crossnore, NC, as well as other diagnostic workshops, and computer classes. She also attends national and regional meetings of the American Phytopathological Society. She is currently working in the Plant Pathology Lab of Dr. G. J. Griffin and in the Plant Physiology Lab of Dr. D. M. Orcutt.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated November 05, 2001

Verlyn K. Stromberg

Laboratory Specialist Senior
Department of Plant Pathology, Physiology and Weed Science
Virginia Tech
Plant Molecular Biology Building, Old Glade Road
Blacksburg, VA 24061-0330

Phone: (540)231-5090 (M,T,W), 231-7703 (Th,F)
Fax: (540)231-5755
E-mail: verlyn@vt.edu

General Introduction

Effective Service Date October 1, 1982. Verlyn has an AA degree in Science from Fresno City College, Fresno, CA (1966), a BA degree in Bacteriology from California State University, Fresno (1968), and two years of postgraduate education in Microbiology at Oregon State University, Corvallis, OR (1968-70). She had seven additional years of technical research experience at Oregon State University in the Departments of Microbiology, Horticulture, and Botany and Plant Pathology. She has several refereed journal articles, chapters proceedings, and published abstracts. She has presented scientific papers in Bulgaria, Hungary, and Blacksburg, and Rochester. Additionally, Verlyn has attended scientific meetings in Arizona, Virginia, California, Maryland, Canada, Georgia, New York, and Washington, DC. Ms Stromberg is a member of the Department's Education Committee and the departmental representative to the College staff association. She works in the Phytobacteriology Laboratory with Dr. George Lacy and the Plant Physiology Laboratory with Dr. Ruth Alscher.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated February 17, 1999

Cynthia Denbow

Research Scientist
317 Fralin Biotechnology Center
Department of Plant Pathology,
Physiology and Weed Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

Phone: 540-231-4145
Fax: 540-231-7126
E-Mail: cdenbow@vt.edu

Education:

- B.S. – Zoology and Poultry Science, N.C. State University at Raleigh
- M.S. – Physiology, NCSU, and Ph.D. – Plant Physiology, Virginia Tech

Professional Experience:

- Research Scientist – Virginia Tech – 1997 to present

Teaching Interests:

- Molecular Biology
- Plant Physiology

Research Interests:

- Production of human proteins from transgenic plants
- Protein trafficking and localization
- Structure/function/cellular localization analyses of plant ABC transporters

Selected Publications:

1. Denbow, C.J., Lang, S. and C. Cramer. The N-Terminal Domain of Tomato 3-Hydroxy-3-methylglutaryl CoA Reductases. J. Biol. Chem. 271: 9710-9715.

Additional Information:

- Carole Cramer's lab homepage

Department of Plant Pathology, Physiology, and Weed Science
Last Updated April 06, 2000

FAN DENG

Research Scientist
Department of Plant Pathology,
Physiology and Weed Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0330

Phone: (540) 231-5835
Fax: (540) 231-5755
E-Mail: fandeng@vt.edu

Education:

- Ph.D., University of Tsukuba, Tsukuba, Japan - 1996
- M.S., Anhui Agricultural University, Anhui, China - 1991
- B.S., Fujian Agricultural University, Fujian, China - 1984

Professional Experiences:

- 1999-present. Research Scientist /Postdoctoral Research Associate, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24060, USA
- 1999 (April - November). Postdoctoral Research Scientist. Plant Biotechnology Research Center, Michigan Technological University, Houghton, MI 49931, USA
- 1996-1999. Domestic Research fellow of Japan Science and Technology Agency. National Agriculture Research Center, Ministry of Agriculture, Forestry & Fisheries, Japan.
- 1996. Postdoctoral Research Associate. Biological Resources of Division, International Research Center for Agricultural Sciences, Ministry of Agriculture, Forestry and Fisheries, Japan
- 1991-1996. Graduate Research Assistant. Institute of Applied Biochemistry, University of Tsukuba, Tsukuba, Ibaraki 305-0042, Japan.

Recent Awards and Honors:

- 2002: A Member of one hundred oversea Scientists Delegation invited by Oversea Division , the State Council of the People's Republic of China
- 2001: Extraordination ability Scientist was approved by INS, USA
- 1999: Outstanding Research Award from the Weed Science Society of Japan.
- 1992-1996: Awarded the scholarship from Japanese Ministry of Education

Sponsors of Current or Recent Research:

Collaborator on a USDA-NRICGP, 1998 - 2002, (PI: Kriton Hatzios)

Research Interests:

- Enzymology, gene expression, and functions of glutathione *S*-transferases (GST) in rice and other plants
- Transformation of Arabidopsis, rice, and other crop plants with GST genes
- Chemical safeners for the protection of rice against injury from chloroacetanilide herbicides
- Lignin and cellulose biosynthesis as target sites for herbicide action

Selected Publications:

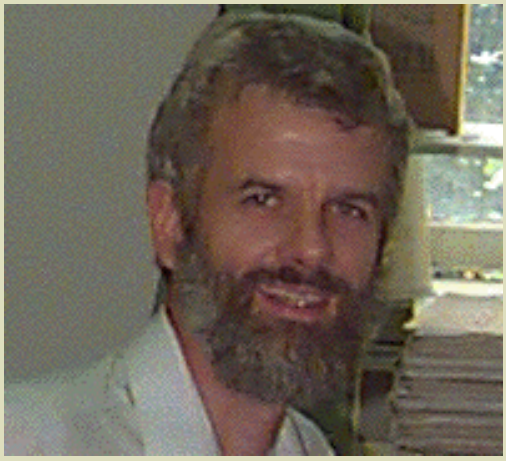
1. Fan Deng, K. Usui and K. Ishizuka. Effects of pretilachlor and fenclorim on growth and glutathione S-transferase activity of rice and early watergrass. Japan Weed Research. 40. (3)163-171. 1995.
2. Fan Deng, K. Usui, I.S. Shim, K.Kobayashi and K. Ishizuka. Characterization of glutathione S-transferase from rice (*Oryza sativa* L.) and early watergrass (*Echinochloa oryzicola* Vasing) seedlings using pretilachlor as a substrate. Japan Weed Research 40. (3) 172-178. 1995.
3. Fan Deng, K. Usui, I.S. Shim, K.Kobayashi and K. Ishizuka. Activity and characterization of glutathione S-transferase from rice and early watergrass seedlings using fenclorim as a substrate. Japan Weed Research. 41. (1) 38-43. 1996.
4. Fan Deng, K. Usui, I.S. Shim, K.Kobayashi and K. Ishizuka. Difference in glutathione content, glutathione S-transferase activity and GS-pretilachlor content between rice and early watergrass seedlings. Japan Weed Research. 41. (4) 295-301, 1996.
5. Fan Deng, K. Usui, I.S. Shim, K.Kobayashi and K. Ishizuka. Induction of glutathione S-transferase in rice by combination treatment of pretilachlor and fenclorim. Japan Weed Research. 41, 26-27, 1996.
6. Kenji Usui and F. Deng. Function of enzyme involved in herbicide action mechanism. The Northeast Asian Weed Science, Symposium of China,Korea and Japan. In China. 98-103. 1996.
7. Fan Deng, A. Nagao, I. S. Shim and K. Usui. Induction of glutathione S-transferase isozymes in rice shoots treated with the combination of pretilachlor and fenclorim. J. Weed Sci. Tech. 42 (3) 277-283. 1997.
8. Fan Deng, T. Nimura and K. Usui Induction and inhibition of P-450 activities in rice and wheat by xenobiotics. Cytochrome P450 and plant Genetic Engineering. 57-58.1997.
9. Fan Deng, Y. Yogo. Effect of bensulfuron methyl and glyphosate on monolignel synthesis and their growth inhibition. J. Weed Sci. Tech. 43. 208-209. 1998.
10. Fan Deng, M. Aoki and Y. Yogo. The effect of nringenin on the monolignol biosynthesis and the growth of annual plants. J. Weed Sci. Tech. 43. 292-293. 1998.
11. Usui K, F. Deng, I.S. Shim and K. Kobayashi. Differential content of pretilachlor, fenclorim and their metabolites between rice and early watergrass (*Echinochloa oryzicola* Vasing) seedlings leading to selectivity and safening actionin. J. Weed Sci. Tech. 44. 37-42. 1999.
12. Fan Deng, M. Aoki and Y. Yogo Substrate specificity of coumarate CoA ligase and inhibition of root growth of several plant species by naringenin. J. Weed Sci. Tech. 44. 306-307. 1999.
13. Aoki. M., F. Deng and Y. Yogo Effect of phenylpropanoids on the growth of Arabidopsis thaliana. J. Weed Sci. Tech. 44. 310-311. 1999.
14. Fan Deng. The role of glutathione S-transferase on selectivity of pretilachlor and safening action. J. Weed Sci. Tech. 44 (3). 383-390. 1999.
15. Usui K, F. Deng O-Dealkylation of counarin esters and effects of safeners, inhibitors and sulfonylureas on rice cytochrome P-450. J. Weed Sci. Tech. 44 (4). 341-348. 1999.
16. K. Usui, Fan Deng, A. Nagao and I. S. Shim, Differential glutathione S-transferase isozyme

activities in rice and early watergrass seedlings. Weed Biology and Management. 1:128-132. 2001.

17. Fan Deng, Yuji Yamada and Kenji Usui, Relationship between safening activity of dymron and fenclorim to pretilachlor and glutathione S-transferase in rice. Weed Biology and Management. 1: 216-221. 2001.
18. Fan Deng, K. K. Hatzios, Characterization and safener-induction of multiple glutathione S -transferase in three genetic lines of rice. Pesticide Biochemistry and Physiology. 72:24-39, 2002.
19. Fan Deng, K. K. Hatzios, Purification and Characterization of Two Glutathione S-transferase Isozymes from Indica-type Rice Involved in Herbicide Detoxification. Pesticide Biochemistry and Physiology. 72:10-23, 2002.

Department of Plant Pathology, Physiology, and Weed Science

Last Updated July 15, 2002



Anton B. A. M. Baudoin

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General

- Associate Professor.
- PhD, University of California, Riverside, 1980.
- Teaching 90%, research 10%.

Teaching

Dr. Baudoin's teaching responsibilities include courses in:

- Pest Management (pathology section), AT 0434, for agriculture technology.
- Plant Pathology, PPWS 3104
- Principles of Plant Disease Management, PPWS 5204
- Diseases of Crop Plants, PPWS 5214
- Epidemiology of Plant Diseases (a section of PPWS 5404, taught separately as PPWS 6004)
- Principles of Biology, BIOL 1106

Click here to go to the current or most recent semester's coursepages

Research

Current research centers on **biology and control of fungal diseases of grapes**, with emphasis on Botrytis bunch rot, black rot, and sour rot. Major areas:

1. Determining feasibility and benefits of vineyard weather monitoring and use of a Botrytis infection model to optimize spray timing against Botrytis bunch rot. Exploring modifications of Botrytis infection models.
2. Determining effect of grape cluster "cleaning" (by blower, to dislodge cluster debris) on Botrytis bunch rot incidence and severity. Exploring feasibility and benefits of this practice for cultural control of bunch rot. (Wolf, T. K., Baudoin, A. B. A. M., and Martinez-Ochoa, N. 1997. Effect of floral debris removal from fruit clusters on Botrytis bunch rot of Chardonnay grapes. Vitis 36: 27-33)
3. Early detection of fungicide resistance. In a survey of Botrytis cinerea in Virginia vineyards, two vineyards were found with high frequency (over 90%) of Botrytis strains with low-level resistance to iprodione (Rovral). Nevertheless, a field test in one of these vineyards showed fairly good

efficacy of iprodione. Iprodione resistance was detected in several additional vineyards, but only at low frequencies. High-level benomyl (Benlate) resistance was found in 60% of Virginia Vineyards surveyed (Baudoin, A.B.A.M. 1994. Iprodione-resistant Botrytis cinerea in Virginia vineyards. Plant Disease 78: 102).

4. Collecting basic information on sour rot, a complex disease caused by a variety of yeasts and bacteria. The role of individual pathogens is under investigation, as well as the role of the composition of the vineyard epiphytic microflora. Changes in fruit chemistry and aroma compounds produced by rots caused by individual pathogenic yeast species are being determined. The possible effect of copper fungicides on berry skin strength, integrity, and susceptibility to cracking is being explored.
5. Refining black rot infection models by determining effects of interruption in leaf wetness periods.
6. Effects of crop oils on grapevines and powdery mildew eradication. Cooperative work with Dr. Tony Wolf has quantified the effects of oil applications on photosynthesis (Finger, S. A., Wolf, T. K. and Baudoin, A. 2002. Effects of horticultural oils on the photosynthesis, fruit maturity, and crop yield of wine grapes. American Journal of Enology and Viticulture 53: 116-124).

Click here for Further information on grape research at Virginia Tech

An additional area of research is the **evaluation of weed pathogens for their potential for biological control of weeds**.

This has included collection and evaluation of pathogens of morningglories, cocklebur, yellow nutsedge, johnsongrass, kudzu, poison ivy, milkweed, hemp dogbane, and others.

A detailed study was made of a smut disease (Ustilago syntherismae) which largely prevents seed production of infected crabgrass. (Johnson, D. A. and Baudoin, A. B. A. M. 1997. Mode of infection and factors affecting disease incidence of loose smut of crabgrass. Biological Control 10: 92-97)

Also evaluated was a rust disease (Puccinia carduorum) of musk thistle (Carduus thoermeri). This rust was introduced into the USA for the purpose of biological control of the thistle. Completed studies include:

1. Field tests of the impact of the rust disease on the growth, development, and seed production of musk thistle as well as field tests to confirm the safety of the pathogen to non-target crops (artichoke) and native, endangered Cirsium species. (Baudoin, A. B. A. M., Abad, R. G., Kok, L. T., and Bruckart, W. L. 1993. Field evaluation of Puccinia carduorum for biological control of musk thistle. Biological Control 3: 53-60.)
2. An examination of the population dynamics and spread of the pathogen. Since its introduction in Virginia in 1987, the pathogen by 1994 had spread spontaneously as far as central Missouri. (Baudoin, A. B. A. M. and Bruckart, W. L. 1996. Population dynamics and spread of Puccinia carduorum in the eastern United States. Plant Disease 80: 1193-1196.)

Peck, A.R., Baudoin, A., Hansen, M.A., and Amrine, J.W. Jr. 2002. Recent spread of rose rosette disease in the southeastern United States. Phytopathology 93 (in Press) (poster presented at meeting of the Potomac Division of the American Phytopathological Society)

Click here for information on the Potomac Division, American Phytopathological Society

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Department of Plant Pathology, Physiology, and Weed Science

Last Updated July 22, 2002

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Education:

- Ph.D., Plant Pathology, North Carolina State Univ. (NCSU), Raleigh, N.C. 1979
- B.A., Biology, Bryan College, Dayton, Tenn., 1974

Professional Experience:

- **Professor**, Dept. Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State Univ. (VPI&SU), Blacksburg, Va., 1994-present.
- **Associate Professor**, Dept. Plant Pathology, Physiology and Weed Science, VPI&SU, Blacksburg, Va., 1990-94
- **Assistant Professor**, Dept. Plant Pathology, Physiology and Weed Science, VPI&SU, Blacksburg, Va., 1985-90
- **Research Associate**, International _*Meloidogyne*_ Project, Dept. Plant Pathology, North Carolina State University (NCSU), Raleigh, N.C., 1979-85
- **Graduate Research Assistant**, Dept. Plant Pathology, NCSU, Raleigh, N.C. 1975-79
- **General Science Teacher**, Ninth Grade, Rhea County Consolidated High School, Evensville, Tenn., 1974-75

Professional Societies:

- Society of Nematologists, 1975
- Organization of Tropical American Nematologists, 1979
- Southeastern Electron Microscopy Society, 1977
- Virginia Academy of Science, 1985
- American Phytopathological Society (APS), 1985
- Biological Photographic Association, 1986
- Gamma Sigma Delta, 1979
- Sigma Xi, 1979

Recent Awards and Honors:

- Ciba-Giegy Award for outstanding contributions to agriculture from the Society of Nematologists, 1996.
- Secretary, Society of Nematologists, 1994-1997.

Research, Teaching and Extension Interests:

- Taxonomy of root-knot nematodes (*Meloidogyne* spp.): My research focuses on the practical identification of the economically most important group of plant-parasitic nematodes. I am interested in light and scanning electron microscopy and molecular techniques for distinguishing the known species of root-knot nematode. Currently, six new species have been described in my lab and several more are currently being described.
- Taxonomy of the Virginia tobacco cyst nematodes (*Globodera tabacum solanacearum* and *G. t. virginiae*: Tobacco cyst nematode is the most important pathogen on tobacco in the state of Virginia. I am interested in useful characters that enable a correct identification of these subspecies. Currently my lab is utilizing light and scanning electron microscopy and molecular techniques. We are comparing several isolates including intergeneric hybrids of *Globodera* and *Heterodera*.
- Resistance to the Northern Root-Knot Nematode, *Meloidogyne hapla*: Northern root-knot nematodes are the most common nematodes found parasitizing soybean in Virginia. More than 50% of the soybean fields in Virginia are infested with the northern root-knot nematode. Unfortunately there are few reports of resistance of soybean cultivars for the northern root-knot nematode. Generally, the cultivars that are resistant to root-knot nematodes, are resistant only to *M. incognita*, *M. arenaria*, and *M. javanica*. Most of these lines are susceptible to *M. hapla* or have not been tested for resistance to this pest.
- Interactive multimedia: I am actively pursuing the incorporation of this new computer technology into courses taught within the department, much of the material for my class has been developed into interactive multimedia.
- Resource development: Resources for teaching nematology are extremely scarce. I have created several items for my own classes and have made them available to others. These resources include posters, slide sets, videos, models, and lab manuals.

Selected Publications:

1. Eisenback, J. D., and H. Hirschmann. 2000. Additional notes on the morphology of *Meloidogyne spartinae*. Nematology 3:xxx-xxx (in press).

2. Rideout, S., C. S. Johnson, J. D. Eisenback, and T. D. Reed. 2000. The Effect of Soil Edaphic and Biological Factors on Reproduction of the Tobacco Cyst Nematode (G. t. s.). Annals of Applied Nematology 32: xxx-xxx (in press)

3. Zunke, U., and J. D. Eisenback. 2000. Mycopix, A journal of mycological images, Vol. 1. Plant-parasitic fungi. Mactode Publication: Blacksburg, VA. ISBN: 1-893961-09-5

4. Rideout, S. , C. S. Johnson, J. D. Eisenback, and C. A. Wilkinson. 2000. Development of selected tobacco cyst nematode (*Globodera tabacum solanacearum*) populations on resistant and susceptible cultivars of flue-cured tobacco. Journal of Nematology 32:62-69.

5. Eisenback, J. D. 2000. Techniques for measuring nematode development and egg production. Pp. 1-4, in, Laboratory Techniques in Nematode Ecology. Wheeler et al., eds. Society of Nematologists: Hyatsville, Md.

6. Eisenback, J. D. 2000. Pin nematodes. Pp. xxx-xxx in The Encyclopedia of Plant Pathology, O. C. Maloy and T. D. Murray, eds., John Wiley Publishers, N.Y. (in press)

7. Eisenback, J. D. 1999. Glossary of plant nematology and related terms. CAB International Publishing, Wallingford, Oxon, U.K. ISBN: 0-85199-226-9

8. Eisenback, J. D., and U. Zunke. 1999. Image Library for Nematology. Expert-center for

Taxonomic Identification. Springer-Verlag:Amsterdam, The Netherlands.

9. Eisenback, J.D., and U. Zunke. 1999. Nemapix Vol. 2, a journal of nematological images. Mactode Publications: Blacksburg, VA. ISBN: 1-893961-07-9
10. Jie, Wang, C. S. Johnson, J. D. Eisenback, and T. D. Reed. 1999. Effects of tobacco cyst nematode on growth of flue-cured tobacco. Journal of Nematology 31: 336-333.
11. Charchar, J. M., J. D. Eisenback and H. Hirschmann. 1999. Description of *Meloidogyne petuniae* n. sp., a Root-Knot Nematode Parasitic on Petunia (*Petunia hybrida*) in Brazil. Journal of Nematology 31:81-91.
12. Eisenback, J. D. 1999. Videos for Teaching Nematology. Nematology Newsletter 44 (3): 28-33.
13. Eisenback, J. D. 1999. Films for Teaching Nematology. Nematology Newsletter 44: (4): 26-30.

Courses Taught:

- Agricultural Botany AT0184
- Plant Pathology Seminar PPWS
- Plant Nematology PPWS 5440

Department of Plant Pathology, Physiology, and Weed Science

Last Updated September 22, 1998

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Education:

- B. S., The Ohio State University, Columbus, Ohio, 1979
- M. S., University of Wisconsin, Madison, Wisconsin, 1984

Professional Experience:

- **Instructor and Plant Clinic Manager,** Department of Plant Pathology, Physiology, and Weed Science, Virginia Tech, Blacksburg, Virginia 24060-0331, 1993-present
- **Plant Clinic Manager,** Department of Plant Pathology, Physiology, and Weed Science, Virginia Tech, Blacksburg, Virginia 24060-0331, 1984-1993
- **Extension Horticulture Intern,** Wood County Extension Office, Wisconsin Rapids, Wisconsin, Summer 1984
- **Research Fellow/ Research Assistant,** Department of Plant Pathology, University of Wisconsin, Madison, Wisconsin, 1981-1984
- **Extension Plant Pathologist Intern,** Farm Advisory Service, Forsogsgaarden Godthaab, Skanderborg, Denmark, 1979-1980

Teaching Interests:

- Diagnostic Plant Pathology
- General Biology

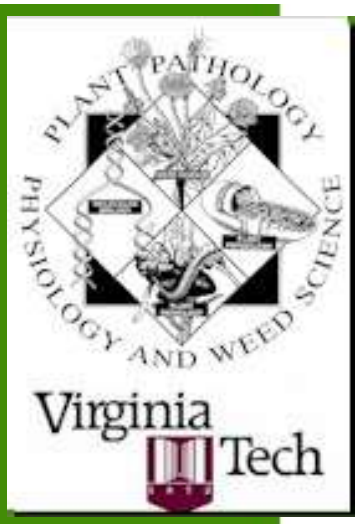
Selected Publications:

1. Hansen, M. A., and Wick, R. L. 1994. Plant disease diagnostics: present status and future prospects. *In*: Advances in Plant Pathology, Volume 10 (J. H. Andrews, ed.), Academic Press, London.
2. Hansen, M. A., Wick, R. L., and Stromberg, E. L. 1990. First report of *Phytophthora megasperma f. sp. glycinea* on soybean in Virginia. Plant Disease 74:183.

On-line Resources:

- Plant Disease Clinic - http://www.ppws.vt.edu/~clinic

Last Updated June 28, 2002



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Plant Disease Clinic and Nematode Assay Lab

Virginia Tech's Plant Disease Clinic provides plant disease diagnostic services to Extension offices in the state of Virginia. The Clinic handles plant samples with problems caused by pathogens, including fungi, bacteria, viruses, and nematodes, and environmental or other abiotic factors. Samples with suspected insect damage should be sent to the Insect Identification Lab.

Disease diagnosis can be provided for any type of plant. Other services provided by the Plant Disease Clinic include mushroom identification and plant identification of non-weedy plants. Weed identifications are handled separately by the Weed Clinic. The Nematode Assay Lab provides diagnostic and predictive assays of nematode problems.

All plant and soil samples should be submitted through the local county Extension office with an appropriate, completed form. If more than one plant is submitted per client, a separate form should be completed for each plant. Different forms are available for plant samples, diagnostic nematode assays, and predictive nematode assays. For instructions on preparing samples and completing forms, please click the Submitting Samples button on the side bar.

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Last Updated June 14, 2002
Comments to clinic@vt.edu
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Education:

- Ph.D. Plant Pathology. Beijing Agricultural University. Beijing, China. 1990
- M.S. Plant Pathology. Beijing Agricultural University. Beijing, China. 1987
- B.S. Plant Protection. Anhui Agricultural College. Hefei, China. 1982

Professional Experience:

- Assistant Professor of Plant Pathology. Hampton Roads Agricultural Research and Extension Center and Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University. Blacksburg, VA. 1999 to present
- Research Plant Pathologist. Kearney Agricultural Center and Department of Plant Pathology, University of California, Davis, CA. 1995 to 1999
- Rothamsted International Fellow. Rothamsted Experimental Station. Harpenden, UK. 1994 to 1995
- Research Fellow. International Crops Research Institute for the Semi-Arid Tropics. Hyderabad, India. 1993 to 1994
- Associate Professor of Plant Pathology. Chinese Academy of Agricultural Sciences. Beijing. China. 1993
- Assistant Professor of Plant Pathology. Chinese Academy of Agricultural Sciences. Beijing. China. 1990 to 1992
- Extension Specialist of Plant Protection. National Extension Service, Jixi County, Anhui, China. 1982 to 1984

Teaching Interests:

- Principles of Plant Disease Management
- Direction of graduate student research programs for M.S. and Ph.D.
- Short courses and workshops for plant health care consultants and industry workers
- Guest lectures on environmental plant pathology

Research Interests:

Nursery and landscape industry is highly diversified in plant species and culture systems. But there also are many common issues facing all nurseries, such as water recycling, interstate and international movement of ornamental materials and products, re-use of green wastes and potting mixes. The mission of our laboratory is to work on these common concerns, seek innovative and practical solutions to the disease problems associated with recycling and trading processes, and help the industry stay one step

ahead of these issues. Our research interests encompass applied and basic aspects of plant pathology including molecular characterization and detection of plant pathogens, investigation of basic pathogen biology and ecology, epidemiology and ornamental disease management. Current areas of interest include characterization and detection of plant pathogens in recycling irrigation systems, ecology and epidemiology of ornamental diseases, biological and economic thresholds of waterborne pathogens for major nursery crops, and integrated control strategies.

Extension Interests:

- Digital Nursery Workshop: Internet Resources for Integrated Pest Management
- Environmental Plant Pathology website

Selected Publications:

1. Hong, C. X., Michailides, T. J., and Holtz, B. A. 2000. Mycoflora of stone fruit mummies in California orchards. Plant Disease 84:417-422.
2. Hong, C. X. and Michailides, T. J. 1999. Mycelial growth, sporulation, and survival of *Monilinia fructicola* in relation to osmotic potential and temperature. Mycologia. 91:871-876.
3. Hong, C. X., Michailides, T. J., and Holtz, B. A. 1998. Effects of wound, inoculum concentration and biological agent on postharvest brown rot of stone fruits. Plant Disease. 82:1210-1216.
4. Holtz, B. A., Michailides, T. J., and Hong, C. X. 1998. Development of apothecia from stone fruit infected and stromatized by *Monilinia fructicola* in California. Plant Disease. 82:1375-1380.
5. Hong, C. X. and Michailides, T. J. 1998. Effect of temperature on the discharge and germination of ascospores by apothecia of *Monilinia fructicola*. Plant Disease. 82:195-202.
6. Hong, C. X., Holtz, B. A., Morgan, D. P., and Michailides, T.J. 1997. Significance of thinned fruit as a source of the secondary inoculum of *Monilinia fructicola* in California nectarine orchards. Plant Disease. 81:519-524.
7. Hong, C. X. and Michailides, T. J. 1997. Prune, plum, and nectarine as hosts of *Trichothecium roseum* in California orchards. Plant Disease. 81:112.
8. Hong, C. X., Fitt, B. D. L., and Welham, S. 1996. Effects of wetness period and temperature on development of dark pod spot (*Alternaria brassicae*) on oilseed rape (*Brassica napus*). Plant Pathology. 45:1077-1089.
9. Hong, C. X. and Fitt, B. D. L. 1996. Factors affecting the incubation period of dark leaf and pod spot (*Alternaria brassicae*) on oilseed rape (*Brassica napus*). European Journal of Plant Pathology. 102:545-553.
10. Hong, C. X. and Fitt, B. D.L. 1995. Effects of inoculum concentration, leaf age, and wetness period on the development of dark leaf and pod spot (*Alternaria brassicae*) on oilseed rape (*Brassica napus*). Annals of Applied Biology. 127:283-295.

Current or Recent Research Sponsors:

- USDA-Southern Region IPM Program
- Virginia Agricultural Council
- Virginia State IPM Program
- Virginia Nursery and Landscape Association
- Individual Nurseries (e.g., Lancaster Farms, and Riverbend)

Additional Information:

Hampton Roads Agricultural Research and Extension Center

(http://www.vaes.vt.edu/hampton/index.html)

Department of Plant Pathology, Physiology, and Weed Science
Last Updated July 19, 2002

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Education:

- B.S., University of North Carolina, Chapel Hill, North Carolina, 1979
- M.S., North Carolina State University, Raleigh, North Carolina, 1982
- Ph.D., North Carolina State University, Raleigh, North Carolina, 1985

Professional Experience:

- Professor and Extension Plant Pathologist, Southern Piedmont Agricultural Research and Extension Center and Department of Plant Pathology, Physiology, and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 2000 to present.
- Associate Professor and Extension Plant Pathologist, Southern Piedmont Agricultural Research and Extension Center and Department of Plant Pathology, Physiology, and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1991 to 2000.
- Assistant Professor and Extension Plant Pathologist, Southern Piedmont Agricultural Research and Extension Center and Department of Plant Pathology, Physiology, and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 1985 to 1991.
- Graduate Research Assistant, Department of Plant Pathology, North Carolina State University, Raleigh, North Carolina 27695.

Recent Awards and Honors:

- Virginia representative in class 7 (1998) of the ESCOP/ACOP Leadership Development Program.

Research and Extension Interests:

- Biology and management of tobacco cyst nematodes (*Globodera tabacum solanacearum*).
- Management of tobacco diseases, particularly blue mold (*Peronospora tabacina*), black shank (*Phytophthora parasitica* var. *nicotianae*), collar rot (*Sclerotinia sclerotiorum*), and damping-off/sore shin (*Rhizoctonia solani*).
- Management of problem weeds in Virginia tobacco fields.

Selected Publications:

1. Wang, J., C. S. Johnson, J. D. Eisenback, and T. D. Reed. 1999. Effects of tobacco cyst nematode on growth of flue-cured tobacco. Journal of Nematology 31(3):326-333.

2. Rideout, S.L., C. S. Johnson, J. D. Eisenback, and C. A. Wilkinson. 2000. Development of selected tobacco cyst nematode isolates on resistant and susceptible cultivars of flue-cured tobacco. Journal of Nematology 32: *in press*.
3. Johnson, C. S., and S. L. Rideout*. 1999. Control of blue mold on burley tobacco in Virginia, 1998. Fungicide and Nematicide Tests 54:426.
4. Clarke, C. T., C. S. Johnson, and S. L. Rideout*. 1999. Fumigation and flue-cured tobacco cultivar NC 71 to control tobacco cyst nematodes in Mecklenburg County, Virginia, 1998. Fungicide and Nematicide Tests 54:295.
5. Johnson, C. S., B. G. Jones, and S. L. Rideout*. 1999. Broadcast vs. in-row fumigation to control tobacco cyst nematodes on flue-cured tobacco in Lunenburg County, Virginia, 1998. Fungicide and Nematicide Tests 54:296.
6. Johnson, C. S., W. B. Wilkinson, and S. L. Rideout*. 1999. Fungicidal control of black shank on burley tobacco in Virginia, 1998. Fungicide and Nematicide Tests 54:425.
7. Clarke, C. T., C. S. Johnson, and S. L. Rideout*. 1999. Controlling Granville wilt with host resistance, Virginia results, 1998. Biological and Cultural Tests 14:37.
8. Johnson, C. S., W. B. Wilkinson, and S. L. Rideout*. 1999. Virginia test for black shank resistance in burley tobacco, 1998. Biological and Cultural Tests 14:30.
9. Johnson, C. S. 1998 Dark-Fired Tobacco Production Guide. Disease Control. Publ. 436-049. Revised 1997.
10. Johnson, C. S. 1998 Dark-Fired Tobacco Production Guide. Weed Control. Publ. 436-049.
11. Johnson, C. S. 1998 Flue-Cured Tobacco Production Guide. Disease Management. Publ. 436-048.
12. Johnson, C. S. 1998 Flue-Cured Tobacco Production Guide. Weed Management. Publ. 436-048.
13. Johnson, C. S. 2000 Pest Management Guide for Field Crops. Diseases of tobacco. Publ. 456-106.
14. Johnson, C. S. 2000 Pest Management Guide for Field Crops. Weed control in tobacco. Publ. 456-106.

Current or Recent Research Sponsors:

- Virginia Bright Flue-Cured Tobacco Board
- Virginia Dark-Fired Tobacco Board
- Burley Stabilization Corporation, Agrichemical Industry
- Philip Morris USA

Additional Information:

- Extension Tobacco Information on the InterNet: http://www.ext.vt.edu:4040/eis/owa/docdb.getcat?cat=ir-cg-cr-to
- Tobacco Blue Mold Control Plant: http://www.ces.ncsu.edu/depts/pp/bluemold/
- Southern Piedmont Agricultural Research and Extension Center: http://www.vaes.vt.edu/blackstone/index.html
- Southwest Virginia Agricultural Research and Extension Center: http://www.vaes.vt.edu/glade/index.html

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Department of Plant Pathology, Physiology, and Weed Science

Last Updated May 28, 2002

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Education:

- Ph.D., Department of Genetics, University of Georgia, 1995.
- B.S., Cell and Molecular Biology, University of Tennessee, 1987.

Professional Experience:

- Assistant Professor of Molecular Plant Pathology, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2000-present.
- Postdoctoral Research, Department of Biology, University of North Carolina, Chapel Hill, NC (Laboratory of Dr. Jeffery L. Dangl), 1995-99.
- Graduate Research, Department of Genetics, University of Georgia (Laboratory of Dr. Richard B. Meagher), 1988-95.

Recent Awards and Honors:

- NIH Postdoctoral Fellow, 1995-1998.
- NIH Predoctoral Training Grant Fellow, 1991-1994.

Teaching Interests:

- ALS/PPWS 5344, Molecular Biology for the Life Sciences
- PPWS 5454, Plant Disease Physiology and Development
- Biol 4774, Molecular Biology Lab
- PPWS 6024, Topics in Molecular Cell Biology and Biotechnology

Research Interests:

Plants can be exploited for “free meals” by a wide variety of pathogens and pests. They have responded to this pressure by evolving inducible defense responses such as programmed cell death and antibiotic production at the site of infection. These innate immune responses are triggered by a sensitive, genetically complex surveillance system comprised of “R genes” that recognize specific molecules from the pathogen (conceptually analogous to an antibody-antigen interaction). My research focuses on the interaction between Arabidopsis and its natural pathogen *Peronospora parasitica* (downy mildew). I use molecular genetic, genomic, and bioinformatics-based approaches to address the following questions:

1. How do R genes “recognize” specific pathogens, and how do novel R genes evolve to recognize emerging pathogen variants? Does recombination between preexisting R genes facilitate evolution

of new resistance genes? Can answers to these questions inform efforts to engineer durable R genes against crop pathogens?

2. What is the configuration of intra- and inter-cellular regulatory networks that mediate between pathogen recognition and defense activation? How do these networks ensure that defenses are activated (and deactivated) in the proper time and place? Can regulatory components be manipulated to provide useful engineered resistance?

Selected Publications:

1. McDowell, J.M. and Woffenden, B.W. Plant Disease Resistance Genes: Recent Insights and Potential Applications. Trends in Biotechnology 21, 178-183 (2003).
2. Beers, E.P., and McDowell, J.M. Regulation and execution of programmed cell death in response to pathogens, stress, and environmental cues. Current Opinion in Plant Biology 4, 561-567 (2001).
3. McDowell, J.M., Cuzik, A., Can, C., Beynon, J., Dangl, J.L. and Holub, E.B. Downy mildew (Peronospora parasitica) resistance genes in Arabidopsis vary in functional requirements for NDR1, EDS1, NPR1, and Salicylic Acid accumulation. The Plant Journal 22, 523-31 (2000).
4. McDowell, J. M., and Dangl, J.L.. Signal Transduction in the Plant Immune Response, Trends Biochem. Sci. 25, 79-82 (2000).
5. McDowell, J. M.*, Dhandaydham, M.*, Long, T. A., Aarts, M. G. M., Goff, S., Holub, E. B., and Dangl, J. L.. Intragenic recombination and positive selection contribute to the evolution of downy mildew resistance at the RPP8 locus in Arabidopsis. The Plant Cell 10, 1861-1874 (1998). *equal first author
6. Grant, M. R.*, McDowell, J. M.*, Sharpe, A. J., Zabala, M., Lydiate, D. J., and Dangl, J. L.. Independent deletions of a pathogen resistance gene in Brassica and Arabidopsis. Proc. Natl. Acad. Sci. USA 95, 15843-15848 (1998). *equal first author
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Current Research Sponsors:

- NIH-NIGMS, 1995-1998, 2001-2006
- USDA-NRICGP, 1998-2005

Further Information:

- Fralin Biotechnology Center

Department of Plant Pathology, Physiology, and Weed Science

Last Updated October 30, 2003

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- B.S. Biology, 1970, Fairmont State College, Fairmont, WV
- M.S. Plant Pathology, 1972, Virginia Tech, Blacksburg, VA
- Ph.D. Plant Pathology, 1974, West Virginia Univ., Morgantown, WV

Professional Experience:

- Post Doctoral Study on Peanut Diseases, 1974-78, NC State Univ.
- Asst. Professor of Plant Pathology, 1978-84, Virginia Tech
- Assoc. Professor of Plant Pathology, 1984-89, Virginia Tech
- Professor of Plant Pathology, 1989-present, Virginia Tech

Recent Awards and Honors:

- Peanut Research and Education Award, American Peanut Foundation, 2000
- Dow AgroSciences Award for Excellence in Education, American Peanut Research & Education Society, 1999
- Extension Excellence Award, The American Phytopathological Society, 1994
- Virginia Tech Alumni Association - Excellence in Extension Award, 1994
- ESCOP/ACOP Leadership Development Program, 1993

Teaching Interests:

- Short courses and workshops for crop consultants and industry workers
- Guest lectures in Principles of Plant Disease Management and Epidemiology
- Direction of graduate student research programs for M.S. and Ph.D

Research Interests:

- Programs focus on diseases of peanut, cotton, soybean, small grain, and corn because of the importance of these crops to the economy in eastern Virginia. Goals are to develop and implement disease management strategies that are safe, effective, and maximize profits with little or no risk of harm to the environment, farm workers or the general public. Priority is given to development of strategies that require a minimum of pesticide input and make a positive contribution towards the goals of integrated pest management (IPM). Research interests include disease forecasting, and reducing the cost and rate of pesticides with new chemistry, cultural practices, variety selection, sanitation, and biological control.

Selected Publications:

1. Phipps, P. M., Maitland, J. C., and Eisenback, J. D. 1999. The growth and yield response of cotton to applications of Temik 15G in the seed furrow. Fungicide & Nematicide Tests 54:290.
2. Phipps, P. M., and Maitland, J. C. 1999. The effect of in-furrow fungicide, hopper box fungicide, and seed planting depth on emergence and growth of cotton. Fungicide & Nematicide Tests 54:375.
3. Phipps, P. M. 1999. Plant growth stages as factors in application of fungicide sprays for control of early leaf spot. Fungicide & Nematicide Tests 54:401.
4. Phipps, P. M., and Eisenback, J. D. 1999. Response of peanuts to various applications of metam and Temik for control of nematodes and Cylindrocladium black rot (CBR). Fungicide & Nematicide Tests 54:406.
5. Phipps, P. M., and Langston, Jr., D. B. 1999. An evaluation of advisory models for optimum timing of fungicide applications for control of Sclerotinia blight of peanut. Fungicide & Nematicide Tests 54:407.
6. Phipps, P. M., Langston, Jr., D. B., and Mozingo, R. W. 1999. Susceptibility of virginia- and runner-type peanuts to Sclerotinia blight. Biological & Cultural Tests 14:83.
7. Phipps, P. M., Holshouser, D. L., and Eisenback, J. D. 1999. Response of cyst nematode resistant, tolerant, and susceptible soybeans to applications of Temik in a naturally-infested field. Biological & Cultural Tests 14:94.
8. Phipps, P. M., and Porter, D. M. 1998. Collar rot of peanut caused by Lasiodiplodia theobromae. Plant Disease 82: 82:1205-1209.
9. Deck*, S. H., and Phipps, P. M. 1997. Development and implementation of a bulletin board system for information transfer to the Virginia peanut and cotton industry. Applied Engineering in Agriculture 13:415-419.
10. Phipps, P. M., and Beute, M. K. 1997. Cylindrocladium black bot. Pages 12-15 in Compendium of Peanut Diseases, N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, Eds., Amer. Phytopathological Soc., St. Paul, MN.
11. Phipps, P. M., Deck*, S. H., and Walker, D. R. 1997. Weather-based crop and disease advisories for peanut in Virginia. Plant Disease 81:236-244.
12. Porter, D. M., and Phipps, P. M. 1997. Diplodia collar cot. Pages 16-17 in Compendium of Peanut Diseases, N. Kokalis-Burelle, D. M. Porter, R. Rodriguez-Kabana, D. H. Smith, and P. Subrahmanyam, Eds., Amer. Phytopathological Soc., St. Paul, MN.
13. Deck*, S. H., and Phipps, P. M. 1996. Critical crop and weather information go online in Virginia. Amer. Soc. Agric. Eng., Resource Magazine 3:8-11.
14. Smith*, F. D., Phipps, P. M., Stipes, R. J., and Brenneman, T. B. 1995. Significance of

insensitivity of Sclerotinia minor to iprodione in control of Sclerotinia blight of peanut. Plant Disease 79:517-523.

15. Phipps, P. M. 1995. An assessment of environmental conditions preceding outbreaks of Sclerotinia blight of peanut in Virginia. Peanut Science 22:90-93.

Current or Recent Research Sponsors:

- Virginia Agricultural Council; Virginia Peanut Board; Virginia Cotton Board; Cotton Incorporated, Cotton Foundation, and Agricultural Chemical and Biotechnology Companies

On-line Resources:

- Peanut/Cotton InfoNet
- Tidewater Agricultural Research & Extension Center
- Soil Fumigation for Cylindrocladium Black Rot
- Risk Thresholds for Nematode Damage in Field Crops
- 2000 Virginia Pest Management Guide - Field Crops
- Virginia Peanut Production Guide
- Virginia Soybean Production Guide

Department of Plant Pathology, Physiology, and Weed Science
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Professional Experience:

- Professor and Extension Plant Pathologist, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0331, 1994 to present.
- Associate Professor and Extension Plant Pathologist, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0331, 1986 to 1993.
- Assistant Professor and Extension Plant Pathologist, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0331, 1981 to 1985.
- Plant Pathologist and Adjunct Assistant Professor, USDA, APHIS, PPQ, Department of Plant Pathology, University of Minnesota, St. Paul, MN 55108.
- Graduate Teaching Assistant, Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR 97331.

Recent Awards and Honors:

- 2001 - Recognition of Outstanding Service, American Phytopathological Society, APS Council, Division Councilor, 1998-2001.
- 2000 - Distinguished Service Award, Potomac Division, The American Phytopathological Society.
- 1997 - The Henderson Award, in Recognition as Outstanding Faculty Member, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University.
- 1996 - U.S. Patent No. 5,574,210, November 12, 1996. "Gray leaf spot resistant corn and the production thereof" For the use of molecular markers in breeding resistance to *Cercospora zeae-maydis* in corn.
- 1996 - The Virginia Small Grains Association, in Recognition for the Development in Implementing Scientifically Based Economic Recommendations for Wheat Disease Control.

Research and Extension Interests:

- Gray leaf spot resistance in maize involves the evaluation of maize germplasm for resistance to gray leaf spot caused by *Cercospora zeae-maydis*. Work with previous students (Dr. P.J. Donahue and M.R. Carter), collaborator Dr. Saghai Maroof has done much to determine how resistance is inherited, where genes for resistance are located on the maize chromosomes, and methods to incorporate such resistance in high yielding hybrid combinations by means of RFLP (restriction fragment length polymorphisms) assisted breeding. This work is reported in a recent article with M.A. Saghai Maroof in *Theor Appl Genet 93-539-546* and a U.S. Patent was awarded to VPI&SU, M.A. Saghai Maroof and E.L. Stromberg on 16 Nov 96.
- Reduction of the economic impact of take-all caused by *Gauemannomyces graminis* var. *tritici* on Virginia wheat production. This involves the management of fertility, crop rotations, seed treatment fungicides, biological agents (*Burkholderia cepacia* and some 20 other genera and species), and the development of DNA specific probes to detect the presence of this pathogen. This work has been done in conjunction with my two Ph.D. graduate students, Mr. Brooks Crozier and Ms. Sansanalak Rachdawong and a Master of Science student Ms, Indira Genowati. Support has been provided in part by the Virginia Small Grains Board, agri-chemical companies, and with Dr. D. P. Roberts of the USDA, ARS, Biocontrol of Plant Diseases Laboratory, Beltsville, MD.
- Refinement of economic thresholds for the control of foliar diseases in wheat for powdery mildew, stagonospora leaf and glume blotch, and tan spot.
- Evaluation of various chemical and biological seed treatments for control of disease in wheat to control seedling diseases, improve seedling vigor, control powdery mildew, and barley yellow dwarf virus.
- Evaluation of wheat germplasm for resistance to fusarium head scab in cooperation with Dr. C.A. Griffey, small grains breeder, two research associates, and a graduate student to identify potential sources of scab resistance (from Chinese spring wheat germplasm) and incorporate into soft-red winter wheats adapted for Virginia and study the edaphic conditions that predispose wheat to scab epidemics.

Selected Publications:

1. Rachdawong, S., C. L.Cramer, E. A. Grabau, G. H. Lacy and E. L. Stromberg. 2002. Gaeumannomyces graminis: PCR differentiation for take-all varieties avenae, graminis, and tritici. Plant Dis. 86: 652-660.
2. Stromberg, E.L. 2002. Evaluation of foliar fungicides for disease control in FFR 555 soft red winter wheat, 2001. Fungic. Nematic. Tests. Report 57:CF12.
3. Stromberg, E.L. 2002. Evaluation of seed treatments for the control of barley yellow dwarf in the soft red winter wheat cultivar FFR 555 in Virginia, 2001. Fungic. Nematic. Tests. Report 57:ST32.
4. Stromberg, E.L. 2002. Evaluation of selected fungicides and biological agents for the control of fusarium head blight in Roane soft red winter wheat in Virginia, 2001. Fungic. Nematic. Tests. Report 57:CF13.
5. Stromberg, E.L. and L.E. Flinchum. 2002. Evaluation of foliar fungicides for control of gray leaf spot of corn in Virginia, 2001. Fungic. Nematic. Tests. Report 57:FC91.
6. Stromberg, E.L., D.P. Roberts, G.H. Lacy, S.M. Lohrke, W.Li, and J.S. Buyer. 2002. Field evaluation of bacterial isolates and seed treatment fungicides for the control of take-all in Virginia, 2001. Bio. Cult. Control Tests. Report 17:S08.
7. Stromberg, E.L. and L.E. Flinchum. 2002. Resistance and agronomic characters of corn hybrids under natural gray leaf spot pressure, Wythe Co., 2001. Bio. Cult. Control Tests. Report 17:C07.
8. Stromberg, E.L. and L.E. Flinchum. 2002. Resistance and agronomic characters of corn hybrids under natural gray leaf spot pressure, Montgomery Co., 2001. Bio. Cult. Control Tests. Report

17:C08.

9. Stromberg, E.L. and G.H. Lacy. 2001. Pathogen. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.733. John Wiley & Sons, Inc, New York. 1346pps.
10. Stromberg, E.L. and G.H. Lacy. 2001. Pathogen-Sucept Interaction. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.735. John Wiley & Sons, Inc, New York. 1346pps.
11. Stromberg, E.L. and G.H. Lacy. 2001. Pathogenesis. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.736. John Wiley & Sons, Inc, New York. 1346pps.
12. Stromberg, E.L. and G.H. Lacy. 2001. Pathogenicity. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.739. John Wiley & Sons, Inc, New York. 1346pps.
13. G.H. Lacy and Stromberg, E.L. 2001. Suscept. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.991. John Wiley & Sons, Inc, New York. 1346pps.
14. G.H. Lacy and Stromberg, E.L. 2001. Susceptibility. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.991. John Wiley & Sons, Inc, New York. 1346pps.
15. G.H. Lacy and Stromberg, E.L. 2001. Virulence. IN Encyclopedia of Plant Pathology, O.C. Maloy and T.D. Murray, eds. pp.1081-1082. John Wiley & Sons, Inc, New York. 1346pps.
16. Stromberg, E.L., E.S. Hagood, A.G. Hager, and D.G. White. 1999. Part II. Noninfectious or Abiotic Disease. Pgs. 64-70 in Compendium of Corn Diseases, Third Edition, D.G. White, ed. APS Press. Ward, J.M., E.L. Stromberg, D.A. Nowell, and F.W.Nutter, Jr. 1999. Gray Leaf Spot: A Disease of Global Importance in Maize Production. Plant Dis. 83:884-895.
17. Roberts, D.P., E.L. Stromberg, G.H. Lacy and J.S. Buyer. 1999. Biological disease control: Considerations for seed treatment and stand establishment. Acta Horticulturae: 504:69-74.
18. Stromberg, E.L., Roberts, D.P., Lacy, G.H., and Buyer, J.S., 1999, Field evaluation of selected bacterial isolates and seed treatment fungicides for the control of take-all in Jackson soft red winter wheat, 1998, Biol. Cult. Tests Control Plant Dis. 14:127-129.
19. Herbert, D.A., Jr., E.L. Stromberg, G.F. Chappell, and S.M. Malone. Reduction of yield components by barley yellow dwarf infection in susceptible winter wheat and winter barley in Virginia. 1999. J.Prod. Agric. 12:105-109.
20. Stromberg, E.L. 1998. Evaluation of foliar fungicides for the control of disease in Wakefield soft red winter wheat, 1997. Fungic. Nematic. Tests 53: 319-320.
21. Stromberg, E.L. 1998. Evaluation of foliar fungicides applied with a fertilizer and herbicide tank mix for control of disease in Wakefield soft red winter wheat, 1997. Fungic. Nematic. Tests 53: 317-318.
22. Stromberg, E.L. and L.E. Flinchum. 1998. Resistance and agronomic characters of corn hybrids under natural gray leaf spot disease pressure, Montgomery Co., VA, 1996. Bio. Cult. Control Tests Control Plant Dis. 13: 12-13.
23. Stromberg, E.L. and L.E. Flinchum. 1998. Resistance and agronomic characters of corn hybrids under natural gray leaf spot disease pressure, Wythe Co., VA, 1997. Bio. Cult. Control Tests Control Plant Dis. 13: 14-15.
24. Maroof, S. A., Y.G. Yue, Z.X. Xaing, E.L. Stromberg, G.K. Rufener. 1996. Identification of quantitative trait loci controlling resistance to gray leaf spot disease of maize. Theor. Appl. Genet. 93:539-546.
25. Maroof, S.A. S.W. Van Scoyoc, Y.G. Yue, and E.L. Stromberg. 1993. Gray leaf spot disease: Rating methodology and inbred line evaluation. Plant Dis. 77:583-587.

26. Griffey, C.A., M.K. Das, and E.L. Stromberg. 1993. Effectiveness of adult plant resistance in reducing loss to powdery mildew in winter wheat. Plant Dis. 77:618-622.
27. Shaner, G., E.L. Stromberg, G.H. Lacy, K.R. Barker, and T.P. Pirone. 1992. Nomenclature and concepts of pathogenicity and virulence. Annu. Rev. Phytopathol. 30:47-66.
28. Donahue, P.J., E.L. Stromberg, and S.L. Meyers. 1991. Inheritance of reaction to gray leaf spot in a diallel cross of fourteen maize inbreds. Crop Sci. 31:926-931.

Current or Recent Research Sponsors:

Virginia Small Grains Board; USDA, Fusarium Head Blight Initiative, ASPIRES Program of Virginia Tech; Virginia Crop Improvement Association; Independent Professional Seedsmen Association; Hybrid Seed Corn Industry; Agri-Chemicals Industry; Virginia Corn Board; Virginia Soybean Board

On-line Resources:

- Integrated Disease Management in Small Grains
- Gray leaf spot fact sheet
- Seed Treatment - Category 4 PowerPoint (.ppt) File

Department of Plant Pathology, Physiology, and Weed Science
Last Updated November 07, 2002

Introduction

Profitable wheat production is attainable when care is taken to integrate practices that reduce or control the development of diseases that reduce the yield potential developed by the agronomic management practices. Each year in the humid Eastern wheat production areas of the United States, a number of diseases can and do cause significant economic losses to producers. The diseases most important to wheat producers in this area of the country are caused by a number of different fungi and viruses. Planning before planting to reduce disease incidence and severity, care taken to regularly scout your developing wheat crop for yield robbing diseases, and the timely application of appropriate disease control practices can ensure significant economic benefits.

The diseases occurring yearly within the region, and potentially the most yield limiting, can be grouped into foliar diseases, head diseases, root and crown diseases, and virus diseases.

Disease and Management Practices

Small grain diseases, although endemic, do not have to exact their toll each year from the prudent and alert wheat producer. There are a number of cultural and management practices that can be employed to significantly reduce the risk of economic loss from disease.

Seed and Seedling Diseases

Fungicide seed treatments, properly applied, are highly recommended and can be considered inexpensive stand establishment insurance. Seed treatments minimize losses from seed decay, seedling blights, and seed- and soil-borne diseases. Slurry applications or commercial liquid applications provide the best adhesion and most

uniform coverage and, thus, provide the most effective control. Recent problems with loose smut control have been attributed to poor fungicide coverage and higher levels of smut in seed that is treated. Hopper box treatments have not been providing the necessary coverage to ensure control.

Foliar Diseases

Foliar diseases reduce photosynthetic leaf area, use nutrients, and increase respiration and transpiration within colonized host tissues. The diseased plant typically exhibits reduced vigor, growth and seed fill. Earlier occurrence, greater degree of host susceptibility, and longer duration of conditions favorable for disease development increase the yield loss.

Head Diseases

Head diseases can cause significant losses. Seeds are replaced by the pathogen in the case of loose smut. With scab, seed may be shriveled or killed, and there is potential for mycotoxin contamination.

Root and Crown Diseases

Root and crown diseases attack the bases of the main stem and tillers. Stems and tillers that are rotted or partially rotted cannot adequately supply nutrients and water to the developing heads. As a result, heads that are produced dry up and die prematurely. They can be recognized as "whiteheads" when healthy heads are flowering.

Virus Diseases

Virus can only be seen with the aid of an electron microscope. They are disease-causing agents composed of nucleic acid surrounded by a protein coat. The viruses that cause disease in wheat are transmitted by insects (aphids, leafhoppers, etc.) or by root colonizing fungi. typically, virus diseases in wheat are characterized by stunting, mosaics and/or yellowing.

Attention

The remainder of this section is a compilation of recommended chemical disease control measures that were registered at the time of this printing. It is not intended to be an exhaustive index of all registered fungicides and nematicides. The information in this section is provided as a guide to available products but does not substitute for or supersede the information found on the pesticide label of a specific product. Trade names are included to aid in the identification of the specific active ingredient of a pesticide known to be effective. No discrimination against a similar product is intended or implied by omission. Mention of a commercial product does not constitute an endorsement by the authors or by their respective Extension services. Consult the pesticide label for any changes in rate, timing, handling, or registration. Use pesticides only as directed.

Design and Constructed by Jinxia Susan Sun.
Last updated February 11, 2003 by Peter Sforza.

URL: http://www.ppws.vt.edu/stromberg/smallgrain/sgrain.html

Diseases and Management Practices

Scouting

Scouting provides the critical necessary information on diseases present, severity of diseases, and potential crop loss if untreated. This information is essential before investing in chemical control or making practices.

Scouting of wheat fields for disease should be undertaken weekly from Zadok's Growth Stage 30 (Feekes' Growth Stage 5) until physiological maturity to justify the use of fungicide application for disease control. The most important time a wheat producer can have during this period of crop development is the twenty minutes per field per week scouting for disease. The information gained from weekly scouting will prevent the unnecessary use and expense of fungicide application or ensure that a fungicide application is made when it will provide the greatest economic return.
Scouting requires examination of 6 to 10 randomly selected sites that represent the character of plants within the field. Examine closely the leaves of each of the tillers selected. The use of a magnifying glass or hand lens may be particularly useful, especially when first beginning to scout. Determine and

make a record of the following:

- **Wheat growth stage:**

  A sharp pocket knife or a single-edged razor blade is useful to split open plants to determine the stage of growth after jointing.

- **Which diseases are present:**

  Check disease photographs and descriptions.

- **Disease severity**

- **Control options:**

  Consult Extension Service personnel and other local experts. Always follow label directions for disease control recommendations.

- **Begin a course of action**

  Only when you are fully "armed" with up-to-date, accurate information.

- **Check crop response to your disease control practice.**

  Leave a non-treated strip for comparison.

Sanitation

Bury pathogen-infested crop residues by tillage or plow down. This practice is useful to reduce risk from Septoria leaf and glume blotch, tan spot and scab.

Rotation

Avoid presence of pathogens by not following wheat with wheat or corn with wheat. This practice reduces risk from scab, Septoria leaf and glume blotch, take-all and tan spot.

Planting date

Avoid pathogen or reduce the infection period. Avoidance of early planting is particularly effective in reducing the risk and impact of barley yellow dwarf, wheat spindle streak and powdery mildew infections.

Seedbed preparation

provide good seed to soil contact and fertility to promote vigorous plant stands.

Good quality, disease-free seed

Promote healthy, vigorous seedling development. This will start wheat free of seedling diseases, reduce potential for Septoria leaf and glume blotch, and control loose smut.

Adapted, disease resistant cultivars

Produce plants able to resist disease attack. However, no cultivar is resistant to all diseases or is disease resistant "forever". The use of resistant cultivars can reduce losses from leaf rust, powdery mildew, barley yellow dwarf and wheat spindle streak and may reduce the need for foliar fungicide applications.

Seed treatment fungicides

Depending on the fungicide, this practice will protect developing seedlings from root rots, powdery mildew infections and loose smut.

Foliarly-applied fungicides

Fungicides can protect the yield established when management practices and cultivar resistance will not prevent economically significant losses from occurring. Foliarly-applied fungicides should be used only when the potential for loss is eminent. This requires the regular scouting of fields for disease, identification, incidence, and severity, and stage of growth of the wheat crop in order to make the decision to apply a fungicide.

Summary

The effectiveness of the various management and cultural practices on the control of the diseases commonly occurring in the humid, Eastern wheat production area is summarized in following table.

Diseases	Resistant cultivars	Sanitation	Crop rotation	Disease free seed	Balanced fertility	Planting date	Seed fungicide	Foliar fungicide	Seed insecticide
Powdery mildew	1	-	-	-	3	2	1	1	-
Leaf rust	1	-	-	-	-	3	3	1	-
Septoria leaf and glume blotch	3	2	2	2	-	-	2	1	-

Tan spot	3	2	2	-	-	-	-	2	-
Loose smut	-	-	-	1	-	-	1	-	-
Scab	-	1	1	-	-	-	-	-	-
Take-all	-	2	1	-	3	3	-	-	-
Barley yellow dwarf	2	-	-	-	-	1	-	-	1
Wheat spindle streak	1	-	-	-	-	2	-	-	-
Wheat streak mosaic virus	-	1	2	-	-	-	-	-	-

1 = Highly effective, 2 = Moderately effective, 3 = Slightly effective, and - = no effect in reducing disease

The effectiveness of the various management and cultural practices on the control of the diseases commonly occurring in the humid, Eastern barley production area is summarized in following table.

Diseases	Sanitation	Resistant Cultivars	Crop Rotation	Plow Down	Balanced Fertility	Planting Date	Seed Fungicide	Foliar Fungicide
Covered smut	-	2	-	-	-	-	1	-
Loose smut	-	2	-	-	-	-	1	-
Powdery mildew	-	1	-	-	3	2	2	1
Leaf rust	-	1	-	-	-	2	3	1
Barley scald	1	1	1	1	-	-	-	1
Net blotch	1	1	1	1	-	-	1	1
Head scab**	1	-	1	-	-	-	-	-
Barley stripe	1	2	-	-	-	-	1	-
Barley yellow dwarf	-	1	-	-	-	2	-	-

1 = Highly effective, 2 = Moderately effective, 3 = Slightly effective

** Seed infested with the head scab fungus will produce weak seedlings that are prone to seedling blight. A fungicide seed treatment may be of some limited benefit if germination rates are acceptable. Scabby seed does not produce head scabbed plants.

Last updated February 04, 2003.

Foliar Disease Management in Small Grains

Introduction

Control of foliar diseases of small grains begins with the selection of well-adapted, disease resistant cultivars (wheat, barley cultivars and their disease reactions). Chemical control of foliar diseases generally has been found to be non-economical unless a high yield potential may be realized. Maximum economic yield (MEY) management practices, especially high nitrogen fertility and narrow rows, increase both the yield and disease potential in a small grain crop. Use of Baytan seed treatment and/or foliar-applied fungicides under high yield management may be required to control foliar diseases and protect the higher yield potential of the crop. The use of Baytan seed treatment should be based on: a) use of high-yield management practices, especially higher nitrogen fertility levels, and b) powdery mildew susceptibility of wheat cultivar(S through MS reactions). Cultivars rated MR to MS may not respond dramatically to Baytan depending on seasonal conditions.The decision to protect yields with fungicides should be made when the expected yield is roughly greater than 70 bu/A (the cut-off depends on the cost of production and on potential market price) and when conditions are forecast to be favorable for continued disease development and stage of crop growth. Conditions for powdery mildew are characterized by temperatures between 60 and 75 F and periods of high relative humidity. Leaf rust develops most rapidly when temperatures are between 60 and 85 F and free moisture from showers or dew can be found on leaves from early evening until late morning hours. Septoria leaf and glume blotch is favored by wind blown rain, high relative humidity, and temperatures between 68 and 82 F. The disease characteristically moves upward from infected lower leaves in the plant canopy. Use disease threshold information

in the "Remarks" section of Foliarly- applied fungicides for disease control in small grains as a guide to knowing when and if to spray.

[complete table of foliarly applied fungicides for disease control in small grains]

Leaf Rust (*Puccinia recondita*)

- Biological Description
- Control Recommendations

Wheat Cultivars Management Practices Pesticides

Powdery Mildew (*Erysiphe graminis* f.sp. *tritici*)

- Biological Description
- Control Recommendations

Wheat Cultivars Management Practices Pesticides

Leaf and Glume Blotch (*Stagonospora nodorum*)

- Biological Description
- Control Recommendations

Wheat Cultivars Management Practices Pesticides

Tan Spot (*Pyrenophora tritici-repentis*)

- Biological Description
- Control Recommendations

Management Practices Pesticides

Barley Leaf Rust (*Puccinia hordei*)

- Biological Description
- Control Recommendations

Barley Cultivars Management Practices Pesticides

Barley Net Blotch(*Pyrenophora teres*)

- Biological Description
- Control Recommendations

Barley Cultivars Management Practices Pesticides

Barley Powdery Mildew (*Erysiphe graminis* f.sp. *hordei*)

- Biological Description
- Control Recommendations

Barley Cultivars Management Practices Pesticides

Barley Scald (*Rhynchosporium secalis*)

- Biological Description
- Control Recommendations

Barley Cultivars Management Practices Pesticides

Barley Stripe (*Helminthosporium gramineum*)

- Biological Description
- Control Recommendations

Management Practices Pesticides

Last updated May 25, 1999.

Disease Management Practices	Foliar Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Seed and Seedling Diseases

Barley, Oats, Rye, Wheat seed decay and seedling blights including the scab fungus (seed treatments do not control the head blight phase of scab disease).

Fungicide seed treatments, properly applied, are highly recommended and can be considered inexpensive stand establishment insurance. Seed treatments minimize losses from seed decay, seedling blights, and seed- and soil-borne diseases. Slurry applications or commercial liquid applications provide the best adhesion and most uniform coverage and, thus, provide the most effective control. Recent problems with loose smut control have been attributed to poor fungicide coverage and higher levels of smut in seed that is treated. Hopper box treatments have not been providing the necessary coverage to ensure control.

complete table of seed treatment fungicides for small grains

Main

Last Updated March 05, 1999

Root and Crown Disease Management in Small Grains

- Take-all

Take-all (*Gaeumannomyces graminis* var. *tritici*)

- Biological Description
- Control Recommendations

Last Updated May 25, 1999.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Virus Diseases

Head Disease Management in Small Grains

- Common bunt or stinking smut
- Common root rot complex
- Loose smut
- Scab

- Loose smut
- Covered smut

- Loose smut
- Covered smut

Introduction

Fungicide seed treatments, properly applied, are highly recommended and can be considered inexpensive stand establishment insurance. Seed treatments minimize losses from seed decay, seedling blights, and seed- and soil-borne diseases. Slurry applications or commercial liquid applications provide the best adhesion and most uniform coverage and, thus, provide the most effective control. Recent problems with loose smut control have been attributed to poor fungicide coverage and higher levels of smut in seed that is treated. Hopper box treatments have not been providing the necessary coverage to ensure control.

Other

Common bunt or stinking smut (*Tilletia caries*)

- Biological Description
- Control Recommendations

Common root rot complex (*Helminthosporium sativum*) and *Fusarium* spp.

- Biological Description
- Control Recommendations

Loose smut (*Ustilago tritici*)

- Biological Description
- Management Practices
- Pesticides

Wheat scab(*Fusarium graminearum*)

- Biological Description
- Management Practices
- Pesticides

Barley

Barley loose smut (*Ustilago nuda*)

- Biological Description
- Management Practices
- Pesticides

Barley covered smut (*Ustilago hordei*)

- Biological Description
- Management Practices
- Pesticides

Oats loose smut (*Ustilago avenae*)

- Biological Description
- Control Recommendations

Oats covered smut (*Ustilago kolleri*)

- Biological Description
- Control Recommendations

Last Updated May 25, 1999.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases

Virus Disease Management in Small Grains

Barley yellow dwarf

Wheat spindle streak

Wheat streak mosaic

Barley yellow dwarf

Barley yellow dwarf

- Biological Description
- Control Recommendations

Wheat Cultivars Management Practices Pesticides

Wheat spindle streak

- Biological Description
- Control Recommendations

Wheat Cultivars Management Practices

Wheat streak mosaic

- Biological Description

Barley yellow dwarf

- Biological Description
- Control Recommendations

Barley Cultivars Management Practices Pesticide

Last Updated April 25, 2000.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Wheat Barley Yellow Dwarf

Control Recommendations: Wheat Cultivars Management Practices Pesticides

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Description:

Barley yellow dwarf is the most widely distributed and destructive of the virus diseases that affect wheat. Symptoms of barley yellow are often confused with various nutritional or non-biological disorders. Leaf discoloration induced by the virus infection typically ranges from shades of yellow to red and sometimes purple, especially extending from the leaf tip to the base and from the leaf margin to the mid-rib. Seedling infections reduce yields most. Plants infected in the fall of the year may not survive the winter or are severely stunted and discolored when growth resumes in the

spring. These diseased plants often occur in circular patches within the field. These patches are associated with the feeding and colonization by the aphid vectors in the fall and early spring. Grain yields from such plants have been shown to be reduced by 30 to 35 percent in experimental plots in Virginia.

The virus can be transmitted by more than 20 species of aphids, five species of which are known to occur in Virginia. The virus persists in small grains (barley, oats, rye and wheat), in corn, and in over 80 species of perennial and annual grass species. The spread of this virus is entirely dependent on the activity of the aphid vectors. The environmental conditions that favor barley yellow dwarf epidemics are cool temperatures (50 degree to 65 degree F) with rainfall that favors wheat and grass growth as well as aphid reproduction and movement. Infections can occur throughout the season and are most abundant where high populations of aphids survive the winter. The leaf discoloration symptoms indicating virus infection develop within about two weeks of inoculation at temperatures between 65 degree to 70 degree F. When infections occur at temperatures above 85 degree F, symptoms do not develop.

The best means of control in barley is to select cultivars that are resistant to the virus and not to plant early in the season. Wheat cultivars range from highly susceptible to moderately susceptible. Planting later in the season will reduce the risk from fall infections of barley yellow dwarf, but this may not be enough in some years. A seed treatment insecticide has been shown to be highly effective in preventing fall barley yellow dwarf infections and significantly reducing spring infections as well.

When barley yellow dwarf has been common in a field and culture is directed towards higher yields then a seed treatment insecticide may be economically beneficial.

Control Recommendations: Wheat Cultivars Management Practices Pesticides

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Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on January 21, 2002.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Cultivars and Their Disease Reactions

Cultivar	Powdery Mildew	Leaf Rust	Leaf and Glume Blotch	Wheat Spindle Streak Mosaic	Barley Yellow Dwarf virus
AgriPro Foster	MR-MS	MS-S	NA	NA	MS
Century II s	S	MS	NA	NA	NA
DynoGro 424	S	R	MS	R	S
Featherstone 520	MS	MS	MS	MS	S
FFR 502W	MR	VS	MS	MS-S	S
FFR 518	MS	R	NA	NA	NA
FFR 520	MR	S	NA	NA	NA
FFR 523W	MS	MR	MS	S	S
FFR 525W	VS	MS-S	MS	S	S
FFR 544W	MS	MR-MS	MS	NA	VS
FFR 550	MR	MS	NA	NA	NA
FFR 555W	S	MS	MS	MS	VS

FFR 560	MS	MR	NA	NA	NA
FFR 566	MR	R	NA	NA	NA
FFR 568W	MS	S	MS-S	MR	S
Florida 302	MS-S	MR-MS	MS-S	VS	MS
Gore	MR-MS	MR	MS	MS	S
Hickory	MS	MR-MS	MS	MS	MS-S
Hoffman 14	S	MS	MS	S	S
Hoffman 57	MR	S	MS	R	MS
Hoffman 95	MS	MR-MS	MS	MS	S
Jackson	MR	MS	MS	MS	MS
Madison	MR-MS	MS	MS	R	MR-MS
Massey	MR	VS	MS	R	MR
McCormick	MR	R	MR	NA	NA
NKCoker Brand 9025	S	R	NA	NA	NA
NKCoker Brand 9134	MS-S	MR	MS	MS	S
NKCoker Brand 9184	MS	R	NA	NA	NA
NKCoker Brand 9663	MS	R	MS	MS	MS
NKCker Brand 9704	MS	MR	MS	R	MS
NKCoker Brand 9733	S	MR	MS	S	MS
NKCoker Brand 9803	MS-S	MS	MS	MR-MS	MS
NKCoker Brand 9835	MS-S	R	MS	MR-MS	MS
Pocahontas	R-MR	MS	MS	S	S
Pioneer Brand 2548	MS	MR	MS	VS	MS
Pioneer Brand 2550	MS-S	S	MS	S	MS
Pioneer Brand 2551	MS-S	MR	MS	S	MS
Pioneer Brand 2555	S	MS	MS	S	MS
Pioneer Brand 2566	S	MR	MS	NA	NA
Pioneer Brand 2580	MR	MR	MS	S	MS
Pioneer Brand 2643	MR-MS	MR-MS	MS	R	MS
Pioneer Brand 2684	MS	MR-MS	MS	MS	MS
Pioneer Brand 2691	MR-MS	MR	MS	MS	MS
Pioneer Brand 26R24	MS	MS	NA	NA	NA

Pioneer Brand 26R38	MS	MS	NA	NA	NA
Pioneer Brand 26R46	MS	MS	NA	NA	NA
Roane	VS	MR-MS	MS	MS	MS
Saluda	VS	MS	MS	VS	MS-S
Sisson	MR	S	MR	MR	NA
Tyler	S	VS	MS	MR	S
Wakefield	VS	MS	MS	MS	VS

***** Disease reactions may change with environmental conditions and the composition of the pathogen races.

** VS=Very Susceptible; S=Susceptible; MS=Moderately Susceptible; MR=Moderately Resistant; R=Resistant; NA=Data not available.

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Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
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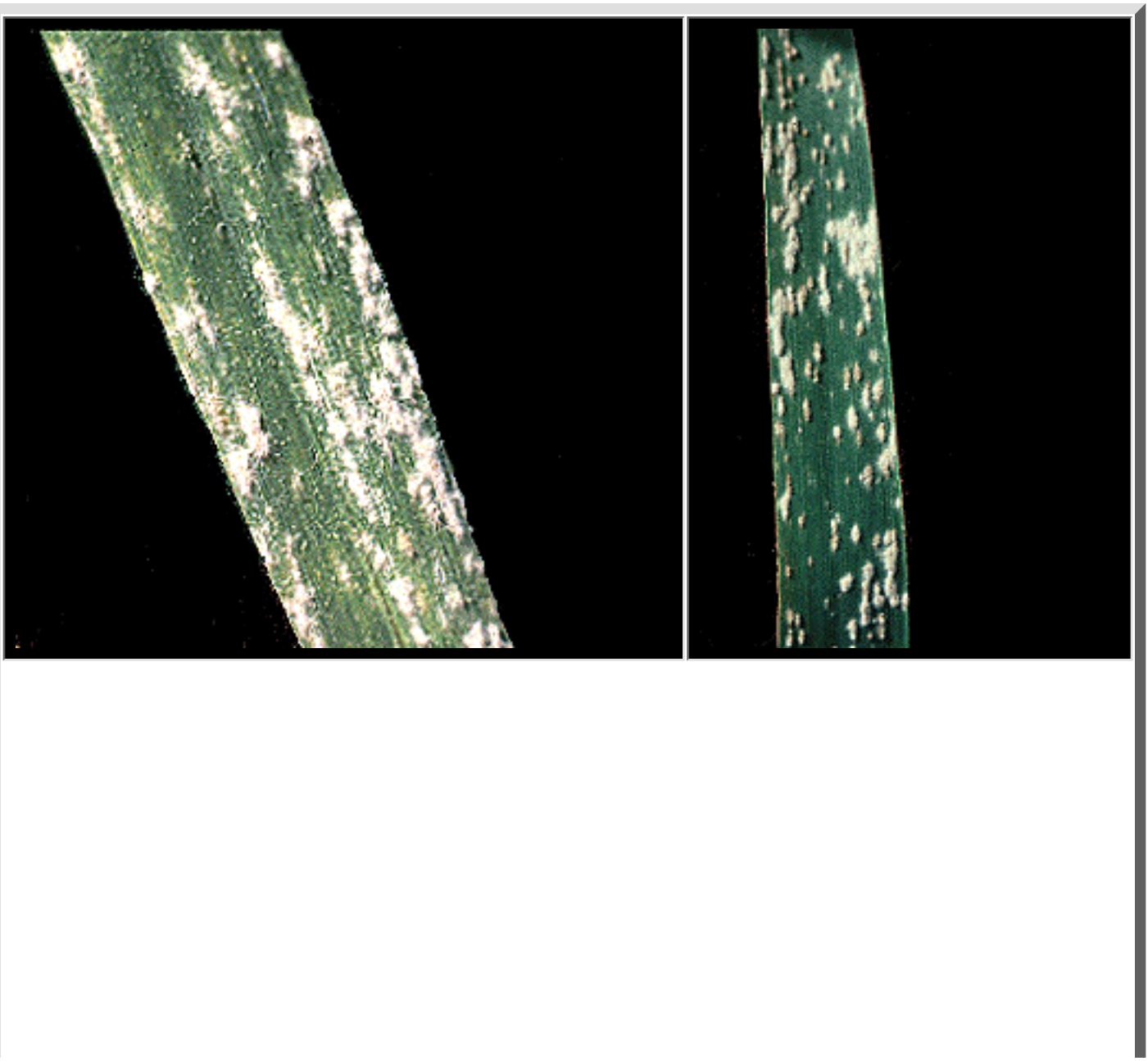
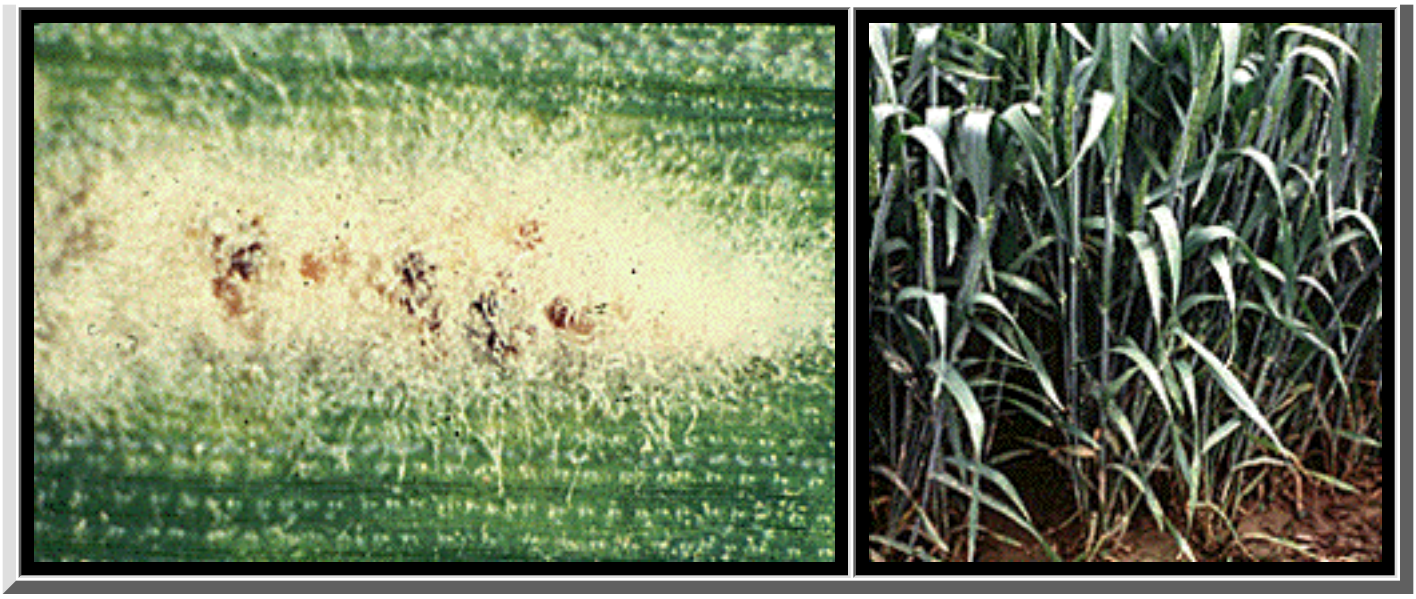
Erik L. Stromberg

Wheat Powdery Mildew





Scientific Name: *Erysiphe graminis* f. sp. *tritici*

Control Recommendations Wheat Cultivars Management Practices Pesticides

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Description:

Powdery mildew on wheat is recognized by small, effuse patches (colonies) of cottony mycelia (masses of fungal threads of hyphae that make up the body of the fungus). These occur on the upper and lower surfaces of the leaves. As these patches sporulate and age, they become a dull tan color. Chlorotic (yellow) patches may later surround the mildew colonies. As the wheat and the mildew colonies mature, the sexual stage of the fungus or cleistothecia are produced. The mildew fungus survives the summer in the absence of wheat in infested wheat debris in the cleistothecia. When the new crop develops as seedlings and fall rains occur, the cleistothecia within the infested wheat debris rupture to release spores. This process is favored by moderate fall temperatures and lush wheat growth. The mildew fungus, survives the winter on the infected wheat seedlings. In the spring, with the return of moderate temperatures, the typical cottony mildew colonies develop and sporulate (asexual reproduction) to infect and colonize the newly developing wheat leaves. This stage of the disease cycle is favored by moderate (59 degree to 72 degree F) temperatures and high relative humidity. The canopy within a lush stand of wheat is an ideal environment for powdery mildew to develop.

As the wheat crop matures and the temperatures rise, the mildew fungus produces the oversummering cleistothecia. Typically, the cottony colonies turn tan and are dotted with the cleistothecia. When the crop is harvested, the cleistothecia remain attached to the infested straw.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Powdery Mildew Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
propiconazole[a]	Tilt 3.6EC Flowable	4.0 fl oz
propiconazole + trifloxystrobin[a]	Stratego 250EC	10.0 fl oz

Other Control Recommendations: Wheat Cultivars Management Practices

Remarks: [a]Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes'GS 5 through GS 10.5) head emergence. Examine plants from 5 to 10 randomly selected areas within the field. Make application only when powdery mildew covers 5-10% of area of fully expanded upper leaves (see leaf area figure), but not before tillers have reached Zadoks'31 (Feekes' GS 6) first joint (see Figure 1), except in the Tidewater region south of the James River. Do not apply more than 4 fl oz/A per year or after Zadoks' GS 59 (Feekes'GS 10.5), head emerged, but not flowering on wheat. Do not apply after GS 37 on Barley. Do not graze or feed livesock treated forage or cut the green crop for hay or silage. After harvest straw may be used for bedding. Follow all label instructions.

Biological Description

Last updated on February 28, 2002.

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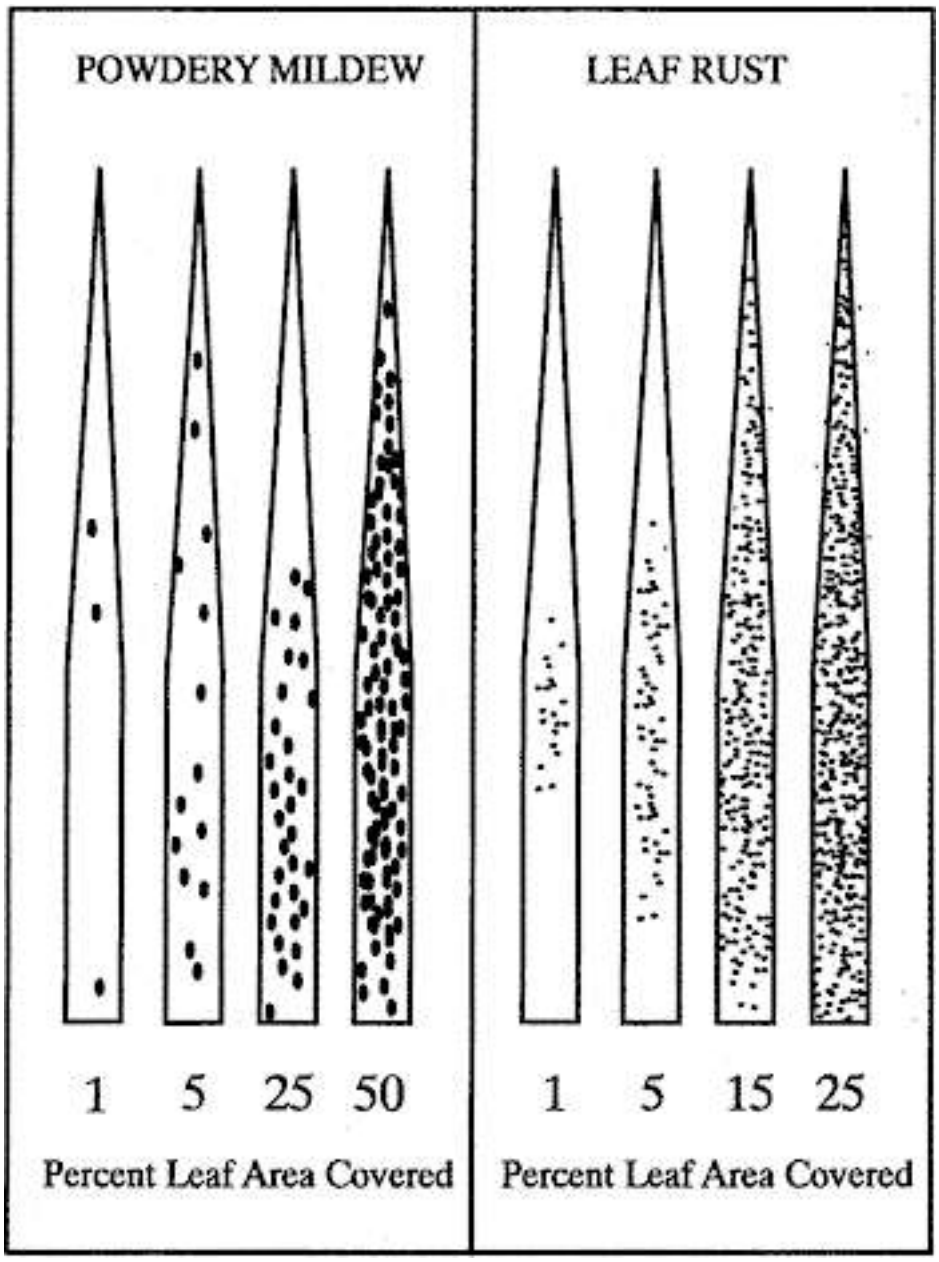
Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Determination of treatment threshold for leaf and glume blotch in wheat



Main

Last updated on February 24, 2000.

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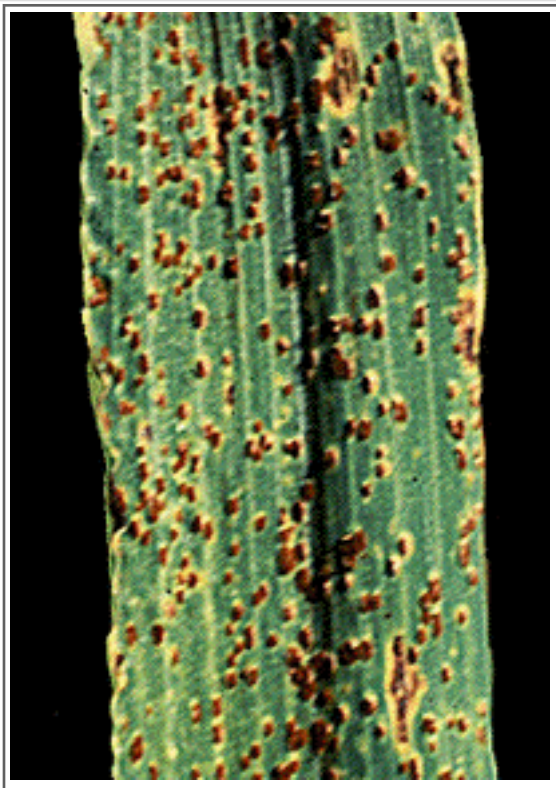
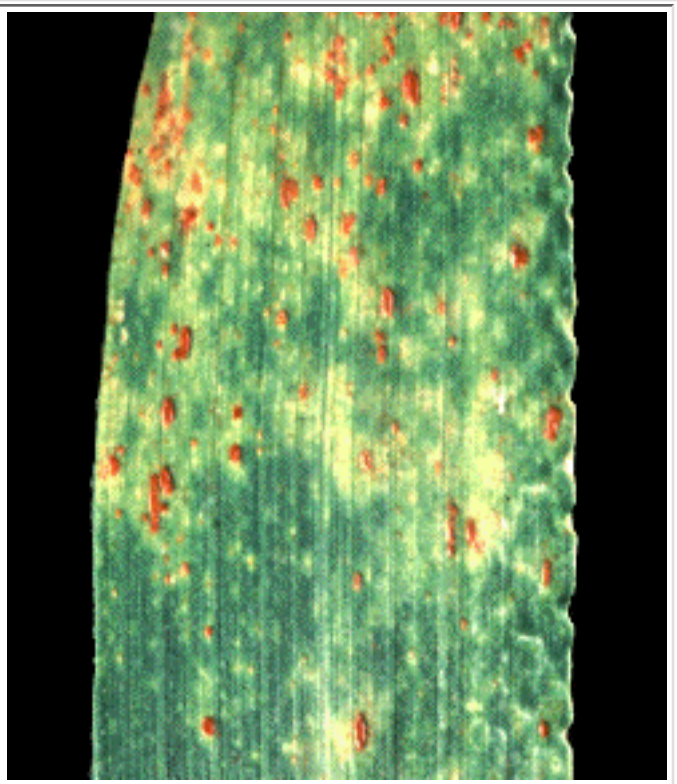
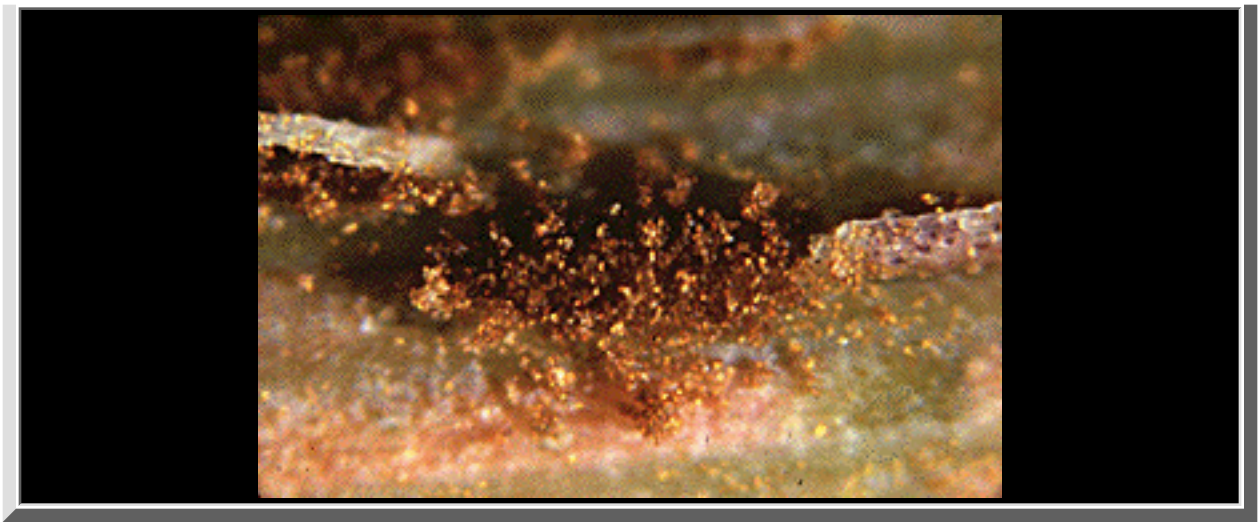
Wheat Leaf Rust







Scientific Name: *Puccinia recondita*

Control Recommendations Wheat Cultivars Management Practices Pesticides

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Description:

Leaf Rust is recognized by its characteristic red-orange pustules that erupt from the upper epidermis of leaves. These pustules are approximately the size of a pin head and filled with thousands of red-orange urediospores that are wind-borne and can infect additional leaves and wheat plants. The urediospores often form the core of rain drops and often initially infect and produce pustules where raindrops have collected at leaf axes and tips. Leaf rust develops extremely rapidly at temperatures of 60 degree to 80 degree F.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat and Barley Leaf Rust Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
azoxystrobin[a] (wheat only)	Quadris	6.2-10.8 fl oz
propiconazole[b]	Tilt 3.6EC	4.0 fl oz
propiconazole + trifloxystrobin[a]	Stratego 250 EC	10.0 fl oz
pyraclostrobin[c]	Headline 2.09EC	6.0 - 9.0 fl oz

Other Control Recommendations: Wheat Cultivars Management Practices

Remarks:

[a]For wheat only. Quadris and Stratego should be integrated into an overall disease management strategy that includes proper selection of varieties with disease tolerance, proper timing and placement of irrigation, removal of plant debris in which inoculum overwinters, plant residue management, and crop rotation. Resistance management: Do not make more than two applications of Quadris per acre per year. Application directions: Quadris should be applied prior to or in the early stages of disease development. Applications may be made at any time, immediately after jointing (Feeks 6 or Zadok's 31) up to late head emergence (Feekes 10.5 or Zadok's 59). A crop oil concentrate adjuvant may be added at 1.0% V/V to optimize efficacy. Do not apply later than Feekes growth stage 10.5 (Zadok's 59). Do not harvest treated wheat for forage. Do not apply more than 0.77 quarts product/acre/season (0.4 lb ai/A). Do not apply within 14 days of harvest for hay. Do not apply within 45 days of harvest for grain and straw.

[b]Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes'GS 5 through GS 10.5). Examine plants from 5 to 10 randomly selected areas within the field. Make application only when rust pustules cover 1-3% of area of fully expanded upper leaves (see leaf area figure), but not before first joint (Feekes' GS 6 or Zadoks' GS 31), except in Tidewater region south of the James River. See Figure 1. Do not apply more than 4 oz/A/ year or after Feekes' GS 10.5 or Zadks' 59 on wheat. Do not apply after Feekes' 8 or Zadoks' 37 on Barley. Do not graze or feed livestock treated forage or cut the green crop for hay or silage. After harvest the straw may be used for bedding or feed. Follow label instructions for additional precautions.

[c]Headline should be integrated into an overall disease management strategy that includes proper selection of cultivars with disease tolerance, removal of plant debris in which inoculum overwinters, and plant residue management. Resistance management: do not make more than two applications of Headline/A/year. Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 69 (Feekes' GS 5 through 10.53). Examine plants from 5 to 10 randomly selected areas within the field. Make application only when rust pustules cover 1% to 3% of area of fully expanded upper leaves (see leaf area figure). Do not apply to barley after Zadoks' GS 55 (Feekes' GS 10.3). Do not apply to wheat after Zadoks' GS 69 (Feekes' GS 10.53). Do not harvest hay within 14 days of application.

Biological Description

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Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
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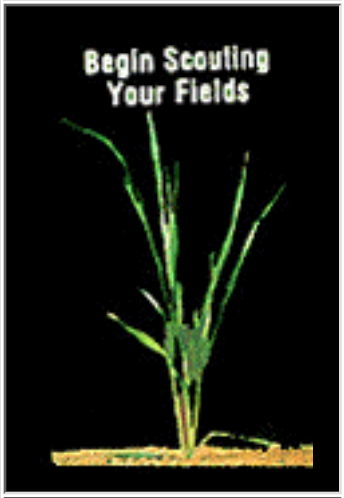
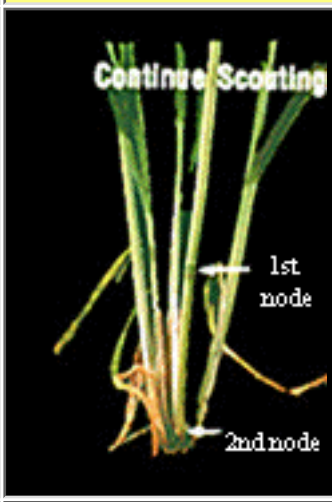
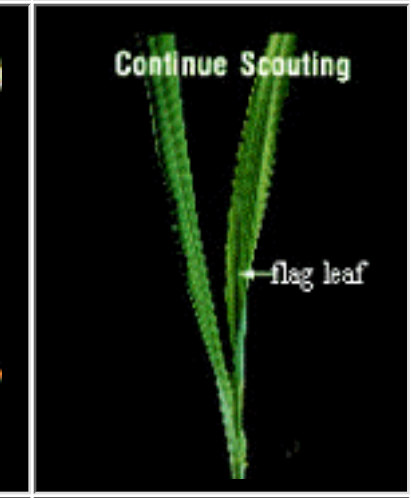
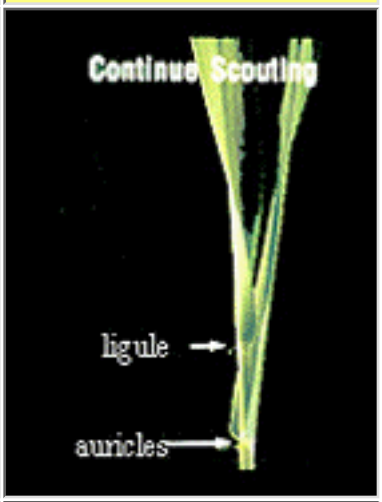
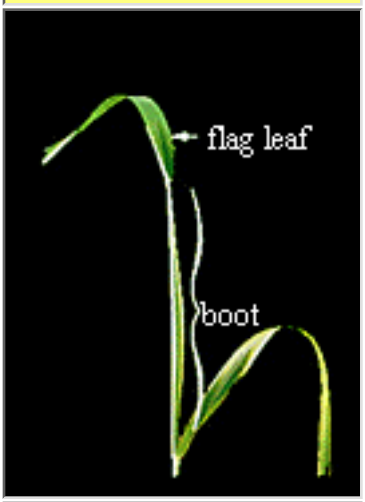
Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Stages of Growth of Small Grains

Zadoks'31	Zadoks'32	Zadoks'37	Zadoks'39
			
First node of stem detectable at base of the main shoot	Second node detectable at base of the main shoot (leaf sheaths peeled back to show first and second nodes)	Flag leaf rolled and just visible	Flag leaf ligule and auricles visible
Feekes' 6	Feekes' 7	Feekes' 8	Feekes' 9

Zadoks'45	Zadoks'50	Zadoks'58	Zadoks'59
			
Boot swollen	First spikelets just visible	Ear emergence complete	Beginning of flowering-Anthers in middle of ear visible
Feekes' 10	Feekes' 10.1	Feekes' 10.5	Feekes' 10.5.1

Last updated on February 24, 2000.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
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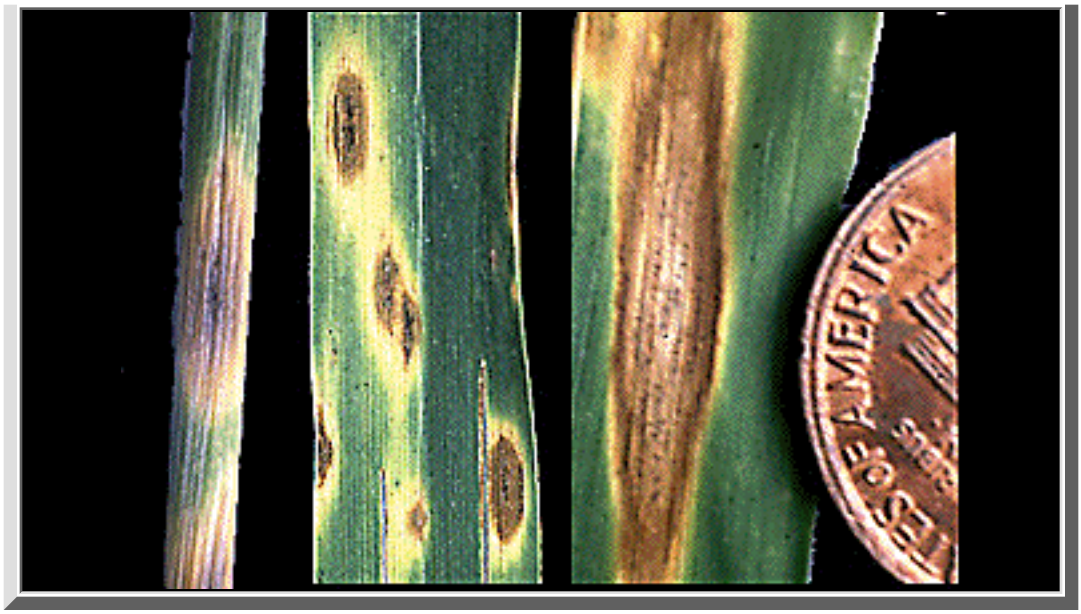
Wheat Stagonospora Leaf and Glume Blotch



Scientific Name: *Stagonospora nodorum*

Control Recommendations Wheat Cultivars Management Practices Pesticides

Description:

Septoria leaf and glume blotch is recognized on leaves by its characteristic lens-shaped lesions. Leaf lesions develop initially as small water-soaked areas that become chlorotic (yellowed) and with reddish-brown centers. As the lesion matures to a size of 1/16 by 1/4 or 1/2 inches, it becomes grayish-brown with chlorotic edges. The centers of the lesions are ashen-colored with minute, dark, globose pycnidia (spore producing structures). The spores within the pycnidia are produced within a gelatinous matrix that oozes out like "toothpaste" during periods of high relative humidity. The spores can only be moved by splashing rain drops.

The spores also infect and colonize stems and the wheat head. When the head is colonized the florets become streaked with a purple-brown color and "dotted' with the minute pycnidia. Within colonized florets the grain fill is impaired and results in low teat weight and shriveled seeds.

The septoria leaf and glume blotch pathogen survives within infested straw, seed and on volunteer wheat and serves as the source of inoculum to start off the disease cycle in the new crop of wheat. The disease is favored by splashing rain, high humidity, and temperatures between 68 degree to 82 degree F. The disease characteristically moves upward from infection initiated on the low leaves within the crop canopy.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Stagonospora Leaf and Glume Blotch Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
azoxystrobin[bc]	Quadris	6.2 - 10.8 fl oz
mancozeb[a]	Dithane M45	2.0 lb
mancozeb[a]	Dithane F45	1.6 qt
mancozeb[a]	Dithane DF	2.0 lb
mancozeb[a]	Manzate 200	2.0 lb
mancozeb[a]	Manzate DF	2.0 lb
mancozeb[a]	Penncozeb	1.5 - 2.0 lb
mancozeb[a]	Penncozeb DF	1.5 - 2.0 lb

propiconazole[b]	Tilt 3.6EC	4.0 fl oz
propiconazole + trifloxystrobin[b]	Stratego 250EC	10.0 fl oz
pyraclostrobin[d]	Headline 2.09EC	6.0 - 9.0 fl oz

Other Control Recommendations: Wheat Cultivars Management Practices

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Remarks:

[a]These fungicides are protectant types that must be applied before infection to provide a barrier to prevent infection. Make first application when flag leaf is fully emerged (Feekes' stage 10 or Zadoks' 45) and repeat when grain head is visible about 10-12 days later. Do not make last application within 26 days of harvest. Livestock may not graze in treated areas within 26 days of last treatment. Penncozeb is only registered for use on wheat.

[b]Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes' GS 5 through GS 10.5) head emergence. For leaf and plume blotch collect main tillers from 10 plants from 10 randomly selected areas within the field. Examine the appropriate indicator leaf from each tiller and record the number of indicator leaves with one or more lesions. If 25% of the 100 indicator leaves have one or more lesions, then a fungicide application is indicated.

[c]QUADRIS should be integrated into an overall disease management strategy that includes proper selection of varieties with disease tolerance, proper timing and placement of irrigation, removal of plant debris in which inoculum overwinters, plant residue management, and crop rotation. Resistance management: Do not make more than two applications of Quadris per acre per year. Application directions: Quadris should be applied prior to or in the early stages of disease development. Applications may be made at any time, immediately after jointing (Feeks 6 or Zadok's 31) up to late head emergence (Feekes 10.5 or Zadok's 59). A crop oil concentrate adjuvant may be added at 1.0% V/V to optimize efficacy. Do not apply later than Feekes growth stage 10.5 (Zadok's 59). Do not harvest treated wheat for forage. Do not apply more than 0.77 quarts product/acre/season (0.4 lb ai/A). Do not apply within 14 days of harvest for hay. Do not apply within 45 days of harvest for grain and straw.

[d]Headline should be integrated into an overall disease management strategy that includes proper selection of cultivars with disease tolerance, removal of plant debris in which inoculum overwinters, and plant residue management. Resistance management: do not make more than two applications of Headline/A/year. Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 69 (Feekes' GS 5 through 10.53). For leaf and glume blotch, collect main tillers from 10 plants from 10 randomly selected areas within the field. Examine the appropriate indicator leaf (see Indicator leaves) from each tiller and record the number of indicator leaves with one or more lesions. If 25% of the 100 indicator leaves have one or more lesions, then a fungicide application is indicated. Do not apply to wheat after Zadoks' GS 69 (Feekes' GS 10.53). Do not harvest hay within 14 days of application.

Biological Description

Main

Last updated on March 03, 2003.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Determination of treatment threshold for leaf and glume blotch in wheat

Scout fields weekly from Zadoks' Growth Stage 31 through 73 (Feekes' 6 through 11). Randomly select 10 locations within a wheat field. At each randomly selected location, examine and record number of indicator leaves out of ten main tillers with one or more leaf and glume blotch lesion(s). If 25% of the (100) indicator leaves in the field have one or more lesions then a fungicide application is indicated.

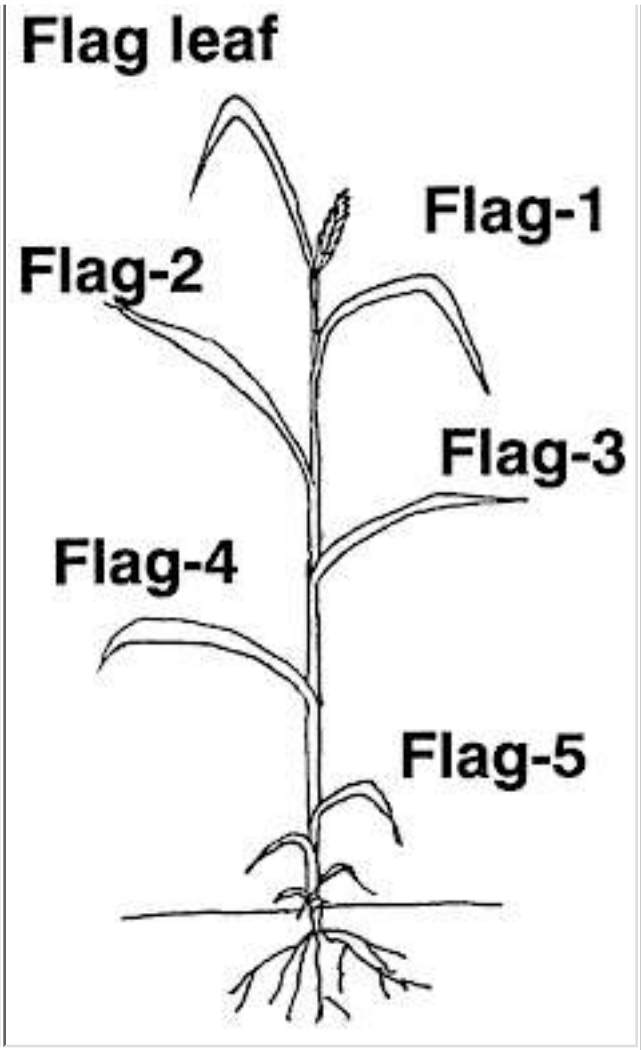
Indicator leaves are:

Flag-4 and **Flag-5** for Zadoks' Growth Stages 31-37 (Feekes' 6-8)

Flag-3 for Zadoks' Growth Stages 38-45 (Feekes' 8-10)

Flag-2 for Zadoks' Growth Stages 46-59 (Feekes' 10-10.51)

Flag-1 from Zadoks' Growth Stages 60-73 (Feekes' 10.52-11)



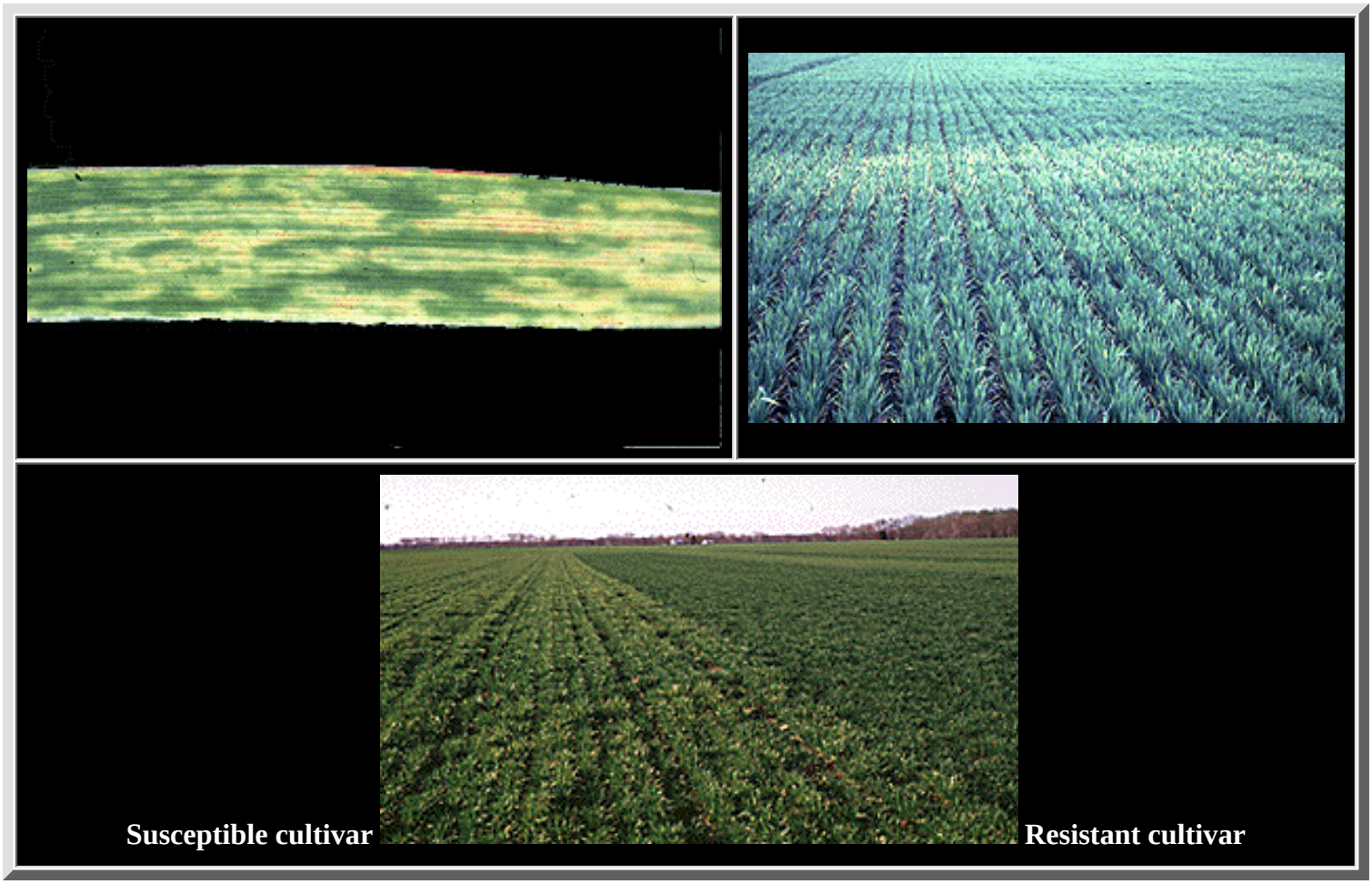
Main

Last updated on February 24, 2000.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Wheat Spindle Streak



Control Recommendations: Wheat Cultivars Management Practices

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Description:

Wheat spindle streak virus is common in some fields in Virginia. Symptoms are typically expressed in leaves as yellow-green mottling with parallel dashes or streaks with tapered ends—hence the name wheat spindle streak. The virus is transmitted to wheat by a soil-borne fungus, *Polymyxa graminis*, which, in the absence of wheat, is

associated with the roots of grassy weeds and other monocot crops (e.g., barley, corn, millet, rye, sorghum, etc.). Most significant infections take place during cool, wet periods in the fall. Often large areas of a field may be affected. Infection does not occur at temperatures above 68°F. The optimal temperature for symptom expression is between 48°F and 55°F. The earlier in the life of the wheat plant that infection occurs, the more severe the symptom expression. During cool spring conditions, the yellow spindle streaks may become necrotic. Affected plants may be mildly stunted and produce fewer tillers and seeds per head.

Control is affected by selecting wheat cultivars that are resistant. A list of wheat cultivar disease resistance and susceptibility is presented in the following table: Wheat Cultivars

Control of wheat streak mosaic virus

Wheat streak mosaic virus (WSMV) was observed for the first time in more than 25 years during the 2000 growing season. The incidence and severity of this disease depends on the environment, vector survival, distribution and frequency of volunteer wheat plants that serve as a source of virus and a haven for the vector, and wheat cultivar susceptibility. Symptoms of wheat streak mosaic virus typically appear in the spring. These symptoms can look very similar to wheat spindle streak caused by wheat spindle streak mosaic virus, which is vectored by the soil-borne fungus *Polymyxa graminis.* However, the field pattern of wheat streak mosaic is related to the distribution and activity of the vector, the wheat curl mite, *Aceria tulipae.* As the wheat crop develops, plants affected with WSMV are typically severely stunted with yellow mottled and streaked leaves. These yellow streaks are often seen as discontinuous dashes running parallel to the leaf veins. As the season progresses, plants affected and colonized by the curl mites may develop "leaf rolling." Leaves appear upright while the margins roll inward. This symptom of mite feeding looks like drought stress in the affected plants. Wheat streak mosaic symptoms tend to become more severe as the weather warms, and severely affected plants may produce sterile heads or die prematurely.

The wheat curl mite, *Aceria tulipae*, is the vector and the only means by which the virus is transmitted in nature. This mite thrives in lush young growth of wheat and other grasses. Thus, volunteer wheat in soybean fields harvested in the fall is a particularly good breeding ground for this mite and the virus. The wheat curl mite is approximately 0.03 mm long. It is invisible to the unaided eye and is easily dispersed by winds. The mite can develop from egg to adult in 8 to 10 days. It reproduces rapidly at temperatures ranging from 75°F to 80°F. Dry conditions also favor the mite's development. It can overwinter as an egg, nymph, or adult either in the crowns of wheat plants of other host grasses. This enables the mite to survive freezing temperatures for several months. Survival is even greater in mild winters. Although wheat is the preferred host for *Aceria tulipae*, many other species of grasses are hosts for both the mite and the virus. These include corn, oats, foxtail, barnyardgrass, and others. Volunteer wheat is the primary means by which the wheat curl mite populations and the wheat streak mosaic virus are maintained. In the absence of a host with live green leaves, the wheat curl mite will only survive for a few days.

Since there are no effective chemicals registered for control of the wheat curl mite, disease management should be directed toward removing host plants during the fall and winter months (e.g., volunteer wheat) to prevent the survival of the mite and the maintenance of the virus in or near the field. Cultivars can vary in their susceptibility to the virus, but at this time the resistance or susceptibility of soft red winter cultivars has not been adequately characterized.

Control Recommendations: Wheat Cultivars Management Practices

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Last updated on January 21, 2002.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Yellow Dwarf Control Recommendations

Insecticide Common Name	Insecticide Trade Name	Formulated rate per CWT seed
Imidacloprid[a]	Gaucho 480	1.0 fl oz
thiamethoxam	Cruiser 5FS	0.75 - 1.33 fl oz

Other Control Recommendations: Wheat Cultivars Barley Cultivars Management Practices

Remarks:

a:

To provide early season protection of seedlings against injury by aphid transmission barley yellow dwarf disease in both wheat and barley, apply 1.0 to 2.0 fluid ounces per hundred weight of seed prior to planting as a slurry treatment. Ensure thorough coverage.

Biological Description

Last updated on February 04, 2003.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Cultivars and Their Disease Reactions

Cultivar	Powdery Mildew	Leaf Rust	Scald	Net Blotch	Barley Yellow Dwarf
Barsoy	S	VS	S	R	S
Boone	S	S	S	MR	MS
Callao	R	MS	MR-MS	MR	MR
Nomini	R	MS	MR-MS	MR	MR
Pumunkey	R	MS	MR-MS	MS	MR
Pennco	R	MR	R	MS	MR
Starling	R	MR-MS	MR-MS	MS	MR
Sussex	R	S	MR-MS	MR	MR
Wysor	R	MR-MS	MR-MS	MR	MR

Remarks: Disease reactions may change with environmental conditions and the composition of pathogen races.

VS = Very Susceptible

MS = Moderately Susceptible

MR = Moderately Resistant

NA = Data not available

S = Susceptible

R = Resistant

Last updated on February 11, 2003.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Barley Powdery Mildew

Scientific Name: *Erysiphe graminis* f.sp. *hordei*

Control Recommendations Barley Cultivars Management Practices Pesticides

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Main

Last updated on February 24, 2000.

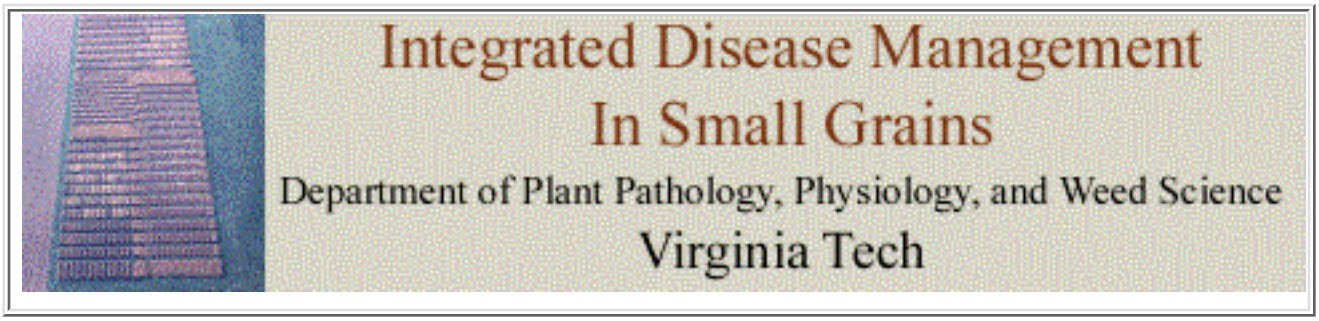
Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Effectiveness of Management and Cultural Practices on Barley Disease Control

Diseases	Resistant Cultivars	Crop Rotation	Plow Down	Balanced Fertility	Planting Date	Seed Fungicide	Foliar Fungicide
Covered smut	2	-	-	-	-	1	-
Loose smut	2	-	-	-	-	1	-
Powdery mildew	1	-	-	3	2	2	1
Leaf rust	1	-	-	-	2	3	1
Barley scald	1	1	1	-	-	-	1
Net blotch	1	1	1	-	-	1	1
Barley stripe	2	-	-	-	-	1	-
Barley yellow dwarf	1	-	-	-	2	-	-

1 = Highly effective, 2 = Moderately effective, 3 = Slightly effective

Last updated on October 07, 1998.



Erik L. Stromberg

Barley Covered Smut

Scientific Name: *Ustilago hordei*

Control Recommendations Management Practices Pesticides

Description:

Covered smut of barley is known to occur wherever barley is grown. It is most characteristically recognized by the semi-persistent membrane that covers the smutted spikelets, unlike loose smut of barley. The pathogen survives a teliospores (resting spores) on seed or in infested soil for long periods of time. Infection occurs as the seedlings emerges from the sprouting seed and is favored by cool soil temperatures (50-56 F). The fungus enters the young seedling and grows systemically

with the growing point of the developing barley plant. In smut infected plants a smutted head emerge rather than a flowering barley head. The membrane covering the smutted tissues keeps the smut spores (teliospores) from being dispersed until harvest.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Covered Smut Control Recommendation

Fungicide Common Name	Fungicide Trade Name
PCNB[a]	Terra-Coat LT-2
carboxin[a]	Vitavax
carboxin[a]	Vitavax 34
carboxin[a]	Vitavax 75W
carboxin + captan[a]	Vitavax 20-20
carboxin + thiram[a]	Vitavax 200
tebuconazole + thiram[a]	Raxil-Thiram

Other Control Recommendations: Barley Cultivars Management Practices

Remarks:

a:

Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.

Biological Description

Last updated on March 05, 1999

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Barley Loose Smut

Scientific Name: *Ustilago nuda*

Control Recommendations Management Practices Pesticides

Description:

Loose smut of barley is known to occur wherever barley is grown. The pathogen survives form one season to the next as dormant mycelium (fungal threads) within the embryo of the barley seed. When a non-protected, infected seed germinates the fungus breaks dormancy and grows systemically within the developing barley plant. When the barley plant would normally produce a head the pathogen invades all the flower parts. When the head of the infected plant emerges it produces massive amount of smut spores (teliospores) instead of a normal flowering barley head. Infection occurs when normal flowering heads of adjacent plants are dusted with the wind-blown teliospores form smutted heads. The teliospores germinate and invade the female parts of the barley flowers and eventually colonize the developing embryo. One the infected seed matures the pathogen goes dormant until the cycle is repeated with the germination of the barley seed.

Unlike other seedborne pathogens loose cannot be controlled by any fungicide that not systemically active. Fortunately there are several very effective seed treatment fungicide.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Managemnt and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Loose Smut Control Recommendation

Fungicide Common Name	Fungicide Trade Name
carboxin[a]	Vitavax
carboxin[a]	Vitavax 34
carboxin[a]	Vitavax 75W
carboxin + captan[a]	Vitavax 20-20
carboxin +thiram[a]	Vitavax 200
tebuconazole-thiram[a]	Raxil Thiram

Remarks:

a:

Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.

Biological Description

Last updated on March 05, 1999.

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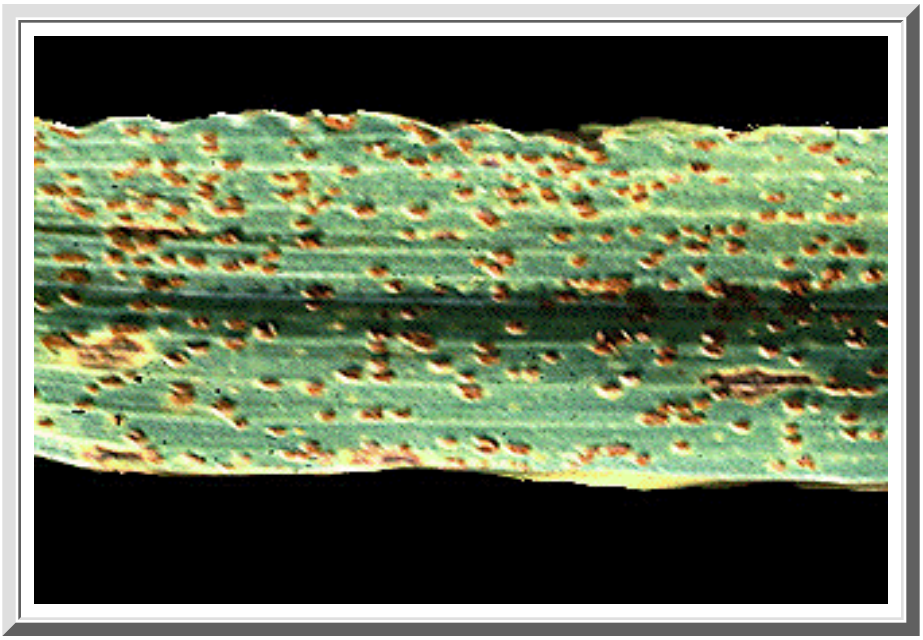
Virginia Tech

Erik L. Stromberg

Barley Leaf Rust



Scientific Name: *Puccinia hordei*

Control Recommendations Barley Cultivars Management Practices Pesticides

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Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Main

Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Leaf Rust Control Recommendations

Fungicide Common Name	Trade Name	Formulated Rate/Acre
propiconazole[a]	Tilt 3.6EC	4.0 fl oz
propiconazole + trifloxystrobin[a]	Stratego 250EC	10.0 fl oz

Other Control Recommendations: Barley Cultivars Management Practices

Remarks:

a:

Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes'GS 5 through GS 10.5). Examine plants from 5 to 10 randomly selected areas within the field. Make application only when rust pustules cover 1-3% of area of fully expanded upper leaves (see leaf area figure), but not before first joint (Feekes' GS 6 or Zadoks' GS 31), except in Tidewater region south of the James River. See Figure 1. Do not apply more than 4 oz/A/ year or after Feekes' GS 10.5 or Zadks' 59 on wheat. Do not apply after Feekes' 8 or Zadoks' 37 on Barley. Do not graze or feed livestock treated forage or cut the green crop for hay or silage. After harvest the straw may be used for bedding or feed. Follow label instructions for additional precautions.

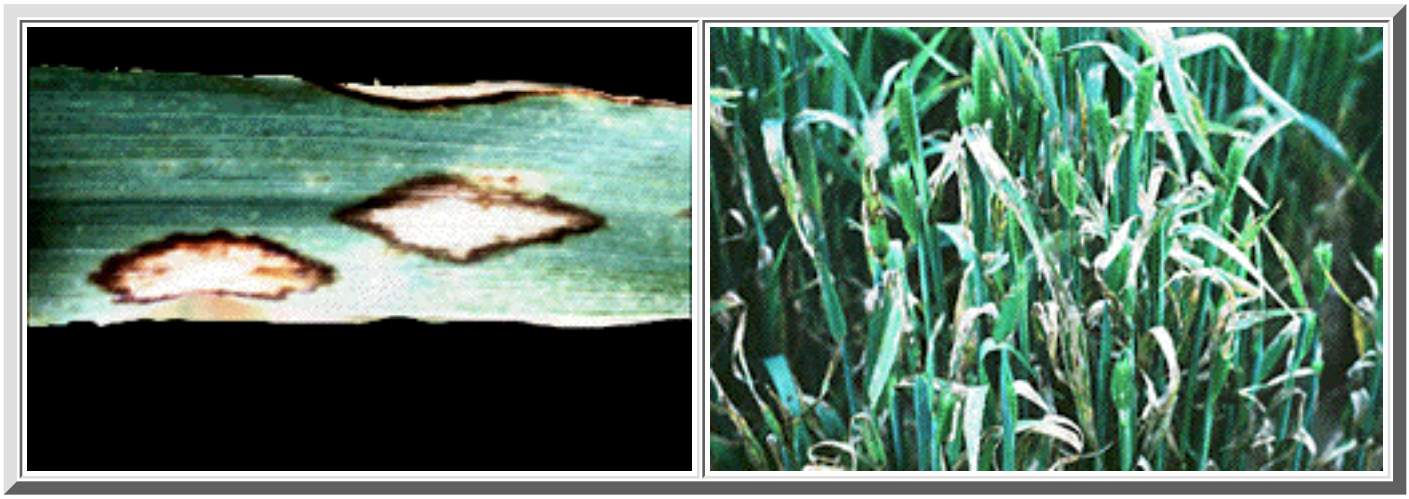
Biological Description

Last updated on February 28, 2002.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Barley Scald



Scientific Name: *Rhynchosporium secalis*

Control Recommendations: Barley Cultivars | Management Practices | Pesticides

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Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Main

Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Scald Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
propiconazole[a]	Tilt 3.6EC	4.0 fl oz

Other Control Recommendations: Barley Cultivars Management Practices

Remarks:

a:

Scout fields weekly from Zadokst growth stages (GS) 30 through 37 (Feekes' GS 5 through GS 8).

Biological Description

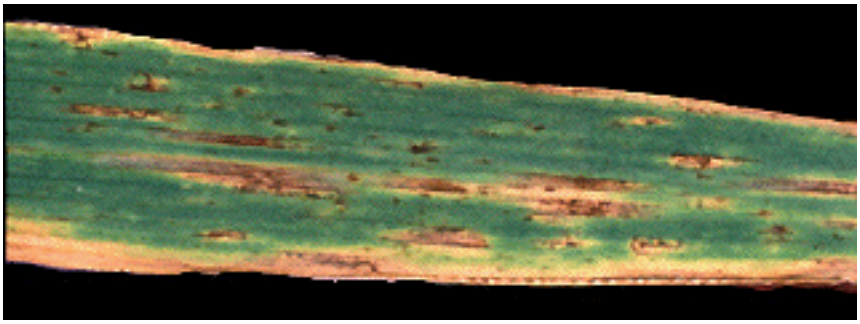
Main

Last updated on March 05, 1999.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Barley Net Blotch



Scientific Name: *Pyrenophora teres*

Control Recommendations Barley Cultivars Management Practices Pesticides

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Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Main

Last updated on February 24, 2000.

Disease Managemnt and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Net Blotch Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
propiconazole[a]	Tilt 3.6EC	4.0 fl oz

Other Control Recommendations: Barley Cultivars Management Practices

Remarks:

a:

Scout fields weekly from Zadokst growth stages (GS) 30 through 37 (Feekes' GS 5 through GS 8).

Biological Description

Main

Last updated on March 05, 1999.

Integrated Disease Management
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Virginia Tech

Erik L. Stromberg

Barley Stripe

Scientific Name: *Helminthosporium gramineum*

Control Recommendations Management Practices Pesticides

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on October 1, 1996.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Stripe Control Recommendations

Fungicide Common Name	Fungicide Trade Name
imazalil[a]	Gustafson Flo-Pro IMZ

Other Control Recommendations: Management Practices

Remarks:

a:

Use according to label instructions.

Biological Description

Main

Last updated on May 25, 1999.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Barley Yellow Dwarf

Control Recommendations Barley Cultivars Management Practices Pesticides

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Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Barley Powdery Mildew Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
propiconazole[a]	Tilt 3.6EC Flowable	4.0 fl oz
propiconazole + trifloxystrobin[a]	Stratego 250 EC	10.0 fl oz

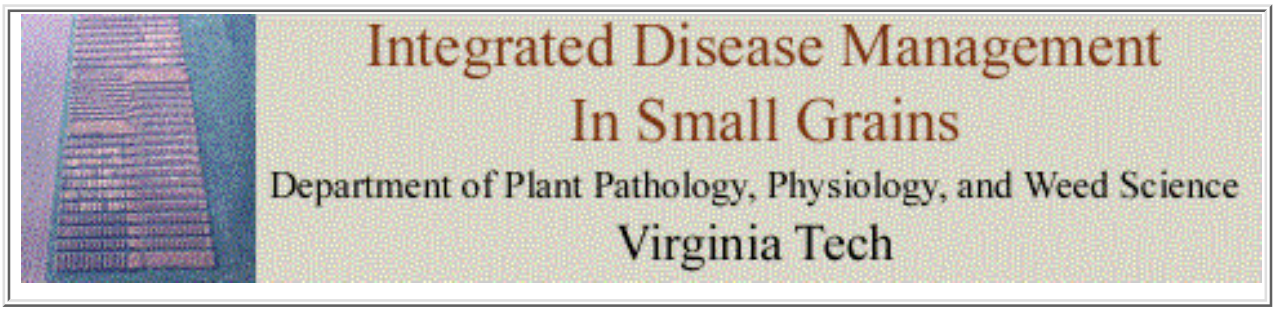
Other Control Recommendations: Barley Cultivars Management Practices

Remarks:

[a]Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes'GS 5 through GS 10.5) head emergence. Examine plants from 5 to 10 randomly selected areas within the field. Make application only when powdery mildew covers 5-10% of area of fully expanded upper leaves (see leaf area figure), but not before tillers have reached Zadoks'31 (Feekes' GS 6) first joint (see Figure 1), except in the Tidewater region south of the James River. Do not apply more than 4 fl oz/A per year or after Zadoks' GS 59 (Feekes'GS 10.5), head emerged, but not flowering on wheat. Do not apply after GS 37 on Barley. Do not graze or feed livesock treated forage or cut the green crop for hay or silage. After harvest straw may be used for bedding. Follow all label instructions.

Biological Description

Last updated on February 28, 2002.



Erik L. Stromberg

Wheat Streak Mosaic

Click to enlarge the images

Description:

Wheat streak mosaic virus (WSMV) infection have been found in Virginia the spring of 2000. The incidence and severity of this disease depends on the environment, vector survival, distribution and frequency of volunteer wheat plants which serve as a source of virus and haven for vector, and wheat cultivar susceptibility.

Symptoms: Symptoms of with wheat streak mosaic virus typically appear in the spring (image). These symptoms can look very similar to WSSMV, caused by wheat spindle streak mosaic virus, which is vectored by the soil-borne fungus, *Polymyxa graminis*. However, the field pattern of wheat streak mosaic is related to the distribution and activity of the vector, the wheat curl mite, *Aceria tulipae*. As the wheat crop develops, plants affected with WSMV are typically severely stunted (image) with yellow mottled and streaked leaves. These yellow streaks are often seen as discontinuous dashes running parallel to the leaf veins (image).

As the season progresses, plants affected and colonized by the curl mites may develop "leaf rolling". Leaves appear upright while the margins roll inward. This symptom of mite feeding looks like drought stress in the affected plants (image). Wheat streak mosaic symptoms tend to become more severe as the weather warms, and severely affected plants may produce sterile heads or die

prematurely.

Vector: The wheat curl mite, *Aceria tulipae*, is the only means by which the virus is transmitted in nature. This mite thrives in lush young growth of wheat and other grasses. Thus, volunteer wheat in soybean fields harvested in the fall is a particularly good breeding ground for this mite and the virus.

The wheat curl mite is approximately 0.03 mm long. It is invisible to the unaided eye. It is easily dispersed by winds. The mite can develop from egg to adult in 8 to 10 days. It produces rapidly at temperatures ranging from 75-80ºF. Dry conditions also favor the mite's development. It can over-winter as an egg, nymph, or adult either in the crowns of wheat plants or other host grasses. This enables the mite to survive freezing temperatures for several months. Survival is even greater in mild winters.

Hosts: Although wheat is the preferred host for *Aceria tulipae*, many other species of grasses are hosts for both the mite and the virus. These include corn, oats, foxtail, barnyardgrass, and others. Volunteer wheat is the primary means by which the wheat curl mite populations and the wheat streak mosaic virus are maintained. In the absence of a host with live green leaves the wheat curl mite will only survive for a few days.

Disease management: There are no effective chemicals registered for control of wheat curl mite. Disease management should be directed towards removing host plants during the fall and winter months (*e.g.* volunteer wheat) to prevent the survival of the mite and the maintenance of virus in or near the field. Cultivars can very in their susceptibility to the virus.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 04, 2003.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Wheat Common Bunt or Stinking Smut

Scientific Name: *Tilletia caries*

Control Recommendations

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Common Bunt or Stinking Smut Control Recommendations

Fungicide Common Name	Fungicide Trade Name
carboxin[a]	Vitavax
carboxin[a]	Vitavax 34
carboxin + captan[a]	Vitavax 20-20
carboxin + thiram[a]	Vitavax 200
PCNB[a]	Gustafson LT-2N
tebuconazole + thiram	Raxil-Thiram
difenconazole + mefanoxam[b]	Dividend XL RTA
difenconazole + mefanoxam[c]	Dividend Apron XL-LS

Remarks:

a:

Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.

b:

Seed treatment fungicide. Apply 5-10 fl oz/100 Ibs of seed.

c:

Apply 0.5-1.0 fl oz/100 Ibs of seed.

Biological Description

Last updated on March 05, 1999.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

Erik L. Stromberg

Wheat Common Root Rot Complex

Scientific Name: *Helminthosporium sativum* and *Fusarium spp.*

Control Recommendations:

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Common Root Rot Complex Control Recommendations

Fungicide Common Name	Fungicide Trade Name	
imazalil	Gustafson Flo-Pro IMZ	Use according to label instructions.
difenconazole + mefanoxam	Dividend XL RTA	Apply 5-10 fl oz/100 Ibs of seed.
difenconazole + mefanoxam	Dividend Apron XL-LS	Apply 0.5-1.0 fl oz/100 Ibs of seed.

Remarks:

Biological Description

Last updated on March 05, 1999.

Integrated Disease Management
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Department of Plant Pathology, Physiology, and Weed Science
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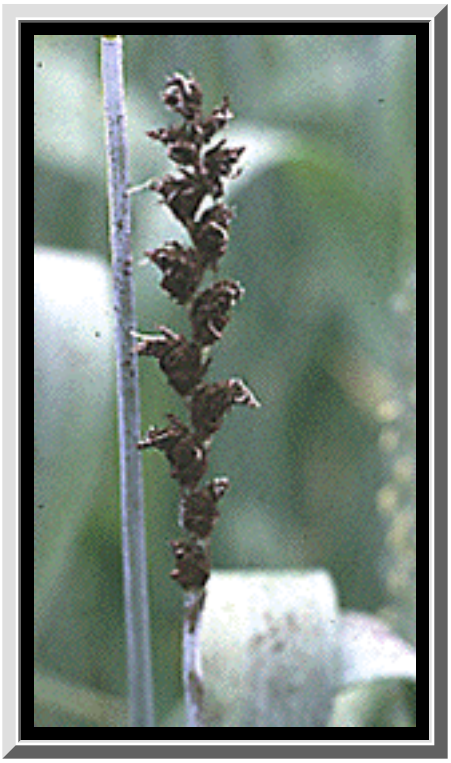
Erik L. Stromberg

Wheat Loose Smut



Scientific Name: *Ustilago tritici*

Control Recommendations Management Practices Pesticides

Description:

Loose smut is most obvious just after the wheat has headed. Diseased plants produce blackened heads among a field of green heads. The spikelets of colonized heads become a mass of olive-black spores that have a characteristic "dead fish" odor. The fungus that causes loose smut survives as dormant mycelia (fungal threads) within the embryo of an infested wheat seed. When the seed germinates, the fungus resumes growth along with the wheat shoot apex. As the juvenile wheat head develops within the wheat stem the fungus colonizes the head develops within the wheat stem the fungus colonizes the seed primordia (tissue that would become a seed within a wheat head). When the head emerges from the boot, instead of flowering and releasing pollen, it releases the olive-black spores that can be wind-blown to "healthy" flowering wheat heads. The spore germinates on the stigma (female receptive portion of wheat flower) of a healthy wheat head and colonizes the developing wheat seed embryo. The colonized seed appears healthy but carries the dormant smut fungus within to start the cycle over again with the planting of the seed.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Seedling Blight Phase of Wheat Scab Control Recommendations[a]

Fungicide Common Name [b]	Fungicide Trade Name
captan[c]	Captan 30-DD
captan[c]	Captan 300
captan[c]	Captan 400
captan[c]	Captan 400-DD Orthocide 4 Flowable Seed Protectant
thiram[c]	Thiram-50WP
thiram[c]	Gustasfon 42-S
carboxin[c]	Vitavax
carboxin + captan[c]	Vitavax 20-20

carboxin + thiram[c]	Vitavax 200
difenconazole + mefanoxam	Dividend XL RTA
difenconazole + mefanoxam	Dividend Apron XL LS
PCNB[c]	Gustafson LT-2N
tebuconazole + thiram[c]	Raxil-Thiram

Remarks:

a:

Seed treatments do not control the head blight phase of scab disease.

b:

Use according to instructions on label. Don not use treated seed for feed or food.

c:

Thiram formulations are not registered for oats. Vitavax formulations, Raxil-Thiram, and Terra-Coat LT-2 are not registered for rye. Use according to instructions on label. Do not use treated seed for feed or food.

d:

For wheat use only. Apply 5-10 fl oz /100 pounds of seed.

e:

For wheat use only. Apply 0.5 - 1.0 fl oz/100 pounds of seed.

Biological Description

Main

Last updated March 05, 1999.

Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
Virginia Tech

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Wheat Scab

Scientific Name: *Fusarium graminearum*

Control Recommendations Management Practices Pesticides

Description:

Scab is early identified in the field when healthy heads are green. Scab-infested spikelets appear prematurely bleached. Often spikelets in one-third to one-half of the head are affected. In several cases the entire head may be colonized. The bleached spikelets are either sterile or contain shriveled and discolored seed. Close examination of affected spikelets may show superficial pink mycelia at the base of the colonized spikelet. The fungi that cause scab overwinter on infested crop residues such as cornstalks, wheat stubble, and stubble from other grasses. During flowering of the wheat, spores are produced on these scab-infested residues. During moist, warm weather the wind-borne scab spores infect and colonize the spent anther cases (pollen producing sacks) of the flowering wheat and go on to invade the spikelet and developing seed.
The grain harvested from wheat fields heavily infested with scab is of poor quality, low test weight, and often contains mycotoxin (toxins produced by fungi) that make the grain less palatable to livestock and humans. Some of these mycotoxins induce vomiting and muscle spasms in man and non-ruminant animals. Other mycotoxins can cause sexual reproductive dysfunction. Some of these toxins can be intoxicating when bread is made from "scabby" wheat.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Main

Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Loose Smut Control Recommendations

Fungicide Common Name	Fungicide Trade Name
carboxin[a]	Vitavax
carboxin[a]	Vitavax 34
carboxin + captan[a]	Vitavax 20-20
carboxin + thiram[a]	Vitavax 200
difenconazole + mefanoxam[b]	Dividend XL RTA
difenconazole + mefanoxam[c]	Dividend Apron XL LS
tebuconazole + thiram	Raxil-Thiram
triadimenol[d]	Baytan 30 Flowable

Other Control Recommendations: Management Practices

Remarks:

a:

Used as seed treatment fungicides according to instructions on label. Must be applied as a slurry treatment for complete coverage.

b:

Apply 5-10 fl oz/100 Ibs of seed.

c:

Apply 0.5-1.0 fl oz/100 Ibs of seed.

d:

This material is only registered for application by certified seed conditioners and is not available for farmer application. Rate is 0.75-1.5 fl oz/100 lb of seed. Caution: Treated seed should not be planted late in the planting season or planted more than 1.5 inches deep. Use according to label instructions.

Biological Description

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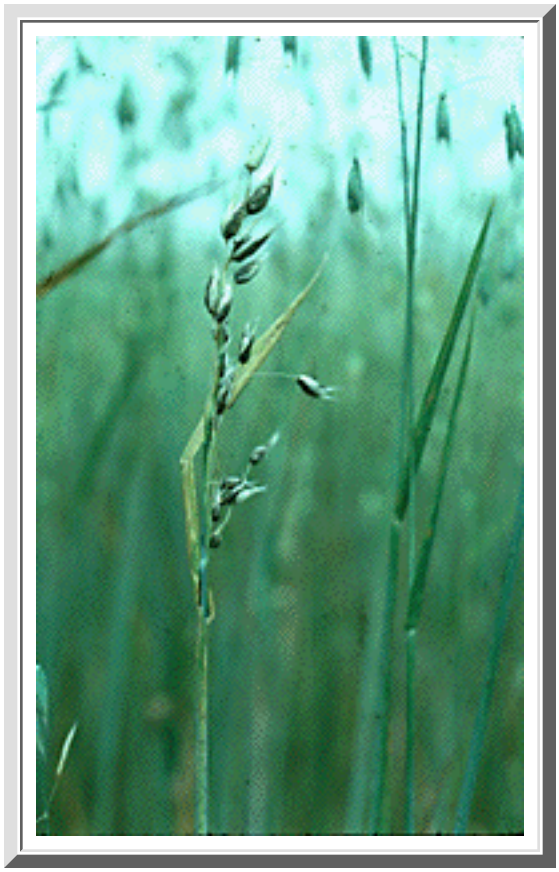
Oat Loose Smut



Scientific Name: *Ustilago avenae*

Control Recommendations

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Last updated on February 24, 2000.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Oats Loose Smut Control Recommendations

Fungicide Common Name[a]	Fungicide Trade Name
carboxin	Vitavax
carboxin	Vitavax 34
carboxin + thiram	Vitavax 200
PCNB	Terra-Coat LT-2
tebuconazole + thiram	Raxil-Thiram

Remarks:

a:

Use according to instructions on the label. Should be applied as a slurry treatment for complete coverage.

Biological Description

Last updated on March 05, 1999.

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Oat Cover Smut

Scientific Name: *Ustilago kolleri*

Control Recommendations

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Oats Covered Smut Control Recommendations

Fungicide Common Name[a]	Fungicide Trade Name
carboxin	Vitavax
carboxin	Vitavax 34
carboxin + thiram	Vitavax 200

Remarks:

a:

Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.

Biological Description

Last updated on March 05, 1999.

Integrated Disease Management
In Small Grains
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Wheat Take-all

Scientific Name: *Gaeumannomyces graminis* var. *tritici*

Control Recommendations

Description:

Wheat Take-all symptoms are most obvious at heading. Diseased plants occur in patches within the field. They are shorter in height than surrounding healthy plants and die prematurely at heading. Their heads are bleached (whiteheads) and may be sterile or contain few, severely shriveled seeds. Typically, take-all infected plants pull out or bread off easily at the soil line. The base and culms of infected plants have sparse root development and characteristically a brown-black rot can be seen at the crown and extending to the base of the stem of tiller under the leaf sheath that covers it. The surface of this brown-black rot is shiny, and the diagnostic character of dark mycelial strands can be seen with the aid of a microscope.

The fungus that causes take-all persists in infested wheat debris and on infected wheat plants. Roots of the next crop become infected when they grow through soil near the infested debris. The fungus initially colonizes the roots of the young wheat plants before colonizing the crowns. If this root infection takes place in the fall or early spring then the disease is much more severe. Initial infection and colonization are favored by moderate temperatures (50 degree to 70 degree F) with adequate moisture.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Other Small Grain Seedling Diseases Control Recommendations

Fungicide Common Name	Fungicide Trade Name
captan	Captan 30-DD
captan	Captan 300
captan	Captan 400
captan	Captan 400DD
thiram	Thiram-50WP
thiram	Gustafson 42-S
carboxin	Vitavax
carboxin + captan	Vitavax 20-20

carboxin + thiram	Vitavax 200
difenconazole + mefanoxam[a]	Dividend XL RTA
difenconazole + mefanoxam[b]	Dividend Apron XL LS
PCNB	Gustafson LT-2N
tebuconazole + thiram	Raxil-Thiram

Remarks: Thiram formulations are not registered for oats. Vitavax formulations, Raxil-Thiram, and Terra-Coat LT-2 are not registered for rye. Use according to instructions on label. Do not use treated seed for feed or food.

a:

For wheat use only. Apply 5-10 fl oz /100 pounds of seed.

b:

For wheat use only. Apply 0.5 - 1.0 fl oz/100 pounds of seed.

Last Updated March 05, 1999.

Disease Management Practices	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Seed and seedling disease control in small grains

Crop	Disease	Fungicide common name	Fungicide trade name	Remarks
Barley, Oats, Rye, Wheat	Seed decay and seedling blights including the scab fungus (seed treatments do not control the head blight phase of scab disease)	captan	Captan 30-DD	Thiram formulations are not registered for oats. Vitavax formulations, Raxil-Thiram, and Terra-Coat LT-2 are not registered for rye. Use according to instructions on label. Do not use treated seed for feed or food.
		captan	Captan 300	
		captan	Captan 400	
		captan	Captan 400DD	
		thiram	Thiram-50WP	
		thiram	Gustafson 42-S	
		carboxin	Vitavax	Not for use on rye
		carboxin + captan	Vitavax 20-20	Not for use on rye
		carboxin + thiram	Vitavax 200	Not for use on rye
		difenconazole + mefanoxam	Dividend XL RTA	For wheat use only. Apply 5-10 fl oz /100 pounds of seed.
		difenconazole + mefanoxam	Dividend Apron XL LS	For wheat use only. Apply 0.5 - 1.0 fl oz/100 pounds of seed.
		PCNB	Gustafson LT-2N	Not for use on rye

		tebuconazole + thiram	Raxil-Thiram	Not for use on rye
Barley	Loose smut *(Ustilago nuda)*, Covered smut *(Ustilago hordei)*	carboxin	Vitavax	Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.
		carboxin	Vitavax 34	
		carboxin	Vitavax 75W	
		carboxin + captan	Vitavax 20-20	
		carboxin + thiram	Vitavax 200	
		tebuconazole + thiram	Raxil-Thiram	
	Covered smut *(Ustilago hordei)*	PCNB	Terra-Coat LT-2	Use according to instructions on the label. Should be applied as a slurry treatment for complete coverage.
	Barley stripe *(Helminthosporium gramineum)*	imazalil	Gustafson Flo-Pro IMZ	Use according to label instructions.
Oats	Loose smut *(Ustilago avenae)*, Covered smut (*Ustilago kolleri*)	carboxin	Vitavax	Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.
		carboxin	Vitavax 34	
		carboxin + thiram	Vitavax 200	
	Loose smut *(Ustilago avenae)*	PCNB + tebuconazole + thiram	Terra-Coat LT-2 Raxil-Thiram	Use according to instructions on the label. Should be applied as a slurry treatment for complete coverage.
Wheat	Loose smut (*Ustilago tritici*)	carboxin	Vitavax	Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.
		carboxin	Vitavax 34	
		carboxin + captan	Vitavax 20-20	
		carboxin + thiram	Vitavax 200	
		difenconazole + mefanoxam	Dividend XL RTA	Apply 5-10 fl oz/100 lbs of seed.
		difenconazole + mefanoxam	Dividend Apron XL LS	Apply 0.5-1.0 fl oz/100 lbs of seed.
		tebuconazole + thiram	Raxil-Thiram	

		triadimenol	Baytan 30 Flowable	This material is only registered for application by certified seed conditioners and is not available for farmer application. Rate is 0.75-1.5 fl oz/100 lb of seed. Caution: Treated seed should not be planted late in the planting season or planted more than 1.5 inches deep. Use according to label instructions.
Wheat	Common bunt or Stinking smut (*Tilletia caries*)	carboxin	Vitavax	Use according to instructions on label. Must be applied as a slurry treatment for complete coverage.
		carboxin	Vitavax 34	
		carboxin + captan	Vitavax 20-20	
		carboxin + thiram	Vitavax 200	
		PCNB	Gustafson LT-2N	
		tebuconazole + thiram	Raxil-Thiram	
		difenconazole + mefanoxam	Dividend XL RTA	Apply 5-10 fl oz/100 Ibs of seed.
		difenconazole + mefanoxam	Dividend Apron XL-LS	Apply 0.5-1.0 fl oz/100 Ibs of seed.
Wheat	Common root rot complex(*Helminthosporium sativum* and *Fusarium spp.*)	imazalil	Gustafson Flo-Pro IMZ	Use according to label instructions.
		difenconazole + mefanoxam	Dividend XL RTA	Apply 5-10 fl oz/100 Ibs of seed.
		difenconazole + mefanoxam	Dividend Apron XL-LS	Apply 0.5-1.0 fl oz/100 Ibs of seed.
Wheat	Powdery mildew (*Erysiphe graminis* f.sp. *tritici*)	tridimenol	Bayton 30 Flowable	This fungicide will prevent the overwintering of powdery mildew and leaf rust in susceptible cultivars. Rate is 1.5 fl oz/100 lb of seed. It is only registered for application by certified seed conditioners and is

				not available for farmer application. Caution: Treated seed should not be planted late in planting season or planted more than 1.5 inches deep. Use according to label instructions.
Wheat	Leaf rust (*Puccinia recondita*)	difenconazole + mefanoxam	Dividend XL RTA	Apply 5-10 fl oz/100 lbs of seed.
		difenconazole + mefanoxam	Dividend Apron XL-LS	Apply 0.5-1.0 fl oz/100 lbs of seed.
				Dividend formulations provide a degree of fall season powdery mildew, leaf rust, and leaf and plume blotch in winter wheat. For full season control, foliar fungicides may be required in the spring on cultivars that are susceptible to moderately susceptible to powdery mildew.

Main

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Integrated Disease Management
In Small Grains
Department of Plant Pathology, Physiology, and Weed Science
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Wheat Common Bunt or Stinking Smut

Scientific Name: *Tilletia caries*

Control Recommendations:

Description:

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Last updated on February 24, 2000.

Disease Management Practices	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Foliarly-applied fungicides for disease control in small grains

Crop	Disease	Fungicide common name	Fungicide trade name	Formulated rate/acre	Remarks
Wheat and Barley	Powdery mildew on wheat (Erysiphe *graminis* f.sp. *tritici*) and barley (*Erysiphe graminis* f.sp. *hordei*)	propiconazole	Tilt 3.6EC	4.0 fl oz	Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes'GS 5 through GS 10.5) head emergence. Examine plants from 5 to 10 randomly selected areas within the field. Make application only when powdery mildew covers 5-10% of area of fully expanded upper leaves (see leaf area figure), but not before tillers have reached Zadoks'31 (Feekes' GS 6) first joint, except in the Tidewater region south of the James River. Do not apply more than 4 fl oz/A per year or after Zadoks' GS 59 (Feekes'GS 10.5), head emerged, but not flowering on wheat. Do not apply after GS 37 on Barley. Do not graze
		propiconazole + trifloxystrobin	Stratego 250EC	10.0 fl oz	

					or feed livesock treated forage or cut the green crop for hay or silage. After harvest straw may be used for bedding. Follow all label instructions.
Wheat	Leaf and glume blotch *(Stagonospora nodorum)* and Tan spot *(Pyrenophora tritici-repentis)*	mancozeb	Dithane M45	2.0 lb	These fungicides are protestant types that must be applied before infection to provide a barrier to prevent infection. Make first application when flag leaf is fully emerged (Feekes' stage 10 or Zadoks' 45) and repeat when grain head is visible about 10-12 days later. Do not make last application within 26 days of harvest. Livestock may not graze in treated areas within 26 days of last treatment. Penncozab is only registered for use on wheat.
		mancozeb	Dithane F45	1.6 qt	
		mancozeb	Dithane DF	2.0 lb	
		mancozeb	Manzate 200	2.0 lb	
		mancozeb	Manzate DF	2.0 lb	
		mancozeb	Penncozeb	1.5 - 2.0 lb	
		mancozeb	Penncozeb DF	1.5 - 2.0 lb	
		propiconazole	Tilt 3.6EC	4.0 fl oz	Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes'GS 5 through GS 10.5). Examine plants from 5 to 10 randomly selected areas within the field. Make application only when rust pustules cover 1-3% of area of fully expanded upper leaves (see leaf area figure), but not before first joint (Feekes' GS 6 or Zadoks' GS 31), except in Tidewater region south of the James River. See Figure 1. Do not apply more than 4 oz/A/ year or after Feekes' GS 10.5 or Zadks' 59 on wheat. Do not apply after Feekes' 8 or Zadoks' 37 on Barley. Do not graze or feed

				livestock treated forage or cut the green crop for hay or silage. After harvest the straw may be used for bedding or feed. Follow label instructions for additional precautions.
Wheat and Barley Leaf rust (*Puccinia recondita*) of wheat and barley	pyraclostrobin	Headline 2.09EC	6.0 - 9.0 fl oz	Headline should be integrated into an overall disease management strategy that includes proper selection of cultivars with disease tolerance, removal of plant debris in which inoculum overwinters, and plant residue management. Resistance management: do not make more than two applications of Headline/A/year. Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 69 (Feekes' GS 5 through 10.53). Examine plants from 5 to 10 randomly selected areas within the field. Make application only when rust pustules cover 1% to 3% of area of fully expanded upper leaves (see leaf area figure). Do not apply to barley after Zadoks' GS 55 (Feekes' GS 10.3). Do not apply to wheat after Zadoks' GS 69 (Feekes' GS 10.53). Do not harvest hay within 14 days of application.

Wheat Leaf Rust (*Puccinia recondita*)		azoxystrobin	Quadris	6.2 - 10.8 fl oz	Quadris and Stratego should be integrated into an overall disease management strategy that includes proper selection of varieties with disease tolerance, proper timing and placement of irrigation, removal of plant debris in which inoculum overwinters, plant residue management, and crop rotation. Resistance management: Do not make more than two applications of Quadris or Stratego per acre per year. Application directions: Quadris or Stratego should be applied prior to or in the early stages of disease development. Applications may be made at any time, immediately after jointing (Feeks 6 or Zadok's 31) up to late head emergence (Feekes 10.5 or Zadok's 59). A crop oil concentrate adjuvant may be added at 1.0% V/V to optimize efficacy. Do not apply later than Feekes growth stage 10.5 (Zadok's 59). Do not harvest treated wheat for forage. Do not apply more than 0.77 quarts product/acre/season (0.4 lb ai/A). Do not apply within 14 days of harvest for hay. Do not apply within 45 days of harvest for grain and straw.
		propoiconazole + trifloxystrobin	Stratego 250EC	10 fl oz	
Barley and rye	Barley scald (*Rhynchosporium secalis*), Net blotch (Pyrenophora *teres*),	propiconazole	Tilt 3.6EC	4.0 fl oz	Scout fields weekly from Zadoks' growth stages (GS) 30 through 37 (Feekes' GS 5 through GS 8).

	propiconazole	Tilt 3.6EC	4.0 fl oz	Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes' GS 5 through GS 10.5) head emergence. For leaf and plume blotch collect main tillers from 10 plants from 10 randomly selected areas within the field. Examine the appropriate indicator leaf (see Figure 3) from each tiller and record the number of indicator leaves with one or more lesions. If 25% of the 100 indicator leaves have one or more lesions, then a fungicide application is indicated. Quadris and Stratego should be integrated into an overall disease management strategy that includes proper selection of varieties with disease tolerance, proper timing and placement of irrigation, removal of plant debris in which inoculum overwinters, plant residue management, and crop rotation. Resistance management: Do not make more than two applications of Quadris or Stratego per acre per year. Application directions: Quadris or Stratego should be applied prior to or in the early stages of disease development. Applications may be made at any time, immediately after jointing (Feeks 6 or
	propiconazole + trifloxystrobin	Stratego 250EC	10.0 fl oz	

				Zadok's 31) up to late head emergence (Feekes 10.5 or Zadok's 59). A crop oil concentrate adjuvant may be added at 1.0% V/V to optimize efficacy. Do not apply later than Feekes growth stage 10.5 (Zadok's 59). Do not harvest treated wheat for forage. Do not apply more than 0.77 quarts product/acre/season (0.4 lb ai/A). Do not apply within 14 days of harvest for hay. Do not apply within 45 days of harvest for grain and straw.
Wheat Leaf and glume blotch (*Stagonospora nodorum*) and Tan spot (*Pyrenophora tritici-repentis*)	azoxystrobin	Quadris	6.2 - 10.8 fl oz	
	pyraclostrobin	Headline 2.09EC	6.0 - 9.0 fl oz	Headline should be integrated into an overall disease management strategy that includes proper selection of cultivars with disease tolerance, removal of plant debris in which inoculum overwinters, and plant residue management. Resistance management: do not make more than two applications of Headline/A/year. Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 69 (Feekes' GS 5 through 10.53). For leaf and glume blotch, collect main tillers from 10 plants from 10 randomly selected areas within the field. Examine the appropriate indicator leaf (see Indicator leaves) from each tiller and record the number

					of indicator leaves with one or more lesions. If 25% of the 100 indicator leaves have one or more lesions, then a fungicide application is indicated. Do not apply to wheat after Zadoks' GS 69 (Feekes' GS 10.53). Do not harvest hay within 14 days of application.
		Indicator leaves are: Flag-4 and flag-5 from Zadoks' GS 31-37 (Feekes' GS 6-8) Flag-3 from Zadok's GS 38-45 (Feekes' GS 8-10) Flag-2 from Zadoks' GS 46-59 (Feekes' GS 10-10.5) Do not treat before Zadoks' GS 31 (Feekes' GS 6) first joint (see Figure 1), except in the Tidewater region south of James River. Do not apply more than 4 fl. oz./acre per year or after Zadoks' GS 59 (Feekes' GS 10.50), head emerged, but not flowering. Do not graze or feed livestock treated forage or cut the green crop for hay or silage. After harvest straw may be used for bedding. Follow all label instructions.			

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Integrated Disease Management
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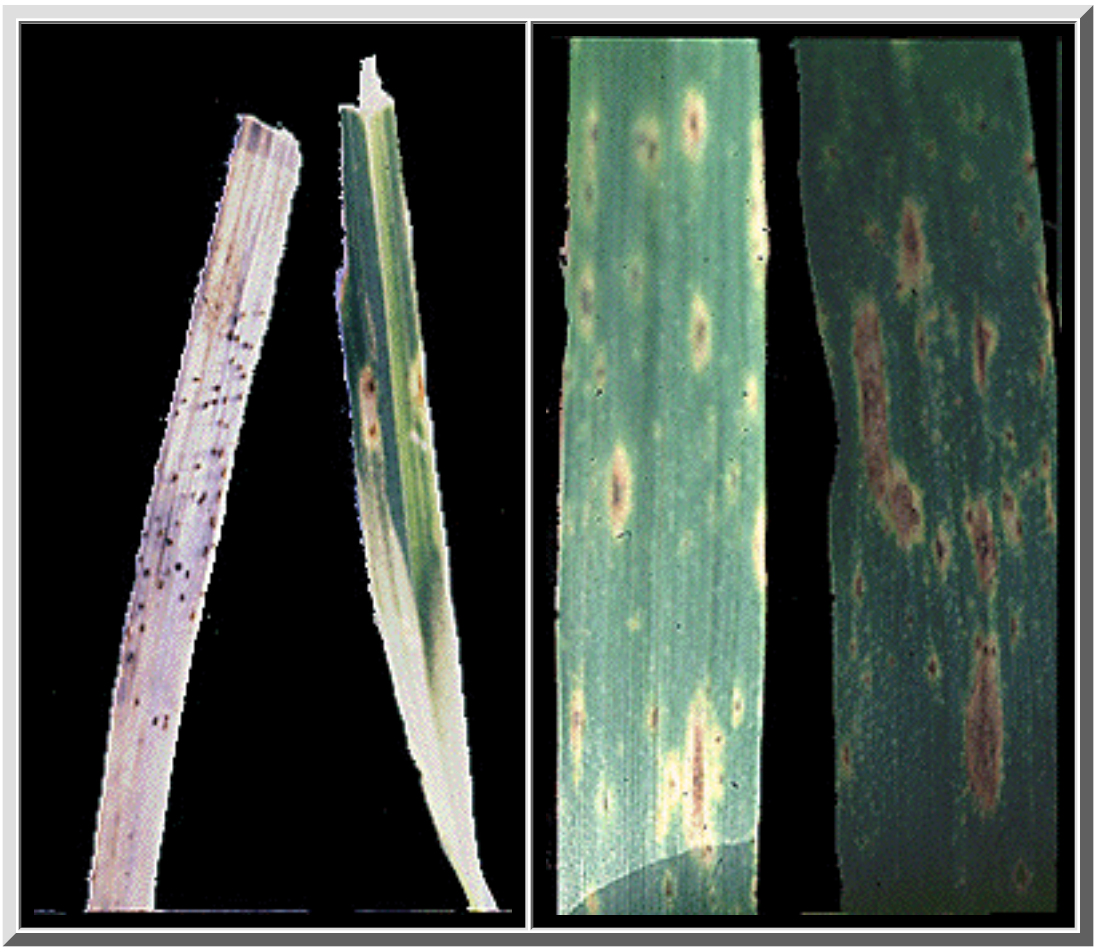
Wheat Tan Spot



Scientific Name: *Pyrenophora tritici-repentis*

Control Recommendations Management Practices Pesticides

Description:

Tan spot develops on both upper and lower leaves. The lesions initially appear as tan-brown flecks that expand into lens-shaped lesions similar to the lesions produced by the septoria leaf blotch fungus. Tan spot lesions range in size from 1/4 to 1/2 inch in length and are surrounded by a chlorotic (yellow) border. As the lesion matures, the center becomes darker due to the production of air-borne olive-brown spores that can infect other leaves, stems and plants. Temperatures ranging between 60 degree to 82 degree F and periods of dew favor infection. As the wheat matures, the lesions produce oversummering reproductive structures called pseudothecia. The infested straw with pseudothecia remaining after harvest serves as the source of inoculum for the next season's wheat crop.

Disease Management Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

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Last updated on February 24, 2000.

Disease Management and Practices	Foliar Diseases	Seed and Seedling Diseases	Root and Crown Diseases	Head Diseases	Virus Diseases

Wheat Tan Spot Control Recommendations

Fungicide Common Name	Fungicide Trade Name	Formulated Rate/Acre
azoxystrobin[c]	Quadris	6.2 - 10.8 fl oz
mancozeb[a]	Dithane M45	2.0 lbs
mancozeb[a]	Dithane F45	1.6 qts
mancozeb[a]	Dithane DF	2.0 lbs
mancozeb[a]	Manzate 200	2.0 lbs
mancozeb[a]	Manzate DF	2.0 lbs

mancozeb[a]	Penncozeb	2.0 lbs
mancozeb[a]	Penncozeb DF	1.5 - 2.0 lbs
propiconazole[b]	Tilt 3.6EC	4.0 fl oz
propoiconazole + trifloxystrobin[b]	Stratego 250 EC	10.0 fl oz
pyraclostrobin[d]	Headline 2.09EC	6.0 - 9.0 fl oz

Other Control Recommendations: Management Practices

Remarks:

a: These fungicides are protestant types that must be applied before infection to provide a barrier to prevent infection. Make first application when flag leaf is fully emerged (Feekes' stage 10 or Zadoks' 45) and repeat when grain head is visible about 10-12 days later. Do not make last application within 26 days of harvest. Livestock may not graze in treated areas within 26 days of last treatment. Penncozab is only registered for use on wheat.

b: Scout fields weekly from Zadoks' growth stages (GS) 30 through 59 (Feekes' GS 5 through GS 10.5) head emergence. For leaf and plume blotch collect main tillers from 10 plants from 10 randomly selected areas within the field. Examine the appropriate indicator leaf (see Figure 3) from each tiller and record the number of indicator leaves with one or more lesions. If 25% of the 100 indicator leaves have one or more lesions, then a fungicide application is indicated.

c: Quadris should be integrated into an overall disease management strategy that includes proper selection of varieties with disease tolerance, proper timing and placement of irrigation, removal of plant debris in which inoculum overwinters, plant residue management, and crop rotation. Resistance management: Do not make more than two applications of Quadris per acre per year. Application directions: Quadris should be applied prior to or in the early stages of disease development. Applications may be made at any time, immediately after jointing (Feeks 6 or Zadok's 31) up to late head emergence (Feekes 10.5 or Zadok's 59). A crop oil concentrate adjuvant may be added at 1.0% V/V to optimize efficacy. Do not apply later than Feekes growth stage 10.5 (Zadok's 59). Do not harvest treated wheat for forage. Do not apply more than 0.77 quarts product/acre/season (0.4 lb ai/A). Do not apply within 14 days of harvest for hay. Do not apply within 45 days of harvest for grain and straw.

d: Headline should be integrated into an overall disease management strategy that includes proper selection of cultivars with disease tolerance, removal of plant debris in which inoculum overwinters, and plant residue management. Resistance management: do not make more than two applications of Headline/A/year. Determination of treatment threshold: Scout fields weekly from Zadoks' growth stages (GS) 30 through 69 (Feekes' GS 5 through 10.53). For leaf and glume blotch, collect main tillers from 10 plants from 10 randomly selected areas within the field. Examine the appropriate indicator leaf (see Indicator leaves) from each tiller and record the number of indicator leaves with one or more lesions. If 25% of the 100 indicator leaves have one or more lesions, then a

fungicide application is indicated. Do not apply to wheat after Zadoks' GS 69 (Feekes' GS 10.53). Do not harvest hay within 14 days of application.

Indicator leaves are: Flag-4 and flag-5 from Zadoks' GS 31-37 (Feekes' GS 6-8)

Flag-3 from Zadok's GS 38-45 (Feekes' GS 8-10)

Flag-2 from Zadoks' GS 46-59 (Feekes' GS 10-10.5)

Do not treat before Zadoks' GS 31 (Feekes' GS 6) first joint (see Figure 1), except in the Tidewater region south of James River. Do not apply more than 4 fl. oz./acre per year or after Zadoks' GS 59 (Feekes' GS 10.50), head emerged, but not flowering. Do not graze or feed livestock treated forage or cut the green crop for hay or silage. After harvest straw may be used for bedding. Follow all label instructions.

Biological Description

Last updated on March 03, 2003.

SUE A. TOLIN

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Education:

- Ph. D. Botany-Plant Pathology, 1965, University of Nebraska, Lincoln
- M. S. Botany-Plant Pathology, 1962, University of Nebraska, Lincoln
- B. S. Agricultural Science, 1960, Purdue University, W. Lafayette, IN

Professional Experience:

- Professor of Plant Pathology, Virginia Tech, 1983-present.
- Shared Faculty appointment (10-20%) with CSRS, USDA, for activities in national and international biotechnology policy, and plant sciences,1979-1992.
- Associate Professor, Virginia Tech, 1971-1983
- Assistant Professor, Virginia Tech, 1966-1971
- On Leave as Plant Pathologist with Plant & Animal Sciences, CSRS, USDA, Washington, D.C. under the Intergovernmental Personal Act (IPA), 6/78-12/78.
- Post-Doctoral Research Associate and Assistant Professor, Temporary - Dept. Botany and Plant Pathology, Purdue University, West Lafayette, IN, 1965-1966.

Recent Awards and Honors:

- Fellow, American Phytopathological Society
- Fellow, American Association for the Advancement of Science.
- Fellow, American Academy of Microbiology.
- Distinguished Alumni Award, Purdue University, College of Agriculture.
- Outstanding Alumni Award, University of Nebraska.
- Presidential Award, American Phytopathological Society.
- Distinguished Service Award, Potomac Div., American Phytopathological Society.

Teaching Interests:

- Teach the graduate level lecture/lab course PPWS 5024 Plant Pathogenic Viruses, and team-teach the graduate courses BIOL/PPWS 6654 Topics in Virology,, and PPWS 5454 Molecular Plant-Microbe Interactions. Provide virology and biotechnology policy and regulation in graduate and advanced courses and seminars. Taught PPWS 6004 Topics in Agricultural Biotechnology Issues, in Spring 2000.

Research Interests:

- Biology, genetics and diversity of plant pathogenic viruses, and control through understanding and deploying resistance mechanisms and management practices. Current programs with soybean mosaic and other viruses in soybean and viruses of hot pepper in Jamaica.

Selected Publications:

1. Ma*, G., Buss, G. R. and **Tolin, S. A.** 2000. Complementary actions of two genes in Columbia for resistance to soybean mosaic virus. Crop Sci. (in press).
2. **Tolin, S. A.** and Vidaver, A. K. 2000. Genetically Modified Organisms: Guidelines and Regulations for Research. Vol. 2, pp.499-509. In, Joshua Lederberg, Ed., ***The Encyclopedia of Microbiology***. Academic Press. Second Edition.
3. **Tolin, S. A.** 1999. Diseases caused by viruses; and specific viruses. p.57-73. In: Hartman, G. L., Sinclair, J. B., and Rupe, J. C. ***Compendium of Soybean Diseases***, 4th edition. American Phytopathological Society, APS Press, St. Paul, MN.
4. Eberwine*, J. E., Hagood, E. S., and **Tolin, S. A.** 1998. Quantification of viral disease incidence in corn (*Zea mays*) as affected by Johnsongrass (*Sorghum halepense*) control. Weed Technology 12:121-127.
5. Ma*, G., Chen**, P., Buss, G. R. and **Tolin, S. A.** 1995. Genetic characteristics of two genes for resistance to soybean mosaic virus in PI486355 soybean. Theor. Appl. Genet. 91:907-914.
6. McDaniel, L. L., Maratos, M. L., Goodman, J. E., and **Tolin, S. A.** 1995. Partial characterization of a soybean strain of tobacco mosaic virus. Plant Disease 79:206-211.
7. Cook, R. J., Gabriel, C. J., Kelman, A., Tolin, S., and Vidaver, A. K. 1995. Research on plant disease and pest management is essential to sustainable agriculture. Bioscience 45:354-357.
8. Chen*, P., Buss, G. R., Roane, C. W. and **Tolin, S. A.** 1994. Inheritance in soybean of resistance and necrotic reactions to soybean mosaic virus strains. Crop Sci. 34:414-422.
9. Yu*, Y. G., Saghai Maroof, M. A., Buss, G.R., and **Tolin, S. A.** 1994. RFLP and microsatellite mapping of a gene for soybean mosaic virus resistance. Phytopathology 84:60-64.
10. **Tolin, Sue A.** 1994. Cucumoviruses. pp. 278-285. In, R. Webster and A. Granoff, Eds. ***Encylopedia of Virology***. Academic Press.
11. Lederman, M. and **Tolin, S. A.** 1993. OVATOOMB: Other viruses and the origins of molecular biology. J. Hist. Biol. 26:239-254.

Current or Recent Research Sponsors:

U.S. Department of Agriculture; United Soybean Board; Virginia Soybean Board; US-AID.

Additional Information:

Current Service At Virginia Tech:

- Chair, Cross-Cutting Initiative on Biosciences and Biotechnology
- Member, Intellectual Properties Committee.
- Member, Biotechnology Oversight/Institutional Biosafety Committee

Professional Service and Outreach Activities:

- Past-President of American Phytopathological Society (www.scisoc.org)
- Member APS National Plant Pathology Board.
- AAAS – Section on Agriculture, Food and Natural Resources past Member-at-Large and Council Delegate.

- American Society for Microbiology, member Environmental Microbiology Committee.
- International Working Group on Legume Viruses, Executive Secretary 1997-2000. Check the Website: http://www.ppws.vt.edu/~virology/
- BIOSCIENCE Editorial Board
- Active in science policy issues concerning: (1) - Genetically Modified Organisms: Food and Environmental Safety Issues; Intellectual Properties; Globalization. (2) Invasive Species; (3) Priorities and Funding of Agricultural Research www.cofarm.org

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Department of Plant Pathology, Physiology, and Weed Science
Last Updated July 19, 2002

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INTERNATIONAL WORKING GROUP ON LEGUME VIRUSES

IWGLV

The IWGLV, established in 1969 is one of the oldest and still active international working groups of crop-oriented plant virologists.

Its 15th meeting will be held August 15-17, 1999 in Perth, Western Australia, immediately following the International Congress for Virology in Sydney, Australia

Click here for information

Click here for program

For Information on IWGLV:
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This page is maintained by Sue Tolin and is running on the WWW Server for the Department of Plant Pathology, Physiology, and Weed Science at Virginia Tech. Here are quick links to the Department of Plant Pathology, Physiology, and Weed Science Homepage and the Viginia Tech Homepage.

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- 15th Meeting of the IWGLV

PROGRAM OF THE 15TH MEETING OF THE INTERNATIONAL WORKING GROUP ON LEGUME VIRUSES

Island Suite, Esplanade Hotel

FREMANTLE, WESTERN AUSTRALIA

AUGUST 15-17TH 1999

Scientific Convenor: **Dr Roger Jones** (CLIMA/ AGWEST, Australia)
Meeting Organisation: **Dr Jane Gibbs** (CLIMA, Australia)

SUNDAY AUGUST 15TH

MORNING

8.00 – 9.00 **REGISTRATION**

[+ PUTTING UP POSTERS]

9.00 - 9.05 **WELCOME**

Dr Mike Ewing, CLIMA Director

9.05 - 9.10 **INTRODUCTION**

Prof. Sue Tolin (Virginia Tech University, USA), IWGLV Chairperson

9.10 - 9.15 **ANNOUNCEMENTS**

9.15 – 10.30 ***SESSION 1: EPIDEMIOLOGY AND CONTROL***

Chair: Prof. Bryan Harrison (SCRI, UK)

9.15 – 9.45 Development of integrated disease management strategies for two non-persistently aphid-transmitted viruses infecting lupin crops. **Roger Jones** (CLIMA/ AGWEST, Australia)

9.45 – 10.05 Modelling and forecasting aphid outbreaks and spread of cucumber mosaic virus in narrow-leafed lupins. **Deborah Thackray** (CLIMA, Australia)

10.05 – 10.30 Aspects of the epidemiology and control of groundnut rosette disease. **David Robinson** (SCRI, UK)

10.30 – 11.00 **Coffee Break**

11.00 – 12.30 ***SESSION 2: TRANSMISSION AND EPIDEMIOLOGY***

Chair: Dr James Ridsdill-Smith (CSIRO, Australia)

11.00 – 11.30 Faba bean necrotic yellows virus requires a helper factor for its aphid transmission. **Alexander Franz** (IPO – DLO, The Netherlands)

11.30 – 11.50 Host plant and temperature effects on aphid growth rates on pulses. **Owain Edwards** (CSIRO, Australia)

11.50 – 12.10 Temporal and spatial spread of potyviruses in bean fields in Spain. **Javier Romero** (INIA, Spain)

12.10 – 12.30 Role of grazing animals in spreading contact-transmitted viruses in legume-based pastures. **Simon McKirdy** (AGWEST, Australia)

AFTERNOON

12.30 – 13.30 **Lunch**

13.30 – 14.40 ***FORMAL POSTER SESSION***

14.40 – 15.30 ***SESSION 3: NATURAL VIRUS RESISTANCE I***

Chair: Prof. Anupam Varma (IARI, India)

14.40 – 15.10 Movement and multiplication of faba bean necrotic yellows nanovirus in susceptible and resistant lentil genotypes. **Khaled Makkouk** (ICARDA, Syria)

15.10 – 15.30 Screening faba bean (*Vicia faba* L.) for bean leaf roll virus resistance. **Khaled Makkouk** (ICARDA, Syria)

15.30 – 16.00 **Coffee break**

16.00 – 17.00 ***SESSION 4: NATURAL VIRUS RESISTANCE II***

Chair: Dr Khaled Makkouk (ICARDA, Syria)

16.00 – 16.20 Viruses and resistance in pulses in northern New South Wales. **Mark Schwinghammer** (AgNSW, Australia)

16.20 – 16.40 Alfalfa mosaic virus in alternative cool season grain, annual pasture and forage legumes: susceptibility, sensitivity and seed transmission. **Lindrea Latham** (CLIMA, Australia)

16.40 - 17.00 Biological properties of the necrotic and non-necrotic strains of bean yellow mosaic virus in cool season grain legumes. **Yvonne Cheng** (CLIMA, Australia)

17.00 –17.30 **IWGLV BUSINESS MEETING**

Chair: Prof. Sue Tolin (Virginia Technical University, USA)

19.30 – 22.00 CONFERENCE DINNER

Manor Ballroom, Esplanade Hotel

Speaker: Dr Khaled Makkouk (ICARDA, Syria)

MONDAY AUGUST 16TH

MORNING

8.45 – 8.50 ANNOUNCEMENTS

8.50 – 10.30 ***SESSION 5: RESISTANCE AND EVOLUTIONARY MECHANISMS, INNOVATIVE DIAGNOSTICS***

Chair: Dr David Robinson (SCRI, UK)

8.50 – 9.20 Resistance mechanisms of molecularly mapped R genes in soybean for resistance to soybean mosaic virus. Sue Tolin (Virginia Tech University, USA)

9.20 – 9.50 Evolutionary mechanisms of peanut stunt virus. Marilyn Roossink (Noble Foundation, USA)

9.50 – 10.10 Antibody fusion proteins produced by bacteria are effective in immunoassays to detect plant viruses. Lesley Torrance (SCRI, UK)

10.10 – 10.30 Quantitative Reverse Transcription – PCR assay for the RNA component of cucumber mosaic virus using the Taqman flurogenic detection system. David Berryman (SABC, Australia)

10.30 – 11.00 Coffee Break

11.00 – 12.30 ***SESSION 6: PROPERTIES OF VIRAL GENOMES***

Chair: Prof. Mike Jones (SABC, Australia)

11.00 – 11.30 Towards a better understanding of the organisation and variability of the faba bean necrotic yellows virus genome. Joseph Vetten (BBA, Germany)

11.30 – 12.00 Genomic characterisation of subterraean clover mottle virus. Geoff Dwyer (SABC, Australia)

12.00 – 12.30 Nucleotide sequence of Indian mungbean mosaic geminivirus infecting grain legumes. Anupam Varma (IARI, India)

AFTERNOON

12.30 – 13.30 Lunch

13.30 – 15.00 SESSION 7: CHARACTERISATION OF NUCLEIC ACIDS AND COAT PROTEINS

Chair: Prof. Sue Tolin (Virginia Tech University, USA)

13.30 – 13.55 Epidemiology and molecular characterisation of bean pod mottle virus. Said Ghabrial (University of Kentucky, USA)

13.55 – 14.15 Effect of environmental conditions on the size of RNA species associated with broad bean mottle bromovirus in vivo. Javier Romero (INIA, Spain)

14.15 – 14.40 Nucleotide substitution frequencies in populations of bean common mosaic potyvirus in the amino acid terminal region of the coat protein cistron. Philip Berger (University of Idaho, USA)

14.40 – 15.00 Molecular analysis of the coat protein of necrotic and non-necrotic strains of bean yellow mosaic potyvirus in narrow-leafed lupins (Lupinus angustifolius). Steven Wylie (SABC, Australia)

15.00 – 15.30 Coffee Break

15.30 -17.10 SESSION 8: GENETIC ENGINEERING FOR VIRUS RESISTANCE

Chair: Prof. Joseph Vetten (BBA, Germany)

15.30 – 16.00 Legume transformation: an opportunity to target viral disease in a range of species. Joanne Barton (CLIMA, Australia)

16.00 – 16.30 Construction of a viral vector that efficiently expresses a foreign gene in legume species. Ichiro Uyeda (Hokkaido University, Japan)

16.30 –16.50 Control of alfalfa mosaic virus in Medicago spp. using protection by genetic transformation. Kith Jayasena (University of Adelaide, Australia)

16.50 – 17.10 Engineering cucumber mosaic virus resistance in narrow-leafed lupins (Lupinus angustifolius) based on a defective replicase gene. Mike Jones (SABC, Australia)

TUESDAY AUGUST 17TH

8.30 – 19.30 ***FIELD TRIP***

- Visits to Plant Virus Laboratories, Glasshouses and Plots at Agriculture Western Australia, South Perth and the State Agricultural Biotechnology Laboratory, Murdoch University

- Visit to field experiments with Plant Viruses in Cool Season Legume Crops at Avondale Research Station, Beverley

POSTERS -
SUNDAY
AUGUST 15

EPIDEMIOLOGY AND CONTROL

1. Hassan, M. M., Dafalla, G. A., Vetten, H. J. and Groneborn, B. Epidemiology of chickpea chlorotic dwarf virus in the Sudan.
2. McKirdy S. J. and Jones, R. A. C. Temporal and spatial patterns of spread of cucumber mosaic virus in chickpea.
3. McKirdy, S. J., Jones, R. A. C., Latham, L. J. and Coutts, B. A. Bean yellow mosaic potyvirus in alternative cool season grain, annual pasture and forage legumes: susceptibility, sensitivity and seed transmission.
4. Latham, L. J., McKirdy S. J. and Jones, R. A. C. Cucumber mosaic virus in alternative cool season grain, annual pasture and forage legumes: susceptibility, sensitivity and seed transmission.

5) Cheng, Y. and Jones, R. A. C. Temporal and spatial patterns of spread with the necrotic and non-necrotic strains of bean yellow mosaic virus in narrow-leafed lupins.

6. Jones, R. A. C. and Ferris, D. G. Alfalfa mosaic virus infection of grazed annual medic swards: suppressing spread using insecticides or admixture with grass, and impacts of infection on seed yields and stem coumestrol content.
7. Thackray, D. J., Jones, R. A. C., Bwye A. M. and Coutts B. A. The effects of pyrethroid and imidacloprid insecticides on spread of cucumber mosaic virus in narrow-leafed lupins.
8. Thackray, D. J. and Jones, R. A. C. Role played by nearby pastures in epidemics of aphid-borne virus diseases in crops in regions with Mediterranean-type climates.
9. Coutts, B. A. and Jones, R. A. C. Incidence of four viruses in white clover-based pastures.

DIAGNOSTICS

9) Delfosse, P., Reddy, A. S., Legreve, A., Thirumala Devi, Abdurahman, M. D., Maraite, H., and Reddy, D. V. R. Immunological methods for detection of Polymyxa graminis, the vector of Indian peanut clump pecluvirus.

10) Freeman A. Incursion management - the changing face of temperate pulse virus quarantine in Australia.

PROPERTIES OF VIRAL GENOMES

11) Li D. A., Buirchell, B., Jones, R. A. C. and Jones, M. G. K. Towards identification of and isolation of an endogenous resistance gene to cucumber mosaic virus in Lupinus luteus.

GENETIC ENGINEERING FOR VIRUS RESISTANCE

12. Sithole-Niang I. and Mundembe, R. Transformation of *Nicotiana benthamiana* with various constructs of the cowpea aphid-borne mosaic potyvirus coat protein gene.
13. Li Liu, Yang, R., Wylie, S. J., Li H., and Jones, M. G. K. Protection conferred by the cucumber mosaic virus replicase gene in transgenic narrow-leafed lupin.
14. Li H., Wylie, S. J. and Jones, M. G. K. Preliminary assessments for resistance to bean yellow mosaic virus in transgenic lupins.
15. Smith, L. J. and Jones, R. A. C. Evaluation of transgenic lupin plants containing pathogen derived constructs for bean yellow mosaic virus.

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INTERNATIONAL WORKING GROUP ON LEGUME VIRUSES

THIRTY-SECOND NEWSLETTER (1998-1999)

Dear Legume Virus Workers:

The 32nd IWGLV Newsletter is sent to you mid-way through the third year of my term as Executive Secretary, and just before the 15th meeting of IWGLV. Those of you providing me an email address are receiving the Newsletter electronically – others by mail. As usual, it contains research reports from members responding to the call for annual reports, and a list of publications they have provided to me. The 32nd Newsletter does not, however, contain the Catalog of Viruses and Antisera as a the listing of cultures and reagents members are willing to share, nor a listing of the current IWGLV membership and their addresses. I have developed database files for these, available on-line and updated as new information is available. To help IWGLV move to the new millenium and join the electronic age, a website has been established at Virginia Tech, which should greatly facilitate communications and reduce mailing costs in the future. It can be accessed at: http://www.ppws.vt.edu/~virology. If you prefer to work from an electronic Excel file or hard copy for your use, please contact me and I will send it to you. The Newletter is expected to continue to be distributed separately to members only, however, because it was the intent of the founders of IWGLV that it be a confidential report to foster communication and cooperation. I plan compile the 33rd Newletter from the contributions I receive by early December, and mail it as my final duty.

The 15th Meeting of the IWGLV will be held in Western Australia ***August 15-17, 1999.*** At our 1996 Cairo meeting, the sites for the next meetings of IWGLV were discussed and the charge to the Executive Committee was to consider options and invitations. During the 1998 ICPP meeting in Edinburgh, I met with several IWGLV members. We agreed to accept the invitation of Dr. Roger Jones to host the meeting immediately following the 11th International Congress for Virology in Sidney. Dr. Khaled Makkouk visited there in September and finalized the arrangements. The Centre for Legumes in Mediterranean Agriculture (CLIMA) graciously agreed to host the meeting and provide support towards the cost of meeting rooms and breaks, thus minimizing costs to registrants. The Esplanade Hotel in the middle of the port city of Fremantle, near Perth. Although I was unable to get this newletter announcing the meeting out earlier, it was well publicized through ICV, email, and Roger's efforts. About 50 scientists have preregistered. Information on the meeting is included with the newsletter in brief form, as is the excellent program organized by Dr. Roger Jones and Prof. Mike Jones. For details, contact Dr. Jane Gibbs, Workshop Co-ordinator, who can be reached at [djgibbs@cyllene.uwa.edu.au] or Ph: 61 (8) 9380 1987 or Fax: 61 (8) 9380 1140. You can also find information on the IWGLV website and on CLIMA's website : http://www.clima.uwa.edu.au/education/iwglv.html.

A Bargain ! The first book published by the Group "***Research on Viruses of Legume Crops and the International Working Group on Legume Viruses; historical facts and personal reminiscences"*** is still available from Dr. Makkouk at the extraordinarily good price of $5 + shipping (see details on next page). Dr. Lute Bos, one of IWGLV's founders, has done a masterful job summarizing the history of IWGLV and, indeed, the history of plant virology. The costs of producing the book have been met; so further sales go toward support of the activities of IWGLV.

Review of IWGLV Objectives and Rules: The founders of the Group, as Bos describes, established a set of rules of operation. The original aim was to promote the study of virus diseases of legume crops and their control by improving international collaboration among actively involved scientists. This is done by preparing confidential Annual Newsletters containing short progress reports and lists of publications of members and non-members from their respective countries, compiled by the Executive Secretary from responses of members. Members are expected to respond to the call for Annual Reports at least one year in three, and provide up-to-date information on viruses, antisera, seed and other reagents that they would be willing to share with others. Meetings are held about every three years, in conjunction with another larger meeting, usually the International Congress for Virology.

Membership: The 31st Newsletter was distributed to 149 names on the IWGLV mailing list. Only 25 members responded to the call for annual reports. I have deleted member names if the letter was returned. Those who have retired represent an extremely prominent group and include seven former executive secretaries(*): Bos* (NE), Duffus (CA, US), Edwardson (FL,US); Ford* (IL, US), Hagedorn* (WI, US), Hamilton* (Canada), Hampton* (OR, US); Hull* (UK); Kaiser (WA, US); Mink (WA, US), Nene* (India), Siegel (MI, US); Silbernagel (WA, US); Verhoyen (Belgium), von Wechmar (S.Africa). The following are no longer actively working on legume viruses and thus do not qualify for membership: Belli (IT), Chu (AU), Dale (AU), Ghanekar (India), R. Goodman (WI, US), Hadidi (MD, US), Milbrath (OR, US), Polston (FL, US), Schmidt (Germany), Scott (SC, US), Shukla (AU), Smith (MD, US), Ward (AU). A number of members remain on our list but have not responded to at least the last six requests for reports. They will receive this newsletter but will forfeit their membership if no response is made to me by the end of the year. We welcome new members: Claude Bragard (Belgium), Richard Larsen (Prosser, WA); and Diego Maeso (INIA, Uraguay).

Coordination of Activities of IWGLV: The Steering Committee is currently composed of Sue Tolin, USA (stolin@vt.edu), Exec. Secretary; Khaled Makkouk, Syria (K.Makkouk@CGNET.COM), Immediate Past Executive Secretary; and Ichiro Uyeda, Japan (uyeda@res.agr.hokudai.ac.jp), Incoming Executive Secretary. Each person serves no more than three periods of three years, with a new member elected at each meeting, which is organized approximately every three years. At the meeting next month, we will be appointing a nominating committee, and then electing a member of the Steering Committee to replace Dr. Makkouk. We welcome, at any time, suggestions and comments, and look forward to seeing you at the meeting.

Sue A. Tolin, Executive Secretary, IWGLV

RESEARCH ON VIRUSES OF LEGUME CROPS AND THE INTERNATIONAL WORKING GROUP ON LEGUME VIRUSES; HISTORICAL FACTS AND PERSONAL REMINISCENCES

by LUTE BOS

1996, 151 pages, ISBN 92-9161-000-03. Price 5 US$ + mail charges (2 US$ for Surface Mail, 4 US$ for Air Mail)

The book can be ordered from

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Checks must be in US $, drawn on a US Bank, payable to S. A. Tolin and sent to the address above.

v RESEARCH REPORTS

***Acronyms for viruses used in the reports are as follows, with virus genus, if known*: AMV (alfalfa mosaic alfamo-); BBMV (broad bean mottle bromo-); BCMV (bean common mosaic poty-); BCMNV (bean common mosaic necrosis poty-); B1CMV (blackeye cowpea mosaic poty-); BLRV (bean leaf roll luteo-); BPMV (bean pod mottle como-); BWYV (beet western yellows luteo-); BYMV (bean yellow mosaic poty-); CABMV (cowpea aphid-borne mosaic poty-); CCMV (cowpea chlorotic mottle bromo-); CMV (cucumber mosaic cucumo-); CPMoV (cowpea mottle); CPMV (cowpea mosaic como-); CPSMV (cowpea severe mosaic como-); CCDV (chickpea chlorotic dwarf gemini-); CSV (chickpea stunt luteo-); CYMV (clover yellow mosaic potex-); CYVV (clover yellow vein poty-); FBNYV (faba bean necrotic yellows nana-); GRSV (groundnut ringspot tospo-) MVDV (milk vetch dwarf); MMV (mungbean mosaic); MYMV (mungbean yellow mosaic begomo-); PCV (peanut clump furo-); PCSV (peanut chlorotic stunt); PEMV (pea enation mosaic enamo-); PMV (pea mosaic poty-); PeMV (peanut mottle poty-; PSbMV (pea seed-borne mosaic poty-); PSV (peanut stunt cucomo-); PStV (peanut stripe poty-); PPSMV (pigean pea sterility mosaic); RCNMV (red clover necrotic mottle diantho-); RCVMV (red clover vein mosaic carla-); SBMV (southern bean mosaic sobemo-); SbDV (soybean dwarf luteo-); SCMoV (subterranean clover mottle sobemo-); SMV (soybean mosaic poty-); SRV (soybean rhabdovirus); SCNMV (sweet clover necrotic mosaic diantho-; TSWV (tomato spotted wilt tospo-); ULCV (urdbean leaf crinkle virus).**

In an attempt to reduce mailing costs of the Newsletter, reports furnished by members may have been edited.

BASHIR, M. – In Islamabad, Pakistan, devotes 95% time to PSbMV, BlCMV, CABMV, CMV, MYMV, and ULCV. MYMV is a serius problem in mungbean and urdbean. ULCV is seed-borne in urdbean at a rate of 2-27%. Five other viruses are also seed-borne in these beans (BlCMV, CABMV, CPSMV, SBMV, CPMoV). In lentil, virus diseases (PSbMV, FBNYV, CMV, BWYV) are severe with annual losses estimated at US$1.5million. Chickpea virus diseases (CCDV, CMV, PSbMV, CSV, FBNYV, AMV) are not of major concern. PSbMV and CMV have been detected in *Lathyrus*.

BERGER, Phil – Continuing work in Idaho on molecular evolution of BCMV and relating results to the quasispecies concept.

BRAGARD, Claude – Has asked to join IWGLV; his main research is on vector-virus interactions between Indian peanut clump virus and Polymyxa. Is willing to share the collection of antiserum and viruses of Prof. Verhoyen, his former colleague in Belgium.

BUJARSKI, Joseph – At Northern Illinois University, devotes 25% time to BBMV and its defecting interfering RNAs, which are derived by in-frame delections in genomic RNA-2, are translationally active, can intensify symptoms in some BBMV hosts where they replicate and encapsidate,, and can be generated by serial passages through BBMV hosts. Now investigating

sequences and host factors responsible for their accumulation and transmission, with a longer goal of developing efficient antiviral strategies.

CHEN, Yong-Xuan – At Nanjing Agricultural University in China, works 25% time on CMV, SMV and PMV.

ENGQVIST, Göran – In Sweden, conducts a limited breeding program for PSbMV resistance in dry peas; only 5% effort on legume viruses.

FORD, Richard - Has retired from University of Illinois, but will work part time as Executive Director of the Consortium for International Crop Protection (CICP), an organization of 12 universities, the USDA and some affiliated International institutes.

HONDA, Yohachiro – Has moved from Hokkaido National Agr. Expt. Stn. at Sapparo to his new position as Associate Director for Research at the Nat. Agric. Res. Ctr. in Tsukuba Science City.

GHABRIAL, Said – Cooperating with U.S. project on soybean viruses, incidence, diversity of isolates, field yield losses, and epidemiology. Finding at least two hybridization groups within BPMV isolates from Kentucky and other states. Transgenic plants with CP of BPMV show resistance, and are being field-tested and crossed with SMV resistant lines. SMV isolates alone, as well as in combination with BPMV, vary in yield loss caused.

JOHNSTONE, G. R. – Continuing work in Tasmania on BLRV and SCRLV (syn. SbDV), devoting 5% time to legume viruses.

JONES, M. G. K. – As part of the CLIMA program focused on engineering resistance to CMV and BYMV in grain legumes, the following work is in progress: synthetic gene constructs for resist-ance to BYMV and CMV; transformation of lupins with the bar gene for herbicide Basta (Liberty) as a selectable marker; transgenic lines of yellow lupin (up to T6 generation) and narrow-leafed lupin (up to T4) with resistance to BYMV and tolerance to Basta; narrow leafed lupin with CMV resistance constructs; seeking molecular markers for Ncm-1 gene for CMV resistance, for ultimate isolation. Also obtained complete genomic sequence of SCMoV, a major pathogen of Western Australia pastures, and working to confirm ORFs and expression mechanism, to construct a full length infectious clone, and to insert GFP at various sites to follow cellular and plant distribution of gene products.

JONES, R. A. C. – The group at CLIMA continues work on epidemiology and control of aphid-borne and other virus diseases of cool season pulses (mainly lupins, chickpeas, lentils, faba beans) and annual pasture legumes. Current emphasis on: determining virus seed transmission rates in different legume species, improved methods for large scale virus detection in seed, finding new natural virus resistance sources, field evaluation of virus-resistant transgenic lupin plants, yield loss determination in fields, surveys for virus occurrence, characterisation of new virus strains, cultural and chemical control measures, integrated virus disease management, and development of virus and aphid vector forecasting and prediction models.

KAMEYA-IWAKI, M. – Devotes 50% time at Yamaguchi Univ. to legume viruses, mainly SMV, PSV and others on soybean.

KOJIMA, Makoto – Located at Niigata Univ. in Japan, has 50% effort on SMV and MVDV in soybean.

KUMARI, Safaa –Work focused on (1) identification and characterization of PEMV affecting lentil in Syria, (2) screening for BLRV and FBNYV resistance in faba bean, lentil and chickpea, (3) production of polyclonal antibodies against purified FBNYV coat protein obtained from expression of the CP gene in *E. coli*. Devotes 95% time to legume viruses, PEMV, FBNYV and luteoviruses as a research assistant at ICARDA in Syria.

LAPIDO, Jacob – Continues to survey viruses of cowpea in Nigeria. In the 1997 growing season, virus symptoms were observed on various cowpea cultivars. Some were identified serologically as SBMV, CPMV, and CPMoV. Others are as yet unidentified, and characterization is in progress.

LOMMEL, Steven – Has shown the barrier to long-distance transport of RCNMV in cowpea and tobacco is plasmodesmata between phloem parenchyma cells and the companion cell and sieve element. The RCNMV RNA-1 subgenomic RNA cannot be expressed unless a 34 nucleotide *trans*-activator on RNA-2 is present, suggesting base pairing with RNA-1 subgenomic promoter. Devotes 80% time at North Carolina State University to research with RCNMV and SCNMV.

MAESO, Diego – Main field of research at INIA in Uruguay is virus diseases of fruit and vegetable, including red clover, in which several viruses have been detected using ISEM-D, herbaceous indicator plants, indirect ELISA with ATCC antisera.

MAKKOUK, Khaled – Activities at ICARDA focus on (1) screening for virus resistance in faba bean, chickpea and lentil, (2) studying resistance mechanisms; (3) ecology and epidemiology; (4) virus and strain characterization; and (5) development of diagnostic reagents. Devotes 60% time to the legume viruses FBNYV, PEMV, BLRV, BWYV, and BYMV.

MAURY, Y. – PEMV is commonly in a complex with a virus which induces yellowing and also stunting and whole plant distortion in pea. The identification of the yellowing component is under study at INRA – Versailles.

NENE, Y.L. – Took early retirement from ICRISAT in Dec. 1996 and is pursuing an interest in history of agriculture in Asia. He has set up the Asian Agri-History Foundation and has translated a 1000 year old Indian manuscript in Sanscrit written on palm leaves.

OHKI, Satoshi – Chairs the plant virus section of a new version of "Common names of plant diseases in Japan", to be published in December 1999 by the Phytopathological Society of Japan. Devotes 20% time to legume viruses, mainly BBWV, in Osaka, Japan.

PIETERSEN, Gerhard – Devotes 80% of his time to legume viruses in South Africa, mainly BYMV, CMV, SMV, and the soybean rhabdovirus (SRV). Has completed soybean virus surveys and isolated the SRV by limiting dilution inoculations, and is developing ELISA for it. Also surveying lupins to assess importance of CMV and BYMV locally. Now has GRSV available and a polyclonal antiserum to it.

ROMERO, Javier – Work at INIA in Madrid is on epidemiology of BCMV and BCMNV in bean fields, biological and molecular characterization of legume luteoviruses, diversity of BYMV from different legumes, molecular characterization of defective interfering RNAs associated with BBMV. Has found FBNYV in broad bean fields, and is characterizing isolates.

SINGH, B. R. – Continuing studies on viral diseases of important legume crops: green gram, red gram, peanut, cowpea and soybean. Screening germplasm lines against MYMV, PPSMV, and bud necrosis (TSWV) have revealed some tolerant lines. A new mosaic disease of green gram has been investigated. Transmission, host range and other properties show the causal virus as a Cucumovirus, con-firmed serologically. Comments on the need to increase activities and membership of IWGLV in order to promote pulse research. Devotes 50% time to the legume viruses BYMV, CPMV, MMV, MYMV, PPSMV, SMV at Kanpur, India.

TOLIN, Sue – Coordinating a multi-state project on soybean viruses in southern U.S. focusing on large scale surveys of virus incidence, field performance of SMV resistance genes, and field yield losses. Finding increased incidence and diversity of SMV and BPMV, and occasional infection with BYMV, PeMV, AMV, CCMV, TRSV and other viruses. Three genes for resistance to SMV map at different loci and have different mechanisms; one is not strain-specific. Has revised most of the virus disease descriptions in the Soybean Disease Compendium, which should be published soon by American Phytopathological Society. Devotes 80% of research at Virginia Tech to legume viruses.

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CONTRIBUTION TO 33rd IWGLV ANNUAL NEWSLETTER - 2000

INTERNATIONAL WORKING GROUP ON LEGUME VIRUSES

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PLEASE SUPPLY INFORMATION BELOW BY DECEMBER 10, 1999

IWGLV rules state that membership is forfeited after the second, non-submitted annual report.

Name: _____ Official title:_____

Address: _____ Telephone: _____

_____ FaxNo.:_____

_____ E-mail: _____

Percentage of time devoted to legume viruses research: _____

Legume viruses under investigation: _____

Informal, confidential report of my legume virus research for 33rd IWGLV Newsletter[a]:

Legume viruses and diagnostic reagents available to other IWGLV members:

Virus culture in

Virus Dessicated tissue seed other

Antiserum

Monoclonal Polyclonal

General Information or Comments:

Legume virus papers published in 1998-99

15th Meeting of the International Working Group on Legume Viruses

August 15-17, 1999 Fremantle, Perth, Western Australia
Hosted by the Co-operative Research Centre for Legumes in Mediterranean Agriculture

Organizing Committee:
Dr. Roger Jones, Plant Pathology, Agriculture Western Australia, South Perth
Prof. Mike Jones, State Agricultural Biotech Centre, Murdoch Univ., Murdoch
Dr. Sue Tolin, IWGLV Executive Secretary, Virginia Tech, Blacksburg, USA

CONFERENCE VENUE

Formal paper sessions and a poster session will be held Sunday 15 - Tuesday 17 August 1999 in the Island Suite, Esplanade Hotel, corner of Marine Terrace and Essex St., Fremantle, Perth..

Tel. +61 8 9432 4000; Fax: +61 8 9430 4539.

CONFERENCE REGISTRATION AND PLANNED ACTIVITIES

Conference registration is sponsored by CLIMA, and is FREE OF CHARGE to participants, and includes satchels containing the agenda, abstract booklets, morning and afternoon tea/coffee, and a light lunch August 15 and 16. Cost of optional activites can be paid at registration. Dinner is AUD $45 (approx. US $28); Field Trip is AUD $35 (approx. US $22). The registration desk opens from 8.00 am Sunday, 15 August, 1999. If you have not pre-registered, please contact immediately:

Dr. Jane Gibbs, Conference Coordinator, at CLIMA; University of Western Australia; Nedlands, Western Australia 6907. Ph: 61 (8) 9380 1987 Fax: 61 (8) 9380 1140 djgibbs@cyllene.uwa.edu.au

ARRIVALS AND ACCOMMODATIONS

Participants arriving at Perth International or Domestic airports may take a taxi to the Esplanade Hotel in Fremantle, at a cost approx. AUD $ 30. Rooms can be reserved at the Esplanade Hotel for IWGLV participants., at a cost of AUD $ 125 (approx. US $82) per night for a single, double or twin-bed room. Please book rooms DIRECTLY with the hotel through the Reservations Manager (Ms Sue Bott), Esplanade Hotel, PO Box 1102, Fremantle Western Australia 6959.

Phone: +61 8 9432 4807; Fax: +61 8 9430 4539. Toll free (in Australia): 1800 998 201. http://www.esplanade-freo.net.au

SCIENTIFIC PROGRAMME – See following pages. Posters will be accepted until July 16, 1999.

For queries, contact Roger Jones: Ph. 61 (8) 9368 3269; Fax: 61 (8) 9367 2625. Email: rjones@agric.wa.gov.au.

15th Meeting of the International Working Group on Legume Viruses (IWGLV)

Perth, Western Australia
15-17 August 1999

hosted by

(CLIMA logo)

(Co-operative Research Centre for Legumes in Mediterranean Agriculture)

http://www.clima.uwa.edu.au

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Scientific Program

Click here for program

Call for Papers

Abstracts of no more than one page should be submitted to the conference coordinator (see below) before June 1, 1999. Abstracts will receive minimal editing. Please use 3 cm (1.2 in) margins, 12 point font. Abstract title should be in bold and names, affiliations and full addresses of authors should be provided. Title, authors etc. should be centred. Main text should be single line spacing and justified (see format example). Paragraphs (no indentation) are permissible. Electronic submission of Abstracts, in Microsoft Word 6 or rtf format, will be accepted.

View sample abstract

Conference Registration

Please complete the attached pre-registration form and return to conference co-ordinator (see below) before June 1, 1999. Registration will occur prior to start of sessions on 15 August, 1999. At this time, payment for optional activities will be accepted and delegates will receive satchels containing the agenda, abstract booklets and name tags. Conference registration is sponsored by CLIMA, and is free of charge to delegates. Included are morning and afternoon tea/coffee, and a light lunch on August 15 and 16.

View or Download the Pre-registration Form

Field Trip

On August 17, arrangements have been made to visit the plant virus facilities and plots at Agriculture Western Australia in South Perth and at the State

Agricultural Biotechnology Centre at Murdoch University. This will be followed by a trip to the Avondale Research Station to examine virus field experiments with legumes. Delegates will lunch at the historic homestead at Avondale, and return to Perth via the touristic early settler town of York.

Cost: AUD $35 (approx. US $22).

Conference Dinner

A conference dinner is planned for Sunday 15 August at the Manor Ballroom, Esplanade Hotel, Fremantle. The Ballroom is situated in a beautifully refurbished colonial building, that served as a syndicate base during the America's Cup Challenge in Fremantle in the mid 1980's.

Cost: AUD $45 (approx. US $28).

Meeting Site and Reservations

Rooms have been reserved at the Esplanade Hotel in Fremantle for IWGLV delegates for the duration of the meeting. Cost will be AUD $ 125 (approx. US $82) per night for a single, double or twin-bed room.

The Esplanade Hotel, a fine example of early colonial architecture, overlooks popular parklands and Marine Harbour and is ideally located in the heart of the historic City of Fremantle. The Port City of Fremantle, just 20 minutes from Perth, is renown for its charm, bustling cafes, variety shopping, infamous pubs, local art, maritime history and sea-side location.

Room reservations should be booked directly through the hotel, at least 30 days prior to arrival. Contact Ms Karyl Treble, Esplanade Hotel, PO Box 1102, Fremantle Western Australia 6959.

International phone: 61 (8) 9432 4807 *International fax*: 61 (8) 9430 4539

Toll free: 1800 998 201 http://www.esplanade-freo.net.au

Prepayment or guarantee by credit card will be required.

Organizing Committee

An Organizing Committee for the 15th IWGLV meeting is composed of:

Roger Jones, Plant Pathology, Agriculture Western Australia, South Perth

Mike Jones, State Agricultural Biotech Centre, Murdoch University, Murdoch

Sue Tolin, IWLGV Executive Secretary, Virginia Tech, Blacksburg, USA

Further Information:

To receive further information contact and to submit abstracts:

Dr. Jane Gibbs, Workshop Co-ordinator, CLIMA
The University of Western Australia
Nedlands, Western Australia 6907
Ph: 61 (8) 9380 1987 Fax: 61 (8) 9380 1140
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ABSTRACT FORMAT EXAMPLE

Resistance to Low Temperature at Flowering in Chickpea.

Heather Clarke and Veronika Reck
CRC for Legumes in Mediterranean Agriculture, University of Western Australia,
Nedlands, Western Australia 6907.
Email: hclarke@cyllene.uwa.edu.au

The grain-belt region of south Western Australia experiences a Mediterranean climate with a mild winter followed by rapid warming in spring, culminating in terminal drought. This requires the adoption of early flowering, winter hardy, short generation crops to maximise yield. Chickpea, a relatively new crop in Australia, is highly susceptible to temperatures below 15oC at flowering. Limited genotypic variation, combined with the complex interaction of other environmental and biotic factors, make it difficult to breed and select improved varieties. The result has been only minor improvements in chickpea yield in cold affected regions worldwide.

A novel approach to increase cold tolerance is being used at the CRC for Legumes in Mediterranean Agriculture (CLIMA) in the University of Western Australia. Accelerated selection is achieved at the haploid phase of the plant cycle by applying a low temperature stress to the plant at the precise time of pollination, so that only the most cold tolerant pollen will succeed in fertilisation.

Despite these achievements, progress is still hampered by the lack of an efficient method for the identification of superior parents and progeny on the large scale required by an effective breeding programme. The aim of the current study is to investigate selective genotyping for cold tolerance to identify putative genomic segments that contribute to this trait in the new breeding lines. The use of Amplified Fragment Length Polymorphisms (AFLPs), a Polymerase Chain Reaction (PCR) based technique, is described for the identification of molecular markers that potentially span the genome of chickpea.

This research is in collaboration with the State Agricultural Biotechnology Centre and Agriculture WA.

15th Meeting of the International Working Group on Legume Viruses (IWGLV)
Perth, Western Australia, August 1999.

PRE-REGISTRATION FORM

Name:

Title: Preferred Name on Name tag:

Address:

Organisation:

Phone:

Fax:

Email:

Please circle appropriate response:

I will / will not be attending the conference dinner on August 15 (Cost: AUD$45 per person).

If yes, please indicate whether an accompanying person will attend. Y / N

I will / will not be attending the field trip on August 17 (Cost: AUD$35 per person).

Please complete this form and send to:

IWGLV Meeting - Perth 1999
CLIMA, The University of Western Australia
Nedlands WA 6907
AUSTRALIA

Fax: 61 8 9380 1140
Email: djgibbs@cyllene.uwa.edu.au

before June 1, 1999. Payment for optional events can be made at the Registration Desk prior to start of sessions on 15 August, 1999.

Keith S. Yoder

Associate Professor of Plant Pathology
Virginia Tech Ag. Research and Extension Center
595 Laurel Grove Road
Winchester, VA 22602

Phone: 540-869-2560 Ext 21
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E-Mail: ksyoder@vt.edu

Education:

- B.A. Biology, Goshen College 1968
- M.S. Plant Pathology, Michigan State University 1972
- Ph.D. Plant Pathology, Michigan State University 1974

Professional Experience:

- Associate Professor, Dept. of Plant Pathology, Physiology & Weed Science, Virginia Polytechnic Institute & State University, 1982-present
- Assistant Professor, Dept. of Plant Pathology, Physiology & Weed Science, Virginia Polytechnic Institute & State University, 1977-82
- Research Plant Pathologist, E. I. DuPont de Nemours and Co., Wilmington, DE, 1974-1976
- Graduate Research Assistant, Michigan State University, 1971-74
- Research Technician, Michigan State University, 1969-1971

Extension Interests:

- Apple Summer Disease Monitoring
- Effect of Powdery Mildew on Apple Yield and Its Economic Management

Research Interests:

- Fireblight Management
- Diseases Resistance and Susceptibility of New Apple Cultivars
- Fruit fungicide activity spectrum and fungal resistance management

Selected Publications:

1. Yoder, K. S., A. R. Biggs, R. K. Kiyomoto, R. McNew and D. A. Rosenberger. 1997. Foliage susceptibility of 23 apple cultivars in the NE-183 trial to scab, powdery mildew, cedar-apple rust, and leaf spots, 1996: Biological and Cultural Tests for Control of Plant Diseases 12:42-43.
2. Yoder, K. S., A. E. Cochran II, W. S. Royston, Jr., S. W. Kilmer and J. E. Scott. 1998. Integrated fungicide schedules for suppression of powdery mildew and other diseases on Idared apple, 1997. Fungic. Nematic. Tests Vol. 53: 43-44.

Current or Recent Research Sponsors:

- Virginia Agricultural Council
- Virginia Apple Research Program
- Various commercial grant-in-aid sponsors

Additional Information:

- Personal Homepage:
  http://www.vaes.vt.edu/winchester/faculty/yoder/yoder.html

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

Boris I. Chevone

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Physiology and Weed Science
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bchevone@vt.edu

Education:

- B.S., University of Massachusetts, 1965
- M.S., University of Massachusetts, 1968
- Ph.D., University of Minnesota, 1974

Professional Experience:

- **Associate Professor**, Dept. of Plant Pathology, Physiology and Weed Science, 1986
- **Assistant Professor**, Dept. of Plant Pathology, Physiology and Weed Science, 1980
- **Postdoctoral Fellow**, Dept. of Plant Pathology, Physiology and Weed Science, 1975

Teaching Interests:

- Advanced Plant Physiology (team teach)
- Physiology and the Environment (team teach)
- Air pollution and elevated CO_2 effects on plants, global climate change

Research Interests:

- Air pollutant effects on plants
  - Photosynthesis and chlorophyll fluorescence responses of tobacco and bean cultivars to ozone under controlled laboratory conditions using CSTR fumigation chambers.
  - The effects of ambient ozone concentrations on photosynthesis and chlorophyll fluorescence in tolerant and sensitive forest tree species.
- Physiological and biochemical basis of ozone tolerance in plants
  - The role of antioxidant enzymes, such as SOD, APX, GR, GST, in conferring ozone tolerance in tobacco BelW3 and BelB and bean genotypes.
- Oxidative stress responses in plants
  - The effects of moisture or heat stress on mRNA production in seedling loblolly pine.

Selected Publications:

1. Tang, Y., J.L. Hess and **B.I. Chevone**. 1999. Ozone-responsive proteins in a tolerant and sensitive clone of white clover (*Trifolium repens* L.). Environ. Pollut. 104: 89-98.

2. **Chevone, B.I.**, W. Manning, A. Varbanov, and S.V. Krupa. 1998. Relating ambient ozone concentrations to adverse biomass responses in white clover: a case study. Environ. Pollut.103: 103-108.

3. **Chevone, B.I.**, Y. Tang, and J.L. Hess. 1997. Antioxidant activity and photosynthesis in two

white clover genotypes with different ozone sensitivities. Proceed. Air & Waste Manag. Assoc. 97-RA122-04. 10 pg.

Current or Recent Research Sponsors:

- Virginia Department of Forestry/USDA
- Environmental Sciences and Engineering/USEPA
- Horton Research Foundation

-

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

CAROLE L. CRAMER

Professor
Department of Plant Pathology,
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Fralin Biotechnology Center
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Fax: (540) 231-7126
E-mail: ccramer@vt.edu

Education:

- Ph.D. 1982, Biological Sciences, University of California, Irvine, Department of Molecular Biology and Biochemistry
- B.A. 1974, Biological Science, University of California, Berkeley

Employment History:

- 1997- Professor, Plant Pathology and Physiology, Virginia Tech
- 1993- Vice President for Research, CropTech Development Corp.
- 1990-1997 Associate Professor, Plant Pathology and Physiology, Virginia Tech
- 1986-1990 Assistant Professor, Plant Pathology and Physiology, Virginia Tech
- 1983-1986 NSF Postdoctoral Fellow in Plant Biology, Salk Institute for Biological Studies, San Diego, California (with C.J. Lamb)
- 1982-1983 Postdoctoral Research Fellow, Plant Biology Lab, Salk Institute
- 1981-1982 Research Assistant, Molecular Biology and Biochemistry, U.C., Irvine
- 1976-1981 Teaching Assistant, School of Biological Science, Univ.Calif., Irvine
- 1975-1976 Research Associate, Department of Genetics, U.C., Berkeley
- 1974 Laboratory Assistant, Department of Genetics, Univ. Calif., Berkeley

Professional Society Memberships:

- American Association for the Advancement of Science
- American Phytopathological Society
- American Society for Biochemistry and Molecular Biology*
- American Society of Plant Physiologists
- Gamma Sigma Delta*
- International Society of Plant Molecular Biology
- Sigma Xi*

[*Elected membership]

Awards and Recognition:

- US Patents (2 awarded, 1997; 1 allowed, 1998; 2 pending)

- NIH FIRST (New Investigator) Award, 1988-1993.
- Henderson Award (Departmental Award for Outstanding Faculty Member, 1989)
- NSF Postdoctoral Fellow in Plant Biology, 1983-1986
- NIH Cellular and Molecular Biology Predoc. Traineeship, U.C., Irvine, 1977-1981

Teaching Interests:

- Molecular Plant-Microbe Interactions
- Biotechnology in a Global Society
- Selected Topics in Molecular Cell Biology and Biotechnology

Research Interests:

- Molecular biology of plant-pathogen interactions
- Genetic engineering of plant disease and stress resistance
- Bioproduction of pharmaceutical proteins in transgenic plants
- Plant development and cell cycle control
- Protein modification and targeting
- Regulation of isoprenoid biosynthesis

Selected Publications (last 4 years):

1. Cramer, C.L., J. Boothe, and K.K. Oishi. 1999. Transgenic plants for therapeutic proteins: Linking upstream and downstream strategies. Curr. Top. Microbiol. Immunol., 240:95-117.
2. Wu, J., C.L. Cramer and K.K. Hatzios. 1999. Characterization of two cDNAs encoding glutathione S-transferase in rice and induction of their transcripts by the herbicide safener fenclorim. Physiol. Plant., 105:102-108.
3. Westwood, J.H., X. Yu, C.L. Foy and C.L. Cramer. 1998. Expression of a defense-related 3-hydroxy-3-methylglutaryl CoA reductase gene in response to parasitization by Orobanche. Mol. Plant-Microbe Interact 11:530-536.
4. Wu, J., C.L. Cramer, and K.K. Hatzios. 1998. Nucleotide sequence of a cDNA encoding glutathione S-transferase from rice (Oryza sativa), Plant Physiol., in press.
5. Wu, J., C.L. Cramer, and K.K. Hatzios. 1998. Nucleotide sequence of a cDNA encoding the second glutathione S-transferase from rice (Oryza sativa), Plant Physiol., in press.
6. Zhou, D., D. Qian, C.L. Cramer, and Z. Yang. 1997. Developmental and environmental regulation of tissue- and cell-specific expression of a pea protein farnesyltransferase gene in transgenic plants. Plant J. 12:921-930.
7. Alscher, R.G., J.L. Donahue and C.L. Cramer. 1997. Reactive oxygen species and antioxidants: Relationships in green cells. Physiol. Plant. 100:224-233.
8. Donahue, J.L., C.M. Okpodu, C.L. Cramer, E.A. Grabau and R.G. Alscher. 1997. Responses of antioxidants to paraquat and sulfur dioxide in pea leaves: Relationships to resistance. Plant Physiol. 113:249-257.
9. Qian, D., D. Zhou, R. Ju, C.L. Cramer and Z. Yang. 1996. Protein farnesyltransferase: Molecular characterization and involvement in plant cell cycle control. Plant Cell 8:2381-2394.
10. Zhou, D., Z. Yang and C.L. Cramer. 1996. A cDNA encoding the -subunit of protein farnesyltransferase from Nicotiana glutinosa. Plant Physiol. 112:1398-1399.
11. Denbow, C.J., S. Lång and C.L. Cramer. 1996. The N-terminal domain of tomato 3-hydroxy-3-methylglutaryl CoA reductases: sequence, microsomal targeting, and glycosylation. J. Biol. Chem. 271:9710-9715.

12. Cramer, C.L., D.L. Weissenborn, K.K. Oishi, E.A. Grabau, S. Bennett, E. Ponce, G.A. Grabowski, and D.N. Radin. 1996. Bioproduction of human enzymes in transgenic tobacco. In: Engineering Plants for Commercial Products and Applications (G.B. Collins and R.J. Shepherd, eds.), Ann. N.Y. Acad. Sci., vol. 792, pp. 62-71.
13. Cramer, C.L., D.L. Weissenborn, K.K. Oishi, and D.N. Radin. 1996. High-level production of enzymatically active human lysosomal proteins in transgenic plants. In: Transgenic Plants: A Production System for Industrial and Pharmaceutical Proteins, M.R.L. Owens and J. Pen, eds., John Wiley and Sons, Ltd., pp. 299-309.
14. Weissenborn, D.L., C.J. Denbow, M. Laine, S.S. Lång, Z. Yang, X. Yu and C.L. Cramer. 1995. HMG CoA reductase and terpenoid phytoalexins: Molecular specialization within a complex pathway. Physiol. Plant. 93: 393-400.

Issued Patents:

- HMG2 Promoter Expression System and Post-harvest Production of Gene Products in Plants and Plant Cell Cultures (US Patent No. 5,670,349, issued Sept. 1997), Inventors: C.L. Cramer and D.L. Weissenborn
- HMG2 Promoter Expression System (US Patent 08/100,816, issued Nov. 18, 1997), Inventors: C.L. Cramer and D.L. Weissenborn

Current or Recent Research Sponsors:

National Science Foundation; US Department of Agriculture; CropTech Development Corp.

Further Information:

- Fralin Biotechnology Center Homepage
- The Cramer Lab Hompage

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

Elizabeth A. Grabau

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Education:

- 1974 B.S. in Biology, Purdue University
- 1981 Ph.D. in Biology University of California, San Diego

Professional Experience:

- 1996-present, Associate Professor, PPWS, Virginia Tech
- 1990-1996, Assistant Professor, PPWS, Virginia Tech
- 1987-1990 Research Associate, Dept. of Agronomy and Plant Genetics, University of Minnesota
- 1981-1986 Research Associate, Howard Hughes Medical Insititute, University of Utah

Teaching Interests:

- Molecular Biology for the Life Sciences (ALS/PPWS 5344)
- Molecular Biology Laboratory (BIOL 4774)
- Biotechnology in a Global Society (ALS/BIOL 2404)

Research Interests:

- Genetic engineering of soybean and peanut
- Modification of soybean to lower phytic acid levels
- Enhancing disease resistance in peanut
- Bioproduction of human proteins in plants

Selected Publications:

1. Grabau, E.A. 2000. Phytase expression in transgenic plants. In: Food Phytates, N.R. Reddy and S.K. Sathe, eds., Technomics Publishing Co., Lancaster, PA, in press.
2. Denbow, D.M., Grabau, E.A., Lacy, G.H., Umbeck, P. and Russell, D.R. 1998. Soybeans transformed with a fungal phytase gene improve phosphorus availability for broilers, Poultry Sci. 77:878-881.
3. Li, J., Hegeman, C.E., Hanlon, R.W., Lacy, G.H., Denbow, D.M., and Grabau, E.A. 1997. Secretion of active recombinant phytase from soybean cell suspension cultures. Plant Physiol. *114*: 1103-1111.
4. Hanlon, R.W. and Grabau, E.A. 1997. Comparison of mitochondrial organization of four soybean cytoplasmic types by restriction mapping. Soybean Genet. Newslett. *24*: 208-210.
5. Hanlon, R.W., Li, J. and Grabau, E.A. 1997. Plant Gene Register PGR 97-025: Nucleotide

Sequence of a 4.9 kb PstI fragment from 'Williams 82' mitochondrial DNA (Accession No. L40816) involved in mitochondrial genome rearrangement. Plant Physiol. *113*: 664.

6. Cramer, C.L., Weissenborn, D.L., Oishi, K.K., Grabau, E.A., Bennett, S., Ponce, E., Grabowski, G.A., and Radin, D.N. 1996. Bioproduction of human enzymes in transgenic tobacco. Annals New York Acad. Sci, *792*: 62-71.

Current or Recent Research Sponsors:

- USDA NRI CGP
- Virginia Agricultural Council

Additional Information:

- Dr. Grabau's Lab Homepage
- Molecular Biology for the Life Sciences (ALS/PPWS 5344)

Department of Plant Pathology, Physiology, and Weed Science
Last Updated April 11, 2000

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Director, CALS Minority Academic Opportunity Program
Department of Plant Pathology,
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Professor.
PhD, Michigan State University, 1972.

MAOP - Minority Academic Opportunity Program

Department of Plant Pathology, Physiology, and Weed Science
Last Updated July 19, 2002

Ruth Grene

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Dept of Plant Pathology,
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Old Glade Road
Virginia Tech
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E-Mail: grene@vt.edu

Education:

- University of California, Davis, California (1968-72)
  Ph.D., 1972 - Plant Physiology
- Washington University, St. Louis, Missouri (1966-68)
  MA, 1968 - Botany
- Trinity College, Dublin, Ireland (1961-65)
  B.A., 1965 - Biochemistry Major (Honors)

Professional Experience:

- Professor of Plant Physiology, 1998-
- Associate Professor of Plant Physiology, Virginia Tech, 1988-98
- Adjunct Assistant Professor of Plant Biology, Cornell, 1985-1988
- Research Associate, Boyce Thompson Institute, Environmental Biology, Ithaca, NY. 1979-1988
- Research Associate, New York State Agricultural Experiment Station, Geneva, NY, 1977-1979
- NIH Postdoctoral Fellow, Laboratory of Dr. Andre Jagendorf, Section of Genetics, Development and Physiology, Cornell University, Ithaca, NY 1975 -77
- NIH Postdoctoral Fellow, Laboratory for Chemical Biodynamics, University of California, Berkeley, 1974-75

Recent Awards and Honors:

- National Science Foundation Career Advancement Award, 1992-94

Teaching Interests:

- Advanced Plant Physiology and Metabolism
- Writing-Intensive Course in Molecular Cell Biology
- Topics in Molecular Cell Biology and Biotechnology

Research Interests:

- Functional genomics: global effects of stress imposition on gene expression.

- Relationships between environmental signaling and stress resistance: mechanisms in plants

Selected Publications:

1. Expresso -- A Problem Solving Environment for Bioinformatics: Finding Answers With Microarray Technology, Ruth G. Alscher, Boris I. Chevone, Lenwood S. Heath, and Naren Ramakrishnan, Proceedings of the High Performance Computing Symposium, Advanced Simulation Technologies Conference (HPC 2001), 2001, pp. 64-69.
2. Studying the Functional Genomics of Stress Responses in Loblolly Pine using the Expresso Microarray Management System, Lenwood S. Heath, Naren Ramakrishnan, Ronald R. Sederoff, Ross W. Whetten, Boris I. Chevone, Craig A. Struble, Vincent Y. Jouenne, Dawei Chen, Leonel Merwe van Zyl, and Ruth Grene, Comparative and Functional Genomics 3, 2002, pp. 226-243.
3. Role of Superoxide Dismutase (SODs) in Controlling Oxidative Stress in Plants, Ruth Grene, Neval Erturk, and Lenwood Scott Heath, Journal of Experimental Botany 53, 2002, pp. 1331-1341. Doulis, A. G., J.L. Donahue and R.G. Alscher (1998) Differential responses to paraquat-induced oxidative injury in a pea (*Pisum sativum)* system. Physiol. Plant. 102: 461-471
4. Alscher, R. G., J.L. Donahue, and C. L. Cramer (1998). Molecular responses to reactive oxygen species: multifaceted changes in gene expression. in L. De Kok and I. Stulem eds. Responses of Plant Metabolism to Air Pollution and Global Changes Backhuys, 233-240
5. Alscher, R. G., J. L. Donahue, and C. L. Cramer. 1997. Reactive oxygen species and antioxidants: relationships in green cells. Physiol. Plant. 100:224-233.
6. Donahue, J. L., C. M. Okpodu, C. L. Cramer, E. A. Grabau, and R. G. Alscher. 1997. Responses of Antioxidants to Paraquat. Plant Physiol. 113:249-257.
7. Okpodu, C.M., R.G. Alscher, E.A. Grabau and C.L. Cramer. 1996 Physiological, Biochemical and Molecular Effects of Sulfur Dioxide. J. Plant Physiol. 148:309-316
8. Madamanchi N.R, Cramer, C.L., Alscher, R.G.,and Pedersen K. (1994) Differential response of CuZn superoxide dismutase in two pea cultivars during a short term exposure to sulfur dioxide Plant Mol Biol, 26: 95-103
9. Madamanchi N.R**,** Yu, X. Alscher, R..G., Hatzios, K.K., and Cramer, C.L (1994) Acquired Resistance to Herbicides in Pea Cultivars by Exposure to Sulfur Dioxide. Pestic. Biochem. Physiol. 48: 31-40
10. Hausladen, A. and Alscher, R.G. (1994) Cold hardiness specific glutathione reductase isozymes in red spruce: thermal dependence of kinetic parameters and possible regulatory mechanisms Plant Physiol, 105: 215-223
11. Hausladen, A. and Alscher, R.G. (1994) Purification and characterization of glutathione reductase isozymes specific for the state of cold hardiness of red spruce Plant Physiol, 105: 205-213
12. Madamanchi N.R., Anderson J.V., Alscher, R.G, Cramer, C.L. and Hess, J.L.(1992) Purification of multiple forms of glutathione reductase from pea (*Pisum sativum* L.) seedlings and enzyme levels in ozone-fumigated pea leaves Plant Physiol. 100:

Current or Recent Research Sponsors:

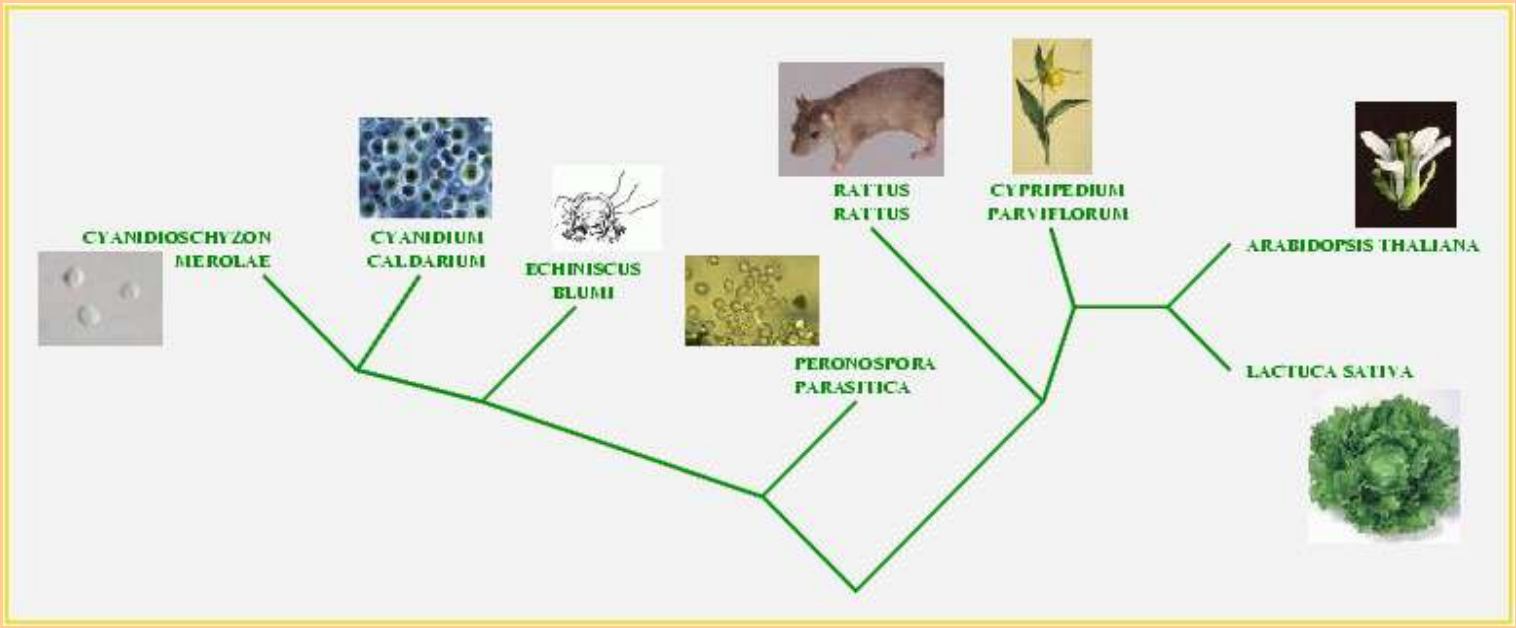
- USDA
- BARD
- NSF

Additional Information:

- BIOL/PPWS 3444 : Explaining Molecular and Cell Biology
- PPWS/GBCB 5314 : Biological Paradigms for Bioinformatics
- GRID IT - Resources for Microarray Technology

Department of Plant Pathology, Physiology, and Weed Science

Last Updated August 06, 2003



BIOL /PPWS 3444, Index 16577

SPRING, 2003

EXPLAINING MOLECULAR CELL BIOLOGY

Dr. Ruth Grene, grene@VT. EDU, 1-6761

MCB 307, TTH 12:30 - 1:45

Office Hours: 435 Old Glade Road, Room 103 (back of The Math Emporium)

TTH 2:30-4, or by appointment.

Cell and Molecular Biology is required for BIOL 3444. Genetics is highly recommended.

CATALOG DESCRIPTION

This writing-intensive course will enable students to improve their own scientific writing and oral skills, and their understanding of the writing of specialists and scientists in other fields. Topics include bacterial, plant, and biomedical

examples of major advances in molecular cell biology and biotechnology. Includes a review of current methodologies, in-class writing workshops and problem-solving sessions, mock press conferences, individual and team presentations, and individual conferences with the instructor.

TEXTS

Cooper, Geoffrey (2000) The Cell A Molecular Approach ASM Press

STRUCTURE OF THE COURSE

BIOL 3444 has no written exams.

Instead, the grade is based on class participation , written assignments and oral presentations (see below for points assigned to each category).

All written work should be your own. However, you are expected to work in teams for the oral presentations.

We will review and consolidate concepts of molecular and cell biology for the majority of the semester, discussing the readings and questions indicated below in each class period. Our class work and the first two writing assignments are preparation for lectures by guest faculty who will present their research. The classes will be conducted in the give and take spirit in which biological research and discussions of results are conducted. **You will be expected to participate in class discussions.** Teams, consisting of four or five students each, will be responsible for presenting answers to assigned questions for the first three weeks. In class, I will ask individual teams to answer the assigned questions and any one of the team may answer. After the first three weeks, each member of the team will be responsible for the assigned problems, but you may work up the answers as a team.

Each student is responsible for writing a short *press report.* This should be modeled on the style of a New York Times or Washington Post science article. The topic should be one of those presented in the eMolecular Medicine e or Key Experimentd entries in the Cooper text. You are required to find the amount of additional information on your chosen subject that you can find in 4-8 newspaper articles on Infotrac http://databases.lib.vt.edu/letfrurl.cfm?Firstletter=i and to prepare a short piece for publication on the subject. ALL sources must be cited.

For the guest lectures , you will again work in teams on mastering the material and on preparing the panel discussions and the press conference. Team members will work together to master the material in the guest lecture, supplemented with visits to the guest faculty with additional questions. The team will then present a joint panel discussion of the work of etheir guest facultyd. The guest faculty member may attend the panel discussion. A written *technical report* on this material is required. Each team will also present a press conference on one other guest presentation or related on-line assignment, getting help and feedback from the team assigned to that guest. The members of the team assigned to the guest will provide responses to the press conferences.

1. Amount of Writing. A total of 22 pages of written work, minimum, will be required.

Assignments 1 and 2: 5 pages each, including diagrams. Assigned problems.

Assignment 3: at least 8 pages. Technical report on guest faculty lecture material

Assignment 4: at least 3 pages. Press Report

2. ***Oral Skills***. The central focus of the course is on the *development of skills* needed to become a professional biologist. This includes discussion and presentation skills, as well as writing, hence the 15% of the grade assigned to in-class participation, 15% for the panel presentation and 10% for the press conference.

3. Conferences. Students will be required to meet with the instructor for discussions of their drafts of Writing Assignments 1-3. Only the final version will be graded.

GRADES

ASSIGNMENTS*	% OF TOTAL
1. Writing Assignment 1	10
2. Writing Assignment 2	15
3. Writing Assignment 3: Technical Report	25
4. Press Report	10
5. Panel Presentation (PowerPoint)	15
6. Press Conference	10
7. Class Participation and Team Work**	15

* I will not assign a passing grade to Writing Assignments 1, 2 or 3 unless I have read a draft of it, and the student has edited it, before the due date.

** What is eteam workd?

a. Helping other team members to understand the material,

b. Working together to prepare the whole presentation, not just your section.

c. Solving hardware or software problems for ALL team members. If you are Mr. or Ms. Computer, spread the wealth!

d. NO, but NO, complaints or gossip to the instructor about your team mates.

e. Participating in group discussions with the guest faculty member. (I will be asking the faculty member for a report on your meeting(s)/interactions with him or her).

f. Rehearsing with team, providing support and help.

SYLLABUS 1/5/03

Meeting and Date	Topic	Reading/Activities
1. 1/14/03	Genome Organization	Chapter 4
2. 1/16/03	DNA Replication and Repair	Chapter 5 Writing Assignment 1
3. 1/21/03	RNA Synthesis and Processing 1	Chapter 6 pp 227-246 Questions 1 and 2 Team 1 Question 3 Team 2 Key Experiment page 247 Team 3
4. 1/23/03	RNA Synthesis and Processing 2	Chapter 6 pp 246- 267 Molecular Medicine page 250 Team 4 **CONFERENCES**
5. 1/28/03	Protein Synthesis 1	**Chapter 7 pp 273-290** Key Experiment pp 280-281 Team 5 **Assignment 1 due at the beginning of class.** **Assignment 2 posted**
6. 1/30/03	Protein Synthesis 2	Chapter 7 pp 290-308 http://www.ergito.com/lookup.jsp?expt=horwich Teams 1, 2 and 3.
7. 2/4/03	Protein Sorting and Transport 1	Chapter 9 pp 347-362 Questions 1 and 2 Team 4 Key Experiment Team 5
8. 2/6/03	Protein Sorting and Transport 2	**CONFERENCES ON Assignment 2** Chapter 9 pp 362-382

9. 2/11/03	The Cytoskeleton 1	**Chapter 11 pp 421-440** **Peer Review of Assignment 2**
10. 2/13/03	The Cytoskeleton 2	**Assignment 2 due at the beginning of class** Chapter 11 pp 440-461 Molecular Medicine: Team 1 Key Experiment: Team 2 Questions 1-3: Team 3 Questions 4 and 5: Team 4
11. 2/18/03	The Cell Surface 1	Chapter 12 pp 467-492 Molecular Medicine Team 5 **Start to work on Press Report**
12. 2/20/03	The Cell Surface 2	Chapter 12 pp 492-516 Key Experiment: Team 1 Questions 1-3: Team 2 Questions 4 and 5: Team 3
13. 2/25/03	Cell Signaling 1	Chapter 13 pp 523 -546
14 2/27/03	Cell Signaling 2	Chapter 13 pp 547- 565 Molecular Medicine: Team 4 Key Experiment: Team 5 Questions 1-3: Team 1 Questions 4- 6: Team 2
15. 3/11/03	The Cell Cycle 1	Chapter 14 pp 571-586 Questions 1-3: Team 4 Key Experiment: Team 5
16. 3/13/03	The Cell Cycle 2	Chapter 14 pp 586- 603 Molecular Medicine: Team 1 Questions 4- 6: Team 2

17.	3/18/03	The Cell Cycle 3	http://www.ergito.com/lookup.jsp?expt=nurse
			Press Reports due: All teams
18.	3/20/03	***Guest Lecture 1***	**Team 1 major responsibility**
		Dr. Craig Nessler	**Team 3 minor responsibility**
19.	3/25/03	**eMetabolic Engineering of Vitamins in Plantsd** ***Guest Lecture 2***	**Team 2 primary responsibility**
		Dr. Jonathan Watkinson	**Team 4 secondary responsibility**
		e Host Gene Expression in Symbiosis: The Colonization of Orchid Rootsd.	
20.	3/27/03	***Guest Lecture 3***	**Team 3 primary responsibility**
		Dr. Allan Dickerman	**Team 5 secondary responsibility**
21.	4/1/03	eDeveloping Phylogenetic Treesd ***Guest Lecture 4***	**Team 4 primary responsibility**
		Dr. Richard Walker	**Team 1 secondary responsibility**
22.	4/3/03	***Panel Presentation:***	**Draft of Assignment 3 due: Team 1.**
		Dr. NesslerÀs work	**Team 3 questions Team 1**
23.	4/8/03	***Guest Lecture 5***	**Team 5 primary responsibility**
		Dr. John McDowell	**Team 2 secondary responsibility**
24.	4/10/03	***Panel Presentation*** ***Guest Lecture 2***	**Draft of Assignment 3 due: Team 2**
			Team 4 questions Team 2.
			Final Draft of Assignment 3 due: Team 1
25	4/15/03	***Panel Presentation:***	**Draft of Assignment 3 due: Team 3.**
		Dr. WatkinsonÀs work	Team 5 questions Team 3.
			Final Draft of Assignment 3 due: Team 2
26.	4/17/03	***Presentation on Bioethics (tentative)***	**Assignment 3 due: Team 3**

27. 4/22/03	***Panel Presentation: Dr. WalkerÀs work.*** ***Team 4***	**Draft of Assignment 3 due: Team 4** **Team 1 responds to presentation**
28. 4/24/03	***Panel Presentation: Dr. McDowellÀs work.*** ***Team 5***	**Draft of Assignment 3 due: Team 5** **Team 2 responds to presentation** **Conferences: Team 5**
29. 4/29/03	**Press Conferences**	Make it amusing! On a lecture that was NOT assigned to your team. **Assignment 3 due: Team 4.**
05/01/03		**Assignment 3 due: Team 5.**

Assignment 1

Provide a chatty but well reasoned 5 page answer to the question below. Be sure to add some diagrams of your own making.

Your roommate tells you that s/he takes penicillin all winter long and this prevents him/her from getting the common cold. Explain why this could or could not be true to this person who has never taken a biology course, and gets his or her information on health issues from popular magazines.

You may send your draft to me as an attachment to an e mail message. PLEASE SPELL CHECK your essay before sending or giving it to me.

PPWS 5314

Fall 2003

CRN 96247

Biological Paradigms for Bioinformatics

TTH Torg 1030

12:30 - 1:45 PM

Instructor: Ruth Grene, 1-6761

grene@vt.edu

Dept of Plant Pathology, Physiology, and Weed Science

Office Hours: T 2:15-3:30 PM, F 9-10:30AM, 435 Old Glade Road, Room 103, or by appointment.

(Take BT Shuttle for Math Emporium, get off at Old Glade Road)

This course is a requirement for students in the computational sciences who enroll in the Genetics, Bioinformatics, and Computational Biology Program , and is also a requirement for the Bioinformatics Option in the Department of Computer Science.

TEXTS:

A: Required Texts:

- **Cooper, Geoffrey M.THE CELL: A MOLECULAR APPROACH. ASM Press, Washington, DC, 2003, 689. *CELL***
- **Hartl, D, L, and E. W. Jones, Essential Genetics: A Genomics Perspective. Jones and Bartlett, Boston, 2002, 613 *GENETICS***

B: Texts on Reserve: *books on reserve*

COURSE POLICIES AND INFORMATION

Students are bound by the Honor Code. Any student found in violation will be reported to the proper authorities.

1. PPWS 5314 is a graduate-level course for students in the computational and mathematical sciences with an interest in bioinformatics.

2. The course will take the form of lectures, class discussions, field trips, a field trip report, two mid-terms, a take-home final, brief informal presentations, and one formal 30-minute presentation.

3. Participation in class is an essential part of learning. Consistent attendance and informed contributions are expected of all students.

4. Students will work in pairs on the contents of the field trip report, the in-class presentations, and on the oral presentation. *All presentations will be graded.*

5. You are strongly encouraged to compile a glossary of terms as the semester progresses. It will be essential in your preparation for your in-class presentation of problems , and in your oral presentation.

6. Students will work in teams of two on preparation for the field trip reports, as stated above. However, field trip reports must be written individually. The instructor, in a one-on-one session, must review one draft of each report during her office hours, or by appointment. Drafts must be handed in by the due date!!! No draft will result in a grade of F for that part of the course.

7. *The oral presentation will be based on one of the readings listed below.*

Stress Transcript

Metabolomics

Genomics

Transcriptomics

Clustering

Networks

8. The midterms will be 2.0 hours long, and will be held from 4:45-6:45 PM on October 14 and November 11.

International students, who did not grow up with English, may take 50% longer on any exam. Take-home final (24 hours, open book, no help from others), will be held December 18-19.

EXAM	LECTURES
MIDTERM 1	1-10
MIDTERM 2	11-20
FINAL	21-27

8. Assignment of grades is on the following basis:

Midterms (2)	40%
Final	20%
Field trip report	15%
Oral presentations by teams	15%
Class participation	10%

LECTURE, READING, ASSIGNMENT, AND FIELD TRIP SCHEDULE

All field trips will be to the Virginia Bioinformatics Institute.

Lecture # and Date	Topic	Assigned Reading	Events/ Presentation Topics
1 08/26/03	Molecular Genetics and Genomics: An Overview.	H. Ch.1	
2 08/28/03	Discussion of Concepts in Chapter 1	H. Ch. 1	Topics pp 28-29
3 09/02/03	The Origins of Genetics: Mendel	H. Ch. 2	
4 09/04/03	The Origins of Genetics: Mendel	H. Ch. 2	Topics: pp 66-68 Problems 2.11, 2.13. 2.17, 2.19
5 09/09/03	Chromosomes and Heredity	H. Ch. 3 pp. 74-105	

6 09/11/03	Chromosomes and Heredity	H. Ch. 3	Topics: pp 114-116 Problems 3.5, 3.7, 3.9, 3.15
7 09/16/03	Genetic Mapping	H. Ch. 4 pp. 124-152	
8 09/18/03	Genetic Mapping	H. Ch. 4	Topics: pp 160-161 Problems 4.3, 4.5, 4.9, 4.13
9 09/23/03	DNA: Chemistry and Replication	H. Ch. 6	
10/ 09/25/03	DNA Replication	H. Ch. 6	Topics: pp. 244-245 Prepare page 228. Problems 6.7, 6.11, 6.15 *Field Trip 1* *7-9 PM*
11 09/30/03	Mutation and Repair	H. Ch. 7	
12 10/02/03	Mutation and Repair	H. Ch. 7	Topics: pp 282- 7.5, Problems 7.5, 7.9, 7.13
13 10/07/03	Gene Expression	H. Ch. 9	

14 10/09/03	Gene Expression	H. Ch. 9	Topics: pp 362-363, Problems 9.9, 9.13
15 10/14/03	Transcriptional Regulation	H. Ch. 10	***Midterm 1*** ***Lectures 1-10*** ***MCB 231***
16 10/16/03	Transcriptional Regulation	H. Ch. 10	Topics: page 402. ***Field Trip Report 1 Due*** ***Field Trip 2 10/15/03*** ***7-9 PM***
17 10/21/03	Tools of Biotechnology and Functional Genomics	H. Ch. 11	
18 10/2303	Tools - continued	H. Ch. 11	Topics: 438-439 Prepare page 433
19 10/28/03	Cells and Tools to View Them	C. Ch. 1	
20 10/30/03	Cells -continued	C. Ch. 1	Questions 1-5. page 38-39 Prepare pp 32 and 35

21 11/04/03	The Nucleus	C. Ch. 8	*Field Trip Report 2 Due* *Review Session* *MCB 655 5:30-6:30, 11/05/03* *Field Trip 3* *7-9PM*
22 11/06/03	The Nucleus	C. Ch. 8	Prepare pages 330, 340 All Questions, pp 352ff
23 11/11/03	Protein Sorting and Transport	C. Ch. 9, pp. 355-380	*Midterm 2* *Lectures 11-20* *4:45 - 6:45 PM* Oral presentation topics posted
24 11/13/03	Cell Signaling	C. Ch. 13, pp 541-561	
25 11/18/03	Cell Signaling	C. Ch. 13, pp 562-584	Questions, p. 587
26 11/20/03	Cell Cycle	C. Ch. 14, pp 591-615	*Field Trip Report 3 Due* Happy Thanksgiving!
27 12/02/03	Cell Cycle	C. Ch. 14, pp 615-625	Questions p. 628
28 12/04/03	Oral Presentations		

29 **12/09/03**	**Oral Presentations**		***Review Session***

The Plant Journal (2002) **31**(3), 279–292

Monitoring the expression profiles of 7000 *Arabidopsis* genes under drought, cold and high-salinity stresses using a full-length cDNA microarray

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[6]*Genome Exploration Research Group, RIKEN Genomic Sciences Center, RIKEN Yokohama Institute, 1-7-22 Suehiro-cho, Tsurumi-ku, Yokohama 230-0045, and*

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Summary

Full-length cDNAs are essential for functional analysis of plant genes in the post-sequencing era of the *Arabidopsis* genome. Recently, cDNA microarray analysis has been developed for quantitative analysis of global and simultaneous analysis of expression profiles. We have prepared a full-length cDNA microarray containing ≈7000 independent, full-length cDNA groups to analyse the expression profiles of genes under drought, cold (low temperature) and high-salinity stress conditions over time. The transcripts of 53, 277 and 194 genes increased after cold, drought and high-salinity treatments, respectively, more than fivefold compared with the control genes. We also identified many highly drought-, cold- or high-salinity- stress-inducible genes. However, we observed strong relationships in the expression of these stress-responsive genes based on Venn diagram analysis, and found 22 stress-inducible genes that responded to all three stresses. Several gene groups showing different expression profiles were identified by analysis of their expression patterns during stress-responsive gene induction. The cold-inducible genes were classified into at least two gene groups from their expression profiles. DREB1A was included in a group whose expression peaked at 2 h after cold treatment. Among the drought, cold or high-salinity stress-inducible genes identified, we found 40 transcription factor genes (corresponding to ≈11% of all stress-inducible genes identified), suggesting that various transcriptional regulatory mechanisms function in the drought, cold or high-salinity stress signal transduction pathways.

Keywords: *Arabidopsis thaliana*, full-length cDNA, cDNA microarray, abiotic stress.

Introduction

Recently, microarray technology has become a useful tool for the analysis of genome-scale gene expression (Eisen and Brown, 1999; Schena *et al.*, 1995). This DNA chip-based technology arrays cDNA sequences on a glass slide at a density of up to 1000 genes cm^{-2}. These arrayed sequences are hybridized simultaneously to a two-colour, fluorescently labelled cDNA probe pair prepared from RNA samples of different cell or tissue types, allowing direct

and large-scale comparative analysis of gene expression. This technology using ESTs was first demonstrated by analysing 48 *Arabidopsis* genes for differential expression in roots and shoots (Schena *et al.*, 1995). Reymond *et al.* (2000) analysed the expression in response to mechanical wounding and insect feeding, and defence-signalling pathways have been analysed using fungal pathogen and signalling molecules (Schenk *et al.*, 2000).

Plant growth is greatly affected by environmental abiotic stresses such as drought, high salinity and low temperature. Plants respond and adapt to these stresses in order to survive. These abiotic stresses are severe limiting factors of plant growth and crop production. These abiotic stresses induce various biochemical and physiological responses in plants to acquire stress tolerance. The mechanism of the molecular response of higher plants against water stress has been analysed by studying a number of genes responding to drought, high-salinity and cold stress at the transcriptional level (Bray, 1997; Hasegawa *et al.*, 2000; Ingram and Bartels, 1996; Thomashow, 1999). The products of the stress-inducible genes can be classified into two groups: those that directly protect against environmental stresses; and those that regulate gene expression and signal transduction in the stress response (Bray, 1997; Hasegawa *et al.*, 2000; Shinozaki and Yamaguchi-Shinozaki, 1997; Thomashow, 1999). Stress-inducible genes have been used to improve the stress tolerance of plants by gene transfer (Bajaj *et al.*, 1999; Holmberg and Bülow, 1998). It is important to analyse the functions of stress-inducible genes, not only to understand the molecular mechanisms of stress tolerance and the responses of higher plants, but also to improve the stress tolerance of crops by gene manipulation. Hundreds of genes are thought to be involved in abiotic stress responses. Expression analyses of drought-, cold- and high-salinity-inducible genes have shown the existence of several regulatory systems of stress-responsive gene expression. Some are dependent on abscisic acid (ABA), others are ABA-independent (Bray, 1997; Shinozaki and Yamaguchi-Shinozaki, 1996; Shinozaki and Yamaguchi-Shinozaki, 1997; Shinozaki and Yamaguchi-Shinozaki, 2000; Thomashow, 1999), which indicate the existence of complex regulatory mechanisms between perception of abiotic stress signals and gene expression (Shinozaki and Yamaguchi-Shinozaki, 1996; Shinozaki and Yamaguchi-Shinozaki, 1997; Shinozaki and Yamaguchi-Shinozaki, 2000; Zhu, 2001).

Previously, we prepared an *Arabidopsis* full-length cDNA microarray using ≈1300 full-length cDNAs, and applied the full-length cDNA microarray to identify drought- or cold-inducible genes, and target genes of DREB1A/CBF3, a transcription factor controlling stress-inducible gene expression (Seki *et al.*, 2001a). Our previous results showed that the full-length cDNA microarray is useful to analyse the expression pattern of *Arabidopsis* genes under drought and cold stresses, and to identify target genes of stress-related transcription factors and potential *cis*-acting DNA elements by combining the expression data with the genomic sequence data.

Recently, we prepared a new full-length cDNA microarray containing ≈7000 independent full-length cDNA groups. In the present study, we applied the 7000 full-length cDNA microarray to identify new drought-, cold- or high-salinity-inducible genes, to analyse the time course of gene expression by drought, cold and high-salinity stresses, and to examine the differences and cross-talk between their signalling cascades. This is the first report on cross-talk of signalling cascades among drought, cold and high-salinity stresses using a global expression-profiling strategy. We also discuss functions of the stress-inducible genes in stress response and tolerance.

Results and discussion

Arabidopsis *full-length cDNA microarray*

Using the biotinylated CAP trapper method, we constructed full-length cDNA libraries from *Arabidopsis* plants under different conditions, including drought-treated, cold-treated and unstressed plants, at various developmental stages from germination to mature seeds (Seki *et al.*, 1998; Seki *et al.*, 2001b). From the full-length cDNA libraries, we isolated ≈7000 independent *Arabidopsis* full-length cDNAs. We used a method described previously (Eisen and Brown, 1999) to array PCR-amplified cDNA fragments onto glass slides. We prepared a full-length cDNA microarray containing ≈7000 *Arabidopsis* full-length cDNAs, including the drought-inducible genes, *responsive to dehydration* (*rd*) and *early responsive to dehydration* (*erd*) (Taji *et al.*, 1999) as positive controls; the PCR-amplified fragment from lambda control template DNA fragment (Takara, Kyoto, Japan) as an external control; and the mouse nicotinic acetylcholine receptor epsilon-subunit (*nAChRE*) gene and the mouse glucocorticoid receptor homologue gene (which have no substantial homology to any sequences in the *Arabidopsis* database) to assess for non-specific hybridization as negative controls.

Isolation of drought-, cold- or high-salinity-stress-inducible genes by cDNA microarray

cDNA microarrays were hybridized with Cy3 and Cy5 fluorescently labelled probe pairs of drought-treated plants plus unstressed plants; cold-treated plants plus unstressed plants; and high-salinity-treated plants plus unstressed plants, prepared as described in Experimental procedures. Hybridized microarrays were

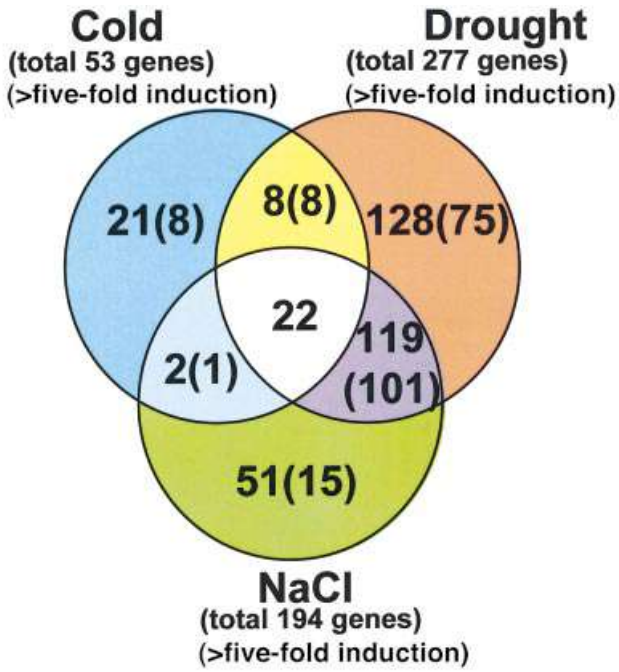

Figure 1. Classification of the drought, cold or high-salinity stress-inducible genes identified on the basis of microarray analyses.
In total, 277 drought-inducible, 53 cold-inducible and 194 high-salinity stress-inducible genes were identified by cDNA microarray analysis. The drought, cold or high-salinity stress-inducible genes identified were grouped into the following seven groups: (1) highly cold-stress-inducible; (2) highly drought-stress-inducible; (3) highly high-salinity-stress-inducible; (4) drought, cold and high-salinity stress-inducible; (5) genes that were highly induced by drought and high-salinity stress; (6) genes that were highly induced by drought and cold stress; (7) genes that were highly induced by cold and high-salinity stress. The number of genes whose expression ratio is more than fivefold for each stress treatment and less than fivefold for the other stress treatments is indicated. Numbers in parentheses represent the number of genes whose expression ratio is more than fivefold for each stress treatment and less than threefold for the other stress treatments. A list of the genes is available as supplementary material (Tables S1 and S2).

scanned by two separate laser channels for Cy3 and Cy5 emissions from each DNA element. The ratio of the two fluorescent signal intensities of each DNA element was then measured as a relative measure to determine changes in the differential expression of genes represented by cDNA spots on the microarrays. In this study, we used the PCR-amplified fragment from lambda control template DNA fragment (Takara) as an external control gene to equalize hybridization signals generated from different samples.

mRNAs from drought, cold or high-salinity stress-treated plants and wild-type unstressed plants were used for preparation of Cy3- and Cy5-labelled cDNA probes, respectively. These cDNA probes were mixed and hybridized with the cDNA microarray. To assess the reproducibility of the microarray analysis, we repeated the same experiment three times. Hybridization of different microarrays with the same mRNA samples indicated good correlation. As for the genes with expression ratios (dehydration/unstressed; cold/unstressed; high-salinity/unstressed) greater than five times that of the lambda control template DNA fragment in at least one time-course point, we identified 277, 53 and 194 genes as drought-, cold- and high-salinity-inducible, respectively. As for the genes with expression ratios (dehydration/unstressed; cold/unstressed; high-salinity/unstressed) greater than three times in at least one time-course point, we identified 742, 229 and 554 genes as drought-, cold- and high-salinity-inducible, respectively. In this study we focused on the genes with expression ratios greater than five times compared with unstressed plants.

Drought, cold or high-salinity stress-inducible genes identified with the full-length cDNA microarray

In total, 277 drought-inducible, 53 cold-inducible and 194 high-salinity-inducible genes were identified by cDNA microarray analysis (Figure 1; Table 1). The number of cold stress-inducible genes was less than one-fifth, and one-third of that of drought-inducible genes and high-salinity stress-inducible genes, respectively, suggesting that drought stress or water deficit is the most severe limiting factor of plant growth. On the other hand, this may be due to the cold stress condition (transfer of plants to 4°C) that were used. The list and expression data for the drought-, cold- or high-salinity-inducible genes identified are available as supplementary material (Table S1). These genes included many reported drought, cold and high-salinity stress-inducible genes, which indicates that our cDNA microarray system functions properly to find drought, cold or high-salinity stress-inducible genes.

Relationship between each stress

The stress-inducible genes were classified into groups on the basis of their expression pattern (Figure 1). The results of the classification are available as supplementary material (Table S2). Analysis of overlapping on the Venn diagram showed that 22 genes were induced under all three stresses. Among these we found six well known stress-inducible genes including *rd29A/cor78*, *cor15a*, *kin1*, *kin2*, *rd17/cor47* and *erd10* (Bohnert *et al.*, 1995; Bray, 1997; Ingram and Bartels, 1996; Kiyosue *et al.*, 1994; Shinozaki and Yamaguchi-Shinozaki, 1997; Shinozaki and Yamaguchi-Shinozaki, 1999; Shinozaki and Yamaguchi-Shinozaki, 2000; Taji *et al.*, 1999). A cDNA (RAFL05-19-G24) that encodes a constans-like protein (GenBank accession number Y10555) and eight cDNAs (RAFL04-09-B07, RAFL04-12-F24, RAFL04-10-D13, RAFL05-10-J09, RAFL05-

Table 1. Number of clones involved in different functional groups upregulated [a]or downregulated [b]by drought, cold or high-salinity stress

Functional category	Gene number	Representative gene names
Upregulated		
Transcription factor	40	Six DREB family transcription factors, two ERF family transcription factors, 10 zinc finger family transcription factors, four WRKY family transcription factors, three MYB family transcription factors, two bHLH family transcription factors, five NAC family transcription factors, three homeodomain family transcription factors, four bZIP family transcription factors, other family transcription factor
Osmoprotectant synthesis	11	Four galactinol synthases, P5CS, two raffinose synthases, two sucrose synthases, arginine decarboxylase, trehalose-6-phosphate synthase
Protein degradation	3	ERD1, RD21, ubiquitin conjugating enzyme
Protease inhibitor	1	Cysteine proteinase inhibitor
LEA protein	9	ERD10, RD17, Rab18, 6 LEA proteins
Hydrophilic protein	2	RD29A, RD29B
KIN protein	2	KIN1, KIN2
Detoxification enzyme	6	Two glutathione S- transferases, three peroxidases, phytochelatin synthase
Heat shock protein	4	Four heat-shock proteins
Lipid-transfer protein	4	Four lipid-transfer proteins
Transport protein, ion channel, carrier	11	ERD6, 2 ABC transporter proteins, oligopeptide transporter protein, potassium transporter protein, sodium sulfate or dicarboxylate transporter protein, neutral amino acid transport system protein, two mitochondrial dicarboxylate carrier proteins, Na^+-dependent inorganic phosphate co-transporter protein, chloroplast protein import component protein
Water channel protein	1	RD28
Membrane protein	4	ERD4, 3 membrane-related proteins
Fatty acid metabolism	6	Three lipases, lysophospholipase, choline kinase, fatty acid elongase
Cytochrome P450	7	Seven cytochrome P450 proteins
Protein kinase	6	Two Ser/Thr protein kinases, two receptor-like protein kinases, two protein kinases
Protein phosphatase	3	ABI1, two protein phosphatase 2C-like proteins
Signalling	4	RD20, calmodulin-binding protein, calmodulin, two-component response regulator
Aldehyde dehydrogenase	2	Two aldehyde dehydrogenases
Plant defence	7	Endochitinase, disease resistance response protein, harpin-induced protein, nematode-resistance protein, beta-1,3-glucanase, polygalacturonase inhibiting protein, pathogen-inducible alpha-dioxygenase
Alcohol dehydrogenase	2	Two alcohol dehydrogenases
ABA biosynthesis	2	ATNCED3, zeaxanthin epoxidase
Ethylene biosynthesis	2	1-aminocyclopropane-1-carboxylate oxidase, ethylene-forming enzyme
JA biosynthesis	1	Lipoxygenase
JA-regulated genes	1	Myrosinase-binding protein
IAA metabolism	4	Three indole-3-acetate beta-glucosyltransferases, nitrilase
Auxin-regulated genes	2	IAA18, auxin-responsive GH3-like protein
Ionic homeostasis	1	Metallothionein-like protein
Senescence-related genes	2	ERD7, SAG29
Cellular metabolism	24	*p*-hydroxyphenylpyruvate dioxygenase, polygalacturonase, carboxyesterase, steroid sulfotransferase, 3-methylcrotonyl-CoA carboxylase precursor, saccharopine dehydrogenase, alanine : glyoxylate aminotransferase, tyramine hydroxycinnamoyl transferase, citrate synthase, aspartate aminotransferase, nodulin/glutamate-ammonia ligase, alpha-hydroxynitrile lyase, 12-oxophytodienoate-10-11-reductase, tyrosine aminotransferase, malate dehydrogenase, isovaleryl-CoA-dehydrogenase, two nodulin-related proteins, acyl-CoA oxidase, 3-ketoacyl-CoA thiolase, glyoxalase, succinate dehydrogenase, L-aspartate oxidase, 3-methylcrotonyl-CoA carboxylase non-biotinylated subunit
Carbohydrate metabolism	20	Glucose-6-phosphate/phosphate translocator precursor, two UDP-glucose glucosyltransferases, beta-galactosidase, two neutral invertases, UDP glucose 4-epimerase, UDP-glucose:flavonoid 7-*O*-glucosyltransferase, three beta-amylases, indole-3-acetate beta-glucosyltransferase, *O*-linked GlcNAc transferase, two beta-glucosidases, UDP-glucose : indole-3-acetate beta-D-glucosyltransferase, two glucosyltransferases, glucose and ribitol dehydrogenase, alpha-L-arabinofuranosidase
Secondary metabolism	12	Three strictosidine synthases, anthocyanidin synthase, reticuline oxidase, berberine bridge enzyme, mannitol dehydrogenase, four cinnamyl-alcohol dehydrogenases, cinnamoyl-CoA reductase

Table 1 (continued)

Functional category	Gene number	Representative gene names
Respiration	4	Alternative oxidase, mono-oxygenase 1, flavin-containing monooxygenase, flavin-binding monooxygenase
Protein synthesis	2	Eukaryotic translation initiation factor, eukaryotic release factor
Reproductive development	2	Pollen coat protein, pollen-specific protein
Cellular structure, organization and biogenesis	9	Three pectinesterases, extracellular dermalglycoprotein, pectin methylesterase, arabinogalactan, two endoxyloglucan transferases, blue copper-binding protein
DNA, nucleus	5	Topoisomerase, histone, nucleolin, regulator of chromosome condensation-like protein, nucleoid DNA-binding protein
Photosynthesis	1	Pyruvate-orthophosphate dikinase
RNA-binding protein	1	RNA-binding protein
Ferritin	1	Ferritin
Downregulated		
Transcription factor	2	Homeodomain family transcription factor, other family transcription factor
Photosynthesis	37	Four RBCS genes, two PsbS genes, nine photosystem II oxygen-evolving complex proteins, six photosystem I subunit proteins, 13 chlorophyll *a*/*b*-binding proteins, ribulose-bisphosphate carboxylase activase, Rubisco subunit-binding protein beta subunit precursor, sedoheptulose-1,7-bisphosphatase
Carbohydrate metabolism	11	Phosphoribulokinase, three glyceraldehyde 3 phosphate dehydrogenases, two aldolases, two fructose-bisphosphatases, three beta-glucosidases
Respiration	2	Two H^+-transporting ATP synthases
RNA-binding protein	3	Three RNA-binding proteins
Lipase	1	Lipase/acylhydrolase
GTP-binding protein	1	GTP-binding protein
DNA-damage repair	1	DNA-damage-repair/toleration protein
Protein synthesis	1	50S ribosomal protein
Amino acid metabolism	1	Asparagine synthetase
Cell wall-related genes	5	Extensin, pectinesterase, three xyloglucan endotransglycosylases
Ethylene biosynthesis	1	*S*-adenosylmethionine synthase
Chloroplast protein	5	CP12-like protein, three 50S ribosomal proteins, peptidyl-prolyl *cis–trans* isomerase
Cytochrome P450	2	Two cytochrome P450 proteins
Protein degradation	1	Aspartic protease
Detoxification enzyme	5	Three glutathione *S*-transferases, 2-cys peroxiredoxin, ascorbate peroxidase
Cytoskeleton	1	Beta-tubulin
Cellular metabolism	4	Isopropylmalate synthase, malate dehydrogenase, hydroxypyruvate reductase, IAA-Ala hydrolase
DNA, nucleus	1	Deoxyribodipyrimidine photolyase

[a]In this study we regarded genes with expression ratios (dehydration/unstressed, cold/unstressed or high-salinity/unstressed) greater than five times that of lambda control template DNA fragment in at least one time-course point as dehydration, cold or high-salinity stress-inducible genes.[b]In this study we regarded cDNAs whose expression level is less than one-fifth in at least one time-course point in drought-stressed and high-salinity-stressed plants of that in wild-type unstressed plants as genes downregulated by drought stress and high-salinity stress, respectively. We also regarded cDNAs whose expression level is less than one-half in at least one time-course point in cold-

19-O22, RAFL05-21-F13, RAFL08-11-P07 and RAFL08-15-M21) whose function is unknown were also included in this group.

Based on Venn diagram analysis, we analysed differences and cross-talk of gene expression among drought, cold and high-salinity stress responses. As shown in Figure 1, 277, 53 and 194 genes were identified as drought-, cold- and high-salinity-induced genes with greater than five times induction, respectively; 141 genes were induced by both drought and high salinity, whereas only 30 genes were induced by both drought and cold stress; and 24 genes were identified as cold- and high-salinity-inducible genes. Seventy per cent of the high-salinity-inducible genes were also induced by drought stress, which indicates a strong correlation between drought and high-salinity stress responses. These results indicate the existence of greater cross-talk between drought and high-salinity stress signalling processes than those between cold and high-salinity stress signalling processes. These results are consistent with our previous observation on the overlap of drought- and high-salinity-responsive gene expression (Shinozaki and Yamaguchi-Shinozaki, 1999; Shinozaki and Yamaguchi-Shinozaki, 2000).

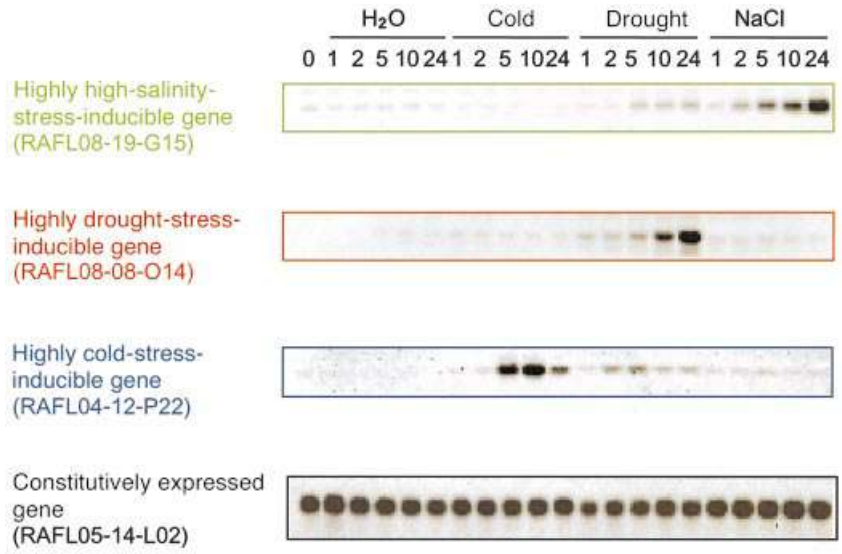

Figure 2. RNA gel-blot analysis of highly drought-, cold- or high-salinity-inducible genes and constitutively expressed genes. Results for a highly high-salinity-stress-inducible gene (RAFL08-19-G15); a highly drought-stress-inducible gene (RAFL08-08-O14); a highly cold-stress-inducible gene (RAFL04-12-P22); and a constitutively expressed gene (RAFL05-14-L02).

Highly stress-inducible genes and constitutively expressed genes

Among the stress-inducible genes identified, we found many genes that were highly induced by each stress. In this study we regard the genes whose expression ratio is more than fivefold for each stress treatment and less than threefold for the other stress treatments as highly stress-inducible genes. We identified 75 highly drought-stress-inducible genes; eight highly cold-stress-inducible genes; and 15 highly high-salinity-stress-inducible genes (Figure 1). Information on each gene is available as supplementary material (Table S2). Among these, we found a cDNA (RAFL08-08-O14) showing sequence similarity with a hypothetical protein (accession number AL035524) as a highly drought-stress-inducible gene; a cDNA (RAFL04-12-P22) showing sequence similarity with a hypothetical protein (accession number AC006193) as a highly cold-stress-inducible gene; and a cDNA (RAFL08-19-G15) showing sequence similarity with putative glucosyl transferase (accession number AC006282) as a highly high-salinity-stress-inducible gene. Expression profiles obtained by microarray analysis were consistent with those obtained by RNA gel-blot analysis (Figure 2).

In the genes that were highly induced by cold stress, genes for DREB1A (accession number AB007787) and beta-amylase (accession number AJ250341) existed (Tables S1and S2). This result is consistent with our previous report (Seki *et al.*, 2001a). We also found a highly cold-stress-inducible cDNA (RAFL04-12-N15) showing sequence similarity with regulator of chromosome condensation-like protein (accession number T47697). In the genes that were highly induced by drought stress, genes in the functional categories such as lipid-transfer protein, secondary metabolism-related genes and transport protein existed (Tables S1and S2). In the genes that were highly induced by high-salinity stress, genes involved in carbohydrate metabolism existed (Tables S1and S2). However, we could not identify any gene families in which all genes are specifically expressed only in a specific stress condition.

We identified three constitutively expressed genes with almost the same expression level under drought, cold and high-salinity stresses. Among these we found a cDNA (RAFL05-14-L02) identical with RUB1 conjugating enzyme (RCE1; accession number AF202771). This gene may be useful as an internal control gene in cDNA microarray analysis.

Characterization of drought-, cold- or high-salinity-inducible genes

In this study we identified 277 drought stress-inducible genes, 53 cold stress-inducible genes and 194 high-salinity stress-inducible genes (Table 1; Table S1). These gene products can be classified into two groups. The first group includes functional proteins or proteins that probably function in stress tolerance. They are late embryogenesis-abundant (LEA) proteins; heat-shock proteins; KIN (cold-inducible) proteins; osmoprotectant biosynthesis-related proteins; carbohydrate metabolism-related proteins; water-channel proteins; sugar transporters; potassium transporters; detoxification enzymes; proteases; senescence-related genes; protease inhibitors; ferritin; and lipid-transfer proteins (Table 1; Table S1). LEA proteins and heat-shock proteins have been shown

to be involved in protecting macromolecules such as enzymes and lipids (Shinozaki and Yamaguchi-Shinozaki, 1999). Proline and sugars probably function as osmolytes in protecting cells from dehydration (Cushman and Bohnert, 2000). KIN proteins may have an unique ability to neutralize ice nucleators and inhibit ice recrystallization (Holmberg and Bülow, 1998). Water-channel proteins and sugar transporters are thought to function in transport of water and sugars through plasma membranes and tonoplast to adjust the osmotic pressure under stress conditions. Potassium transporters may function in the transport of K^+, which is an essential cofactor for many enzymes (Hasegawa *et al.*, 2000); or control K^+ uptake and regulate Na^+ uptake, which can be an important determinant of salinity tolerance (Bray, 1997). Detoxification enzymes such as glutathione S-transferase are thought to be involved in protection of cells from active oxygens. Proteases including cysteine proteases, CIP protease and ubiquitin-conjugating enzyme are thought to be required for protein turnover and recycling of amino acids. Drought stress has been shown to accelerate leaf senescence which is characterized by many subcellular changes, including an increase in protease activities (Thomas and Stoddart, 1980). The protease inhibitors may perform a defensive role against the proteases. Ferritin may have a function in protecting cells from oxidative damage caused by various stresses, by sequestering intracellular iron involved in the generation of various reactive hydroxyl radicals through a Fenton reaction (Bajaj *et al.*, 1999). Lipid-transfer proteins and fatty acid metabolism-related genes may have a function in repair of stress-induced damage in membranes or changes in the lipid composition of membranes, perhaps to regulate permeability to toxic ions and the fluidity of the membrane (Holmberg and Bülow, 1998; Torres-Schumann *et al.*, 1992).

The second group contains regulatory proteins, that is, protein factors involved in further regulation of signal transduction and gene expression that probably function in stress responses. They are various transcription factors, protein kinases, protein phosphatases, enzymes involved in phospholipid metabolism, and other signalling molecules such as calmodulin-binding protein (Table 1; Table S1). Among 40 stress-inducible genes for transcription factors, we found novel families of transcription factors such as NAC and WRKY. These may function in regulation of some stress-inducible genes. Among six protein kinase genes, we found two receptor-like protein kinase genes. These regulatory proteins are thought to function in further regulating various functional genes under stress conditions.

Various genes involved in the metabolism of ethylene, jasmonic acid (JA) and auxin, and JA- or auxin-regulated genes were identified as drought-inducible genes (Table 1; Table S1), suggesting a link between ethylene, JA and auxin, and drought stress-signalling pathways. Also, aldehyde dehydrogenase genes, genes related to secondary metabolism, genes involved in various cellular metabolic processes, genes encoding membrane proteins, and cytochrome P450 were identified as drought stress-inducible genes (Table 1; Table S1). At present the functions of most of these genes are not fully understood. We also found many drought stress-inducible genes whose functions are unknown.

Several similar studies have reported gene expression profile analysis under abiotic stress in other plant species such as rice (Bohnert *et al.*, 2001; Kawasaki *et al.*, 2001). They analysed the expression profiles using cDNA microarray including ≈1700 cDNAs under salt stress conditions in rice, and similarly reported that transcripts of protease inhibitor, beta-glucosidase, detoxification enzyme, water-channel protein and protein synthesis-related genes are upregulated after salt stress.

Drought, cold or high-salinity stress-inducible transcription factors

In this study, 40 genes (corresponding to ≈11% of all stress-inducible genes identified) for transcription factors were identified as drought, cold or high-salinity stress-inducible genes (Table 1; Table S1). This result suggests the existence of many transcriptional regulatory mechanisms in the drought, cold or high-salinity stress signal transduction pathways. Among these stress-inducible transcription factors, there are six DREB family cDNAs, two ERF family cDNAs, 10 zinc finger family cDNAs, four WRKY family cDNAs, three MYB family cDNAs, two bHLH family cDNAs, four bZIP family cDNAs, five NAC family cDNAs, and three homeodomain transcription factor family cDNAs. These transcription factors regulate various stress-inducible genes co-operatively or separately. Information on each stress-inducible transcription factor is available as supplementary material (Table S1). Among these were transcription factors highly induced by each stress (Table S1). We will study the function of these stress-inducible transcription factors using knock-out mutants and transgenics, including overexpression (Jaglo-Ottosen *et al.*, 1998; Kasuga *et al.*, 1999; Liu *et al.*, 1998); antisense suppression (Huang *et al.*, 1999; Nanjo *et al.*, 1999); and double-stranded RNA interference (RNAi) (Chuang and Meyerowitz, 2000; Smith *et al.*, 2000). We will also study the target genes of the transcription factors by cDNA microarray analyses of these mutants and transgenic plants.

Various expression profiles of stress-inducible genes during stress treatment

To evaluate the validity of expression profile analysis of gene expression during stress treatment using cDNA

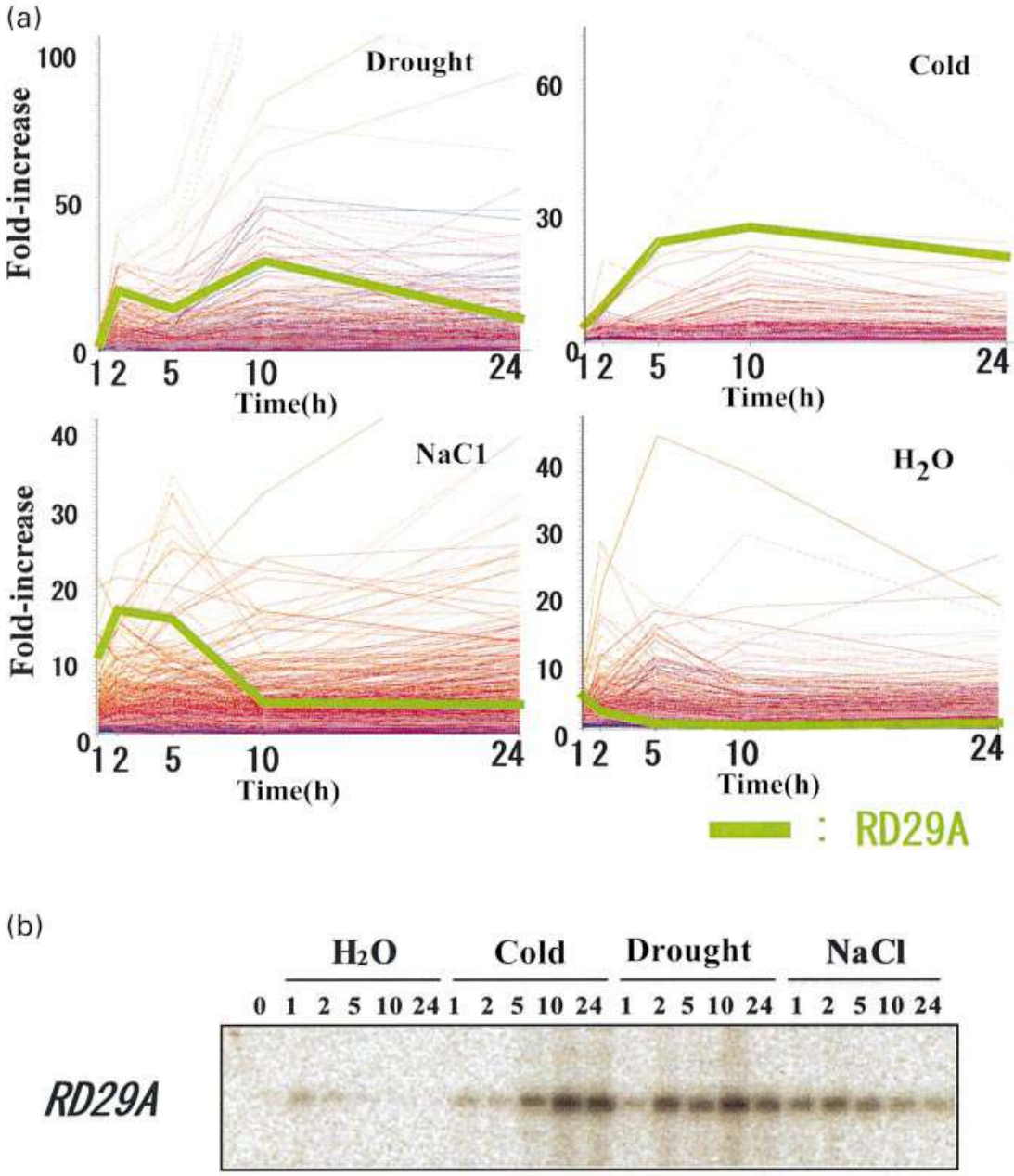

Figure 3. Expression pattern of ≈7000 *Arabidopsis* genes after drought, cold and high-salinity stress treatments.
(a) Time course of changes in expression pattern of ≈7000 *Arabidopsis* genes after drought, cold and high-salinity stress treatments, and plants transferred to a plate containing water as control. The *x* axis shows time after each treatment; the *y*-axis shows the fold-increase in expression level. The expression pattern of drought-inducible gene RD29A is shown as green, bold bars.
(b) RNA gel-blot analysis of the RD29A gene.

microarray, we performed RNA gel-blot analysis on 16 stress-inducible genes. The results of expression data obtained by microarray analyses were in good agreement with those obtained by RNA gel-blot analyses (data not shown). This is consistent with our previous report (Seki *et al.*, 2001a). An example of a drought-inducible gene, *rd29A* (Yamaguchi-Shinozaki and Shinozaki, 1993), is shown in Figure 3. Expression profiles of drought, cold or high-salinity stress-inducible genes were classified by principal components analysis and *K*-mean clustering using the GENESPRING software. These expression profile analyses demonstrated that there are several gene groups which show different expression profiles.

Analysis of the expression profiles of cold-inducible genes during cold treatment (Figure 4) showed the exist-

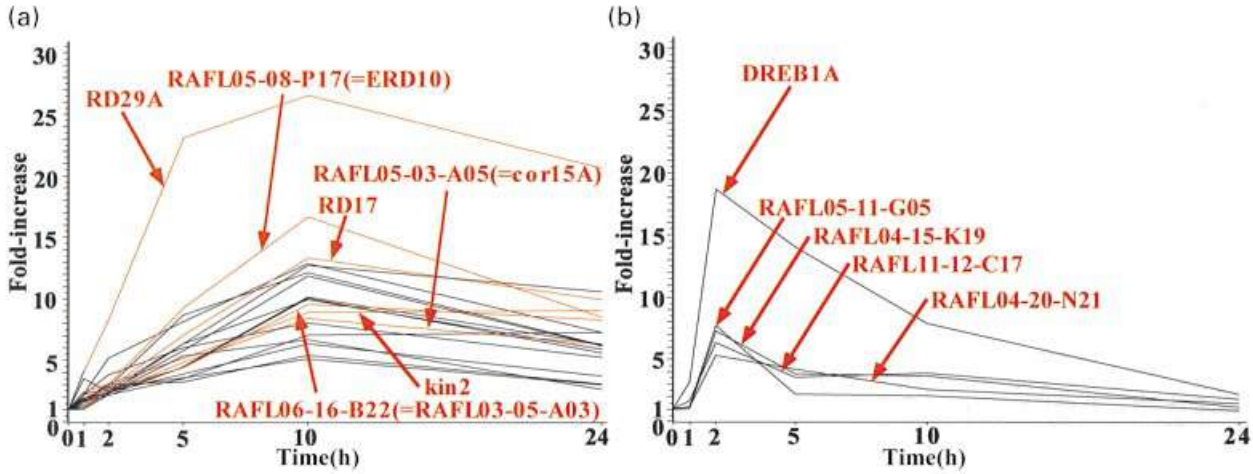

Figure 4. Classification of cold-inducible genes divided into two groups on the basis of expression pattern under cold stress.
In one group (b) containing DREB1A, RAFL04-15-K19, RAFL05-11-G05, RAFL04-20-N21 and RAFL11-12-C17, expression was induced rapidly after cold treatment, reached a maximum at 2 h after cold treatment, and then decreased. In the other group (a) containing DREB1A target genes such as RD29A, ERD10, cor15A, RD17, kin2 and RAFL06-16-B22 (= RAFL03-05-A03), expression was induced after cold treatment within 2 h, and strongly expressed after 5 h.

ence of at least two groups that show different expression profiles. In one group containing the *DREB1A* gene, gene expression was rapid and transient in response to cold treatment, reached a maximum at 2 h, and then decreased (Figure 4). In the other group containing DREB1A target genes such as *rd29A*, *erd10*, *cor15A*, *rd17*, *kin2* and RAFL06-16-B22 genes, their expression increased slowly and gradually after cold treatment within 10 h (Figure 4). Expression of the DREB1A gene during cold stress preceded that of the DREB1A target genes. These results support our previous findings that *DREB1A* regulates the expression of DREB1A target genes such as *rd29A*, *erd10*, *cor15A*, *rd17*, *kin2* and RAFL06-16-B22 genes (Kasuga *et al.*, 1999; Seki *et al.*, 2001a). Among the genes whose expression was rapid and transient in response to cold treatment, we found cDNAs (RAFL04-15-K19 and RAFL05-11-G05) showing sequence identity with salt tolerance-related zinc-finger protein (accession number X95573) and mitochondrial uncoupling protein (accession number AJ286346) and cDNAs (RAFL04-20-N21 and RAFL11-12-C17) whose function is unknown.

Analysis of expression profiles of drought-inducible genes during drought stress treatment also exhibited the existence of at least two groups showing different expression profiles (data not shown). In one group, containing the *rd22BP1* and *DREB2A* genes, gene expression was rapid and transient after drought stress treatment; reached a maximum at 2 h; and then decreased. In this group we found cDNAs (RAFL04-15-K19, RAFL06-07-B08, RAFL09-12-N16, and RAFL08-16-D06) showing sequence identity with salt tolerance-related zinc finger protein (accession number X95573); SOS2-like protein kinase PKS5(accession number AF339146); putative bHLH transcription factor (accession number AC006418); AP2domain-containing protein RAP2(accession number NP_173638) and cDNAs (RAFL05-11-M11, RAFL05-18-H12 and RAFL05-14-I17) showing sequence similarity with an AP2 domain-containing protein (accession number AF332422); *Petroselinum crispum* transcription factor WRKY4 (accession number AF204925); and growth factor-like protein (accession number AF325104). These genes may function as regulatory protein factors involved in the regulation of signal transduction and gene expression functioning in stress responses. In the other group containing the *rd22* and *rd29A* genes, gene expression slowly and gradually increased after drought stress treatment within 2 h and reached a maximum at 10 h, then decreased gradually.

Promoter analysis of stress-inducible genes

In this study, 22 genes were identified as drought, cold and high-salinity stress-inducible genes. As we identified the 5′-end of each mRNA based on comparison of full-length cDNAs and genomic sequences, the promoter sequences and *cis*-acting elements of each stress-inducible gene can be studied on the basis of full-length cDNA sequences. Table 2 summarizes ABRE, DRE and CCGAC core sequences observed in the 19 drought, cold and high-salinity stress-inducible genes identified by the cDNA microarray analysis. Among these, 16 genes (84%) contain DRE (TACCGACAT) or DRE-related CCGAC core motif in their promoters (Shinozaki and Yamaguchi-Shinozaki, 2000; Thomashow, 1999; Yamaguchi-Shinozaki and Shinozaki, 1994), suggesting that the 16 genes were regulated by the DREB1/CBF or DREB2 transcription factors. Also, 15 genes (79%) contained ABRE

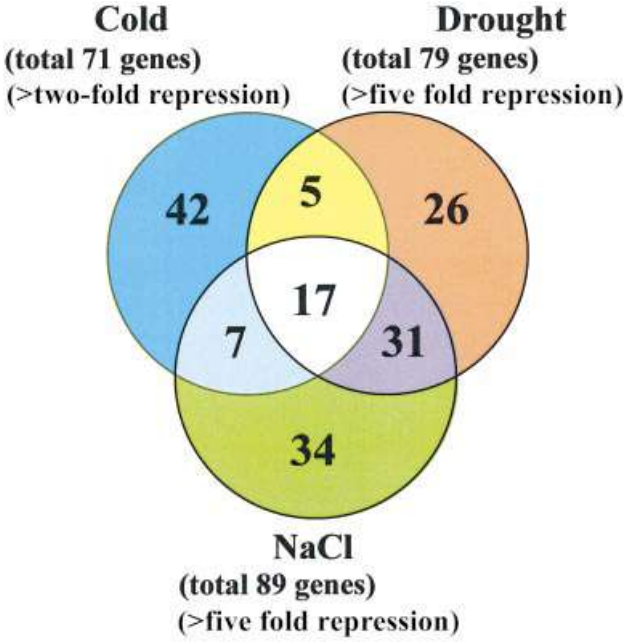

Figure 5. Classification of the drought, cold or high-salinity stress-downregulated genes identified on the basis of microarray analyses.
The drought, cold or high-salinity stress-downregulated genes were grouped in the following seven groups: (1) highly cold-stress-downregulated genes; (2) highly drought-stress-downregulated genes; (3) highly high-salinity stress-downregulated genes; (4) drought, cold and high-salinity-stress-downregulated genes; (5) genes that were highly downregulated by drought and high-salinity stress; (6) genes that were highly downregulated by drought and cold stress; and (7) genes that were highly downregulated by cold and high-salinity stress. A list of the genes is available as supplementary material (Tables S4 and S5).

(PyACGTG(T/G)C) in their promoters, suggesting that they were ABA-inducible.

We identified 53 cold-inducible genes in this study and obtained the promoter sequence for 41 genes. Among these, nine genes (RAFL07-18-O08, DREB1A, RAFL06-16-M17, RAFL08-17-G11, RAFL05-14-E16, RAFL05-20-O23, DREB2A, RAFL05-11-G05 and RAFL06-15-O23) did not contain DRE or DRE-related CCGAC core motif in their promoters. These results suggest the existence of novel *cis*-acting elements involved in cold-inducible gene expression.

Among the 351 drought, cold or high-salinity stress-inducible genes, we constructed a promoter database on 279 genes. Data on ABRE, DRE and CCGAC core sequences observed in the promoter regions of the 279 genes are available as supplementary material (Table S3).

Drought, cold or high-salinity stress-downregulated genes

Analysis of stress-downregulated as well as stress-upregulated genes is important in understanding molecular responses to abiotic stresses. In this study, we regarded the cDNAs as stress-downregulated genes whose expression levels are less than one-fifth in at least one time-course point during drought or high-salinity stress treatment than in wild-type unstressed plants. As for cold stress-downregulated genes, we found 0 and 4 cDNAs with expression ratio (cold/unstressed) less than one-fifth and one-third, respectively, in at least one time-course-point. Therefore, in this study we regarded the cDNAs as cold-downregulated genes whose expression level is less than half in at least one time-course-point in cold-treated plants than in wild-type unstressed plants. A total of 79, 89 and 71 genes were identified as drought, high-salinity and cold stress-downregulated genes by microarray analysis (Figure 5; Table 1). The list and expression data on these drought, cold or high-salinity stress-downregulated genes is available as supplementary material (Table S4). The drought, cold or high-salinity stress-downregulated genes were classified into groups on the basis of their expression profiles (Figure 5). The results of the classification are available as supplementary material (Table S5). Among the drought, cold or high-salinity stress-downregulated genes, we found many photosynthesis-related genes such as ribulose 1,5-bisphosphate carboxylase small subunit (*rbcS*); chlorophyll *a*/*b*-binding protein (*cab*); and the components of photosystems I and II (Table 1; Table S4). These results are consistent with a previous report that water stress inhibits photosynthesis (Tezara *et al.*, 1999).

Conclusions and perspectives

In the present study we identified 277 drought-inducible, 53 cold-inducible, and 194 high-salinity stress-inducible genes. These results show that full-length cDNA microarray analysis is a powerful tool for the identification of stress-inducible genes. We first compared the signalling cascades of the three abiotic stresses (drought, cold and high-salinity stress) using a global expression-profiling technique. Our results indicated the existence of greater cross-talk between drought and high-salinity stress signalling processes than between cold and high-salinity stress signalling processes.

Using our full-length cDNA microarray, it is easy to isolate full-length cDNAs for further functional analysis. Biochemical characteristics of the gene products are easily analysed from overexpression of the full-length cDNAs in bacteria or yeast. Functions of the gene products *in planta* can be analysed by overexpression of full-length cDNAs in transgenic plants. Moreover, promoter sequences and putative *cis*-acting elements of each gene can be predicted by comparing full-length cDNA sequences with the *Arabidopsis* genomic sequence. We are planning to isolate more than 15 000 independent *Arabidopsis* full-length cDNAs and prepare a new cDNA microarray using the cDNA clones for identifying new stress-inducible genes,

Table 2. ABRE, DRE and CCGAC core sequences [a]observed in the promoter regions of the drought, cold and high-salinity-stress-inducible genes [b]identified by microarray analysis.

Gene	ABRE (PyACGTG(T/G)C)	DRE (TACCGACAT)	CCGAC Core Motif (CCGAC)
RAFL04-10-D13	GACGTGGC (−99 to −106)[c]		AGCCGACAT (−128 to −120)
			TTCCGACAC (−65 to −73)
RAFL04-12-F24			AGCCGACAT (−340 to −348)
			CGCCGACAT (−201 to −209)
RAFL04-17-F01	TACGTGTC (−66 to −59)	TACCGACAT (−226 to −218)	GACCGACTA (−276 to −268)
		TACCGACAT (−169 to −161)	AGCCGACAC (−132 to −124)
RAFL04-20-N09	TACGTGTC (−920 to −913)		GACCGACAT (−996 to −988)
			AGCCGACCA (−967 to −959)
			TACCGACTT (−162 to −154)
RAFL05-03-A05	CACGTGGC (−132 to −125)		GGCCGACAT (−361 to −353)
			GGCCGACCT (−184 to −176)
			AACCGACAA (−416 to −424)
RAFL05-08-P17	GACGTGGC (−998 to −991)		GACCGACAT (−966 to −958)
	CACGTGGC (−805 to −798)		CACCGACCG (−173 to −165)
			GACCGACCG (−169 to −161)
			GACCGACGT (−165 to −157)
RAFL05-10-J09	CACGTGGC (−897 to −904)	TACCGACAT (−754 to −762)	GACCGACAG (−869 to −861)
	AACGTGGC (−736 to −743)		
RAFL05-14-E16	TACGTGTC (−141 to −134)		
RAFL05-19-G24	CACGTGGC (−82 to −89)		GACCGACTT (−674 to −666)
RAFL05-19-O22			GACCGACCC (−114 to −106)
RAFL05-20-O23	CACGTGGC (−90 to −83)		
RAFL05-21-F13	TACGTGTC (−799 to −806)		TGCCGACTC (−71 to −63)
			AACCGACCG (−224 to −232)
			GACCGACGT (−132 to −140)
RAFL06-08-N16		TACCGACAT (−120 to −112)	ATCCGACAT (−719 to −711)
RAFL06-16-B22	CACGTGGC (−74 to −67)	TACCGACAT (−415 to −407)	TGCCGACAT (−806 to −798)
	CACGTGGC (−69 to −76)		
RAFL08-11-P07	CACGTGGC (−232 to −239)		CGCCGACAT (−326 to −318)
			GGCCGACAT (−140 to −132)
RAFL08-15-M21			GACCGACAC (−71 to −63)
			TGCCGACAT (−155 to −163)
RAFL08-19-H17	AACGTGGC (−990 to −983)		GACCGACCG (−211 to −203)
			GACCGACAT (−207 to −199)
RAFL04-17-B12[d]	CACGTGGC (−79 to −72)	TACCGACAT (−138 to −130)	
DREB2A[d]	TACGTGTC (−817 to −824)		
	TACGTGTC (−108 to −115)		

[a]ABRE, DRE, and CCGAC core sequences observed in 1000 bp upstream regions of the 5′ termini of the cDNA clones isolated are listed.
[b]These genes represent those whose expression ratio is more than fivefold for drought, cold and high-salinity stress treatments.
[c]Numbers in parentheses indicate the nucleotide beginning at the 5′ terminus of the cDNA clone isolated. Minus signs indicate that the nucleotide exists upstream of the 5′ terminus of the putative transcription start site.
[d]The promoter sequences of the RAFL04-17-B12 and DREB2A were analysed using the cDNA sequences of kin2 (GenBank accession number: X55053) and DREB2A (GenBank accession number: AB007790), respectively.The promoter sequences of the following cDNA clones were not analysed because we have not obtained the 5′-end sequences as of June 1 2001: RAFL04-09-B07, RAFL05-17-B13 and RAFL08-08-L20.

new hormone-inducible genes, new tissue-specific-expressed genes, and new target genes of stress-related transcription factors.

In this study we identified many stress-inducible genes. However, the functions of many remain unknown. It is important to analyse function of the stress-inducible genes, not only for further understanding of the molecular mechanisms of stress tolerance and responses of higher plants, but also for improving the stress tolerance of crops by gene manipulation. Full-length cDNAs are useful resources for transgenic analyses, such as overexpression (Jaglo-Ottosen *et al.*, 1998; Kasuga *et al.*, 1999; Liu *et al.*, 1998); antisense suppression (Huang *et al.*, 1999; Nanjo *et al.*, 1999); and double-stranded RNA interference (RNAi) (Chuang and Meyerowitz, 2000; Smith *et al.*, 2000). Therefore we will apply the identified full-length cDNAs

to the transgenic analyses and biochemical analyses of the encoded proteins.

Experimental procedures

Plant materials, stress treatments and RNA isolation

Arabidopsis thaliana (Columbia ecotype) was germinated and grown on germination medium (GM) containing Murashige and Skoog salts, 3% sucrose (WAKO, Osaka, Japan), and 0.8% Bacto-agar (Difco, Detroit, MI). The plants were grown for 3 weeks in a growth chamber at 22°C under 16 h light/8 h dark. Dehydration, cold and high-salinity stress treatments were applied essentially as reported previously (Yamaguchi-Shinozaki and Shinozaki, 1994). For dehydration treatments, plants were removed from the agar and desiccated in plastic dishes at 22°C under dim light (0.7–0.8 μmol sec^{-1} m^{-2}). For cold treatments, plants were grown under dim light (0.7–0.8 μmol sec^{-1} m^{-2}) at 4°C. For high-salinity stress treatments, plants were transferred to and grown hydroponically in water containing 250 mM NaCl under dim light (0.7–0.8 μmol sec^{-1} m^{-2}). The plants were subjected to stress treatments for various periods (1, 2, 5, 10 and 24 h), then frozen in liquid nitrogen for further analyses. Total RNA was prepared using TRIZOL Reagent (Life Technologies, Rockville, MD), and mRNA was prepared using a mRNA isolation kit (Miltenyi Biotec, Auburn, CA, USA).

CDNA clones

In the cDNA microarray analyses, we used ≈7000 cDNA sequences representing RIKEN *Arabidopsis thaliana* full-length (RAFL) cDNA clones (Seki *et al.*, 2002) isolated from full-length cDNA libraries (Seki *et al.*, 1998); and the drought- and cold-inducible genes, *responsive to dehydration* (*rd*) and *early responsive to dehydration* (*erd*) (Taji *et al.*, 1999). As external controls, PCR-amplified fragment from lambda control template DNA fragment (TX803; Takara, Kyoto, Japan) was used. As negative control, two DNAs derived from the mouse nicotinic acetylcholine receptor epsilon-subunit (*nAChRE*) gene and the mouse glucocorticoid receptor homologue gene were used.

The RAFL cDNA clones whose full-length cDNA sequences are determined by the *Arabidopsis* SSP sequencing consortium, which comprises the Salk Institute (principal investigator Dr Joseph R. Ecker), the Stanford Genome Technology Center (principal investigator: Dr Ronald W. Davis), and the Plant Gene Expression Center (principal investigator: Dr Athanasios Theologis) are available from RIKEN Bioresource Center (Seki *et al.*, 2002).

Sequence analysis

The cDNA clones were grown in a 96-deep-well plate using a micro-incubator (TAITEC, Saitama, Japan). Plasmid DNA was extracted with DNA extraction instrument (model Biomek; Beckman Coulter, Tokyo, Japan) and purified using MultiScreen 96-well filter plates (Millipore, Bedford, MA). DNA sequences were determined using the dye terminator cycle sequencing method (Big Dye Terminator Cycle Sequencing Kit, Perkin-Elmer Applied Biosystems, Foster City, CA) with a DNA sequencer (model ABI Prism 3700; Perkin-Elmer). Sequence homologies were examined with the GenBank/EMBL database using the BLAST program.

Amplification of cDNA inserts

In the cDNA microarray analyses we used ≈7000 cDNA clones and the lambda control template DNA fragment (TX803; Takara) as an external control. As negative controls, DNA derived from the mouse nicotinic acetylcholine receptor epsilon-subunit (*nAChRE*) gene and the mouse glucocorticoid receptor homologue gene were used. The vectors used for cDNA library construction were modified lambda ZAP (Carninci *et al.*, 1996) and lambda FLC-1 (Carninci *et al.*, 2001). Inserts of cDNA clones were amplified by PCR using primers complementary to vector sequences flanking both sides of the cDNA insert, as described previously (Seki *et al.*, 2001a). PCR products were precipitated in ethanol and the DNA was resuspended at ≈2 μg μl^{-1} in TE buffer (10 mM Tris-HCl, pH 8.0, and 1 mM EDTA). One aliquot of each finished reaction was electrophoresed on a 0.7% agarose gel to confirm amplification quality and quantity. Two μl of DNA were mixed with 2 μl 2 × polymer (Fuji Photo Film Co., Kanagawa, Japan) and 4 μl dimethyl sulfoxide (DMSO) (Kishida Chemical Co., Osaka, Japan) at least 10 times using an automatic dispenser (model EDS-384S; Biotech Co., Ltd, Tokyo, Japan).

CDNA microarray preparation

PCR products were arrayed from 384-well microtitre plates onto a micro slide glass (model Super Aldehyde substrates; Telechem International Inc., Sunnyvale, CA) using the microarray stamping machine (model SPBIO2000; Hitachi Software Engineering Co. Ltd, Tokyo, Japan). Of the 2 μl of PCR products (500–1000 ng μl^{-1}) from 384-well microtitre plates, 0.5 nl was deposited per slide on 48 slides with a spacing of 300 μm. The slides were post-processed according to the manufacturer's protocol (Telechem International Inc.). The printed slides were dried (RH < 30%) and subjected to UV cross-linking. They were rocked in 0.2% SDS for 2 min three times and then rocked in distilled water for 2 min twice vigorously. The slide racks were transferred into a chamber containing boiling water and left for 2 min. The blocking solution containing 1 g sodium borohydride, 300 ml PBS (Life Technologies) and 90 ml 100% ethanol] was poured into the glass chamber. The slide racks were shaken gently for 5 min, then transferred into a chamber containing 0.2% SDS and shaken gently for 1 min three times. They were transferred into a chamber containing distilled water, shaken gently for 1 min, and dried by centrifugation for 20 min.

Microarray hybridization and scanning

Each mRNA sample was reverse-transcribed in the presence of Cy3-dUTP or Cy5-dUTP (Amersham Pharmacia, Piscataway, NJ). The reverse transcription reaction was performed in a 20 μl volume containing 1 μg denatured poly(A)$^+$ RNA with 1 ng lambda poly(A)$^+$ RNA-A (TX802; Takara) as an external control, 50 ng μl^{-1} oligo-(dT) 12–18-mer (Life Technologies); 0.5 mM each dATP, dGTP and dCTP; 0.2 mM dTTP; 0.1 mM Cy3 dUTP or Cy5 dUTP; 100 units RNase inhibitor; 10 mM DTT; and 200 units Superscript II reverse transcriptase (Life Technologies) in 1 × Superscript first-strand buffer (50 mM Tris–HCl pH 8.3, 75 mM KCl, 3 mM $MgCl_2$, 20 mM DTT) (Life Technologies). Following incubation at 42°C for 35 min, 200 units of Superscript II was added and the reaction sample was incubated for an additional 35 min. Following addition of 5 μl 0.5 M EDTA, 10 μl 1 N sodium hydroxide and 20 μl distilled water to stop the reaction and to degrade the template, they were incubated for 1 h

at 65°C. The solution was neutralized with 25 μl 1 M Tris–HCl pH 7.5. The reaction products of two samples (one with Cy3 labelling and the other with Cy5 labelling) were combined. The samples were placed in a Microcon 30 microconcentrator (Millipore). TE buffer (250 μl) was added and spun for 10 min in a benchtop microcentrifuge at high speed to a volume of 10 μl, and the flow-through product was discarded. This step was repeated four times. The probes were then collected by inverting the filter and spun for 5 min. Several microlitres of distilled water was added to the Microcon. The filter was inverted and spun so that the final volume of the collected probes was 18 μl. Then 5.1 μl 20 × SSC, 2.5 μl 2 μg μl^{-1} yeast tRNA and 4.8 μl 2% SDS were added to the probes. The probe samples were denatured by placing them in a 100°C heat block for 2 min, left at room temperature for 5 min, then used for hybridization. The slides were placed in a sealed hybridization cassette (Telechem International Inc.) and submerged in a 65°C water bath for 16–20 h. After hybridization, slides were washed in 2 × SSC, 0.03% SDS for 2 min, then in 1 × SSC for 2 min, and finally in 0.05 × SSC for 2 min. Then the slides were immediately dried by centrifugation (1 min at 2500 *g*). Slides were scanned with a ScanArray 4000 (GSI Lumonics, Oxnard, CA) as described previously (Seki *et al.*, 2001a).

Data analysis

For the microarray data analysis, image analysis and signal quantification were performed with QUANTARRAY version 2.0 (GSI Lumonics). Background fluorescence was calculated on the basis of the fluorescence signal of the negative control genes, the mouse nicotinic acetylcholine receptor epsilon-subunit (*nAChRE*) gene and the mouse glucocorticoid receptor homologue gene. Genes showing a signal value <1000 (typically twice the mean background value) in both Cy3 and Cy5 channels were not considered for the analyses. Lambda control template DNA fragment (TX803; Takara) was used as external control to equalize hybridization signals generated from different samples. Gene-clustering analysis was performed with the GENESPRING software (Silicon Genetics, San Carlos, CA).

RNA gel-blot analysis

Isolated total RNA was also used for RNA gel-blot hybridization. The isolated total RNA was denatured with the mixture of 2.15 M formaldehyde and 50% formamide, then fractionated by electrophoresis on a 1.0% agarose gel that contained 2.2 M formaldehyde according to the protocol described earlier (Maniatis *et al.*, 1982), and subsequently capillary transferred to nylon membrane using 20 × SSC. The membrane was probed with DIG-labelled antisense RNAs prepared by *in vitro* transcription using an RNA transcription kit (Roche Molecular Biochemicals, Mannheim, Germany) according to the manufacturer's protocol. The nylon membranes were washed twice with the mixture of 2 × SSC and 0.1% SDS for 5 min at room temperature, then twice with the mixture of 0.1 × SSC and 0.1% SDS for 15 min at 68°C and subjected to detection of DIG-labelled RNA probes using the DIG Chemiluminescent Detection Kit (Roche Molecular Biochemicals).

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Supplementary Material

The supplementary material is available from http://www.gsc.riken.go.jp/plant/index.html.

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GENOMICS ARTICLE

Metabolic Profiling Allows Comprehensive Phenotyping of Genetically or Environmentally Modified Plant Systems

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Metabolic profiling using gas chromatography–mass spectrometry technologies is a technique whose potential in the field of functional genomics is largely untapped. To demonstrate the general usefulness of this technique, we applied to diverse plant genotypes a recently developed profiling protocol that allows detection of a wide range of hydrophilic metabolites within a single chromatographic run. For this purpose, we chose four independent potato genotypes characterized by modifications in sucrose metabolism. Using data-mining tools, including hierarchical cluster analysis and principle component analysis, we were able to assign clusters to the individual plant systems and to determine relative distances between these clusters. Extraction analysis allowed identification of the most important components of these clusters. Furthermore, correlation analysis revealed close linkages between a broad spectrum of metabolites. In a second, complementary approach, we subjected wild-type potato tissue to environmental manipulations. The metabolic profiles from these experiments were compared with the data sets obtained for the transgenic systems, thus illustrating the potential of metabolic profiling in assessing how a genetic modification can be phenocopied by environmental conditions. In summary, these data demonstrate the use of metabolic profiling in conjunction with data-mining tools as a technique for the comprehensive characterization of a plant genotype.

INTRODUCTION

Enormous progress has been made over the last few years in the development of tools to create and characterize genetic diversity in plant systems. Transgenic knock-out populations, transposon insertions, chemical gene machines, and highly efficient ways to genotype single nucleotide polymorphisms within large populations have paved the way to a much broader base of diversity than imagined a few years ago (Aarts et al., 1993; Schaefer and Zryd, 1997; Strepp et al., 1998; Cho et al., 1999; Zhu et al., 1999). Furthermore, these developments have occurred in tandem with the elucidation of complete genomes and the rapid development of multiparallel technologies designed to access and describe the properties of biological systems (Celis et al., 2000). Most prominent among these new technologies has been the establishment of protocols for determining the expression levels of many thousands of genes in parallel, mRNA profiling. This is achieved by a process of mass hybridization reactions that use arrays of either expressed sequence tag or oligonucleotide collections representing large portions of the entire genome of the system in question (Lockhart et al., 1996; Ruan et al., 1998; Terryn et al., 1999; Aharoni et al., 2000; Richmond and Somerville, 2000). A second, albeit currently less advanced technology concerns the detection and quantification of the protein complement, or proteome, of a system (Shevchenko et al., 1996; Santoni et al., 1998; Chang et al., 2000).

Much attention has been focused on developing mRNA profiling and proteomic approaches, whereas the development of multiparallel techniques allowing analysis of the levels of low molecular weight compounds has been largely overlooked. This is true not only in plant sciences but across all biological disciplines, and thus this field is still in its infancy (Trethewey et al., 1999a). There are a few examples of this approach being applied to medical analyses (e.g., Duez et al., 1996; Matsumoto and Kuhara, 1996; Ning et al., 1996); however, only a handful of reports detail its application to plant systems (e.g., Adams et al., 1999; Katona et al., 1999).

We recently developed a method allowing the nonbiased, simultaneous, and rapid determination of metabolites in plants, using potato tubers or Arabidopsis as the experimental

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system. This technology, which combines gas chromatographic separation of compounds with a subsequent mass spectrometric identification, allows the simultaneous detection of >100 compounds within a single analysis (Fiehn et al., 2000; Roessner et al., 2000). In this article, the application of metabolic profiling to a variety of different genetically manipulated systems is described. We used various transgenic potato lines variously modified in sucrose metabolism as a first example for two main reasons. First, these lines have been extensively characterized previously by the use of classical biochemical approaches—a prerequisite that was important to authenticate data obtained from metabolic-profiling studies. Second, we specifically chose these examples because the applied genetic modifications targeted the same metabolic locus, that of sucrose degradation. This approach was taken to gain insight into the resolving power of metabolic profiling and to test its capacity to distinguish very similar situations.

In addition to presenting the results of our analyses and interpreting their physiological implications, we also describe the application of data-mining tools to the data set obtained. These tools include hierarchical clustering and principal component analysis, detection of the metabolites determining the clustering behavior of the grouped plants, and a comprehensive analysis of the correlations between all metabolites of the various plants studied. Finally, we extended this analysis to include environmental manipulations of wild-type tissue in an attempt to produce phenocopies of the applied genetic manipulations. The data shown demonstrate that the application of data-mining tools to metabolic-profiling analysis allows insight into the relatedness of certain genetic situations. Moreover, correlation analysis allows the confirmation of established hypotheses concerning metabolic interactions within these systems. We believe these data further illustrate the use of metabolic profiling as an additional tool in multiparallel system analysis and as such demonstrate its importance for functional genomics.

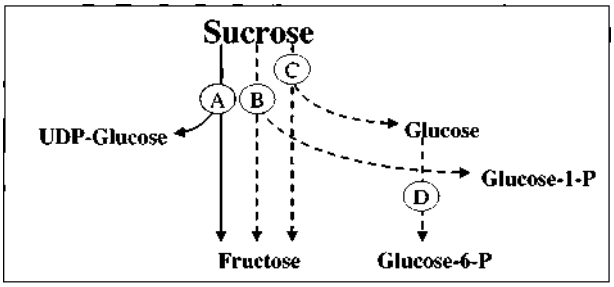

Figure 1. Substrates and Products of Endogenous and Introduced Reactions of Sucrose Catabolism within the Transgenic Potato Lines Studied.

The solid line (A) represents the plant's endogenous sucrose synthase, whereas the broken lines (B to D) represent the reactions catalyzed by the expression of a bacterial sucrose phosphorlase (SP lines), a yeast invertase (INV lines), and a bacterial glucokinase (expressed in combination with the yeast invertase; GK3 lines), respectively. Additional cofactors required for the reactions are UDP for sucrose synthase, Pi for sucrose phosphorylase, and ATP for glucokinase.

RESULTS

Confirmation of Transgene Expression and Primary Metabolic Characterization

We grew transgenic potato plants that had been altered in tuber sucrose catabolism, as explained in Figure 1, in parallel under identical greenhouse conditions and then harvested samples from developing tubers. We chose the following transgenic lines for this study because the primary metabolic changes in these lines are well documented: INV-30, INV-33, and INV-42 (Sonnewald et al., 1997; Riedel, 1999); GK3-41, GK3-29, and GK3-38 (Trethewey et al., 1998); and SP-2, SP-11, and SP-29 (Trethewey et al., 2001). The introduced enzyme activities observed in extracts from these plants were similar to those we have previously reported (data not shown). Having confirmed that the plants do indeed express heterologous enzymes, we decided to verify that the primary changes within the potato tubers were in accordance with those previously determined (Figures 2A to 2D; Sonnewald et al., 1997; Trethewey et al., 1998, 2001; Riedel, 1999); notably, glucose levels were not increased in lines INV-42 and GK3-38. We then determined the levels of the other possible products of sucrose catabolism—UDP-Glc, glucose-6-P, glucose-1-P, and fructose-6-P (Figures 2E to 2H). The levels of all these compounds were in close agreement to those determined previously (Trethewey et al., 1998, 2001; Riedel, 1999), and as such they documented the suitability of these lines for further study.

Comparison of Relative Metabolite Levels within the Transgenic Tubers

Having confirmed that the transgenic lines were suitable for further experimentation, we extracted replicate samples from the same plants used for the preliminary characterization and then separated and characterized the detectable hydrophilic metabolite complement using a recently established gas chromatography–mass spectrometry (GC-MS) protocol (Roessner et al., 2000). Because of the large sample size of this experiment, we extracted a separate set of wild-type samples per transgenic line, despite the fact that all plants were grown in parallel under identical conditions. This allowed us independent references for each individual machine run. Results from this analysis are presented in

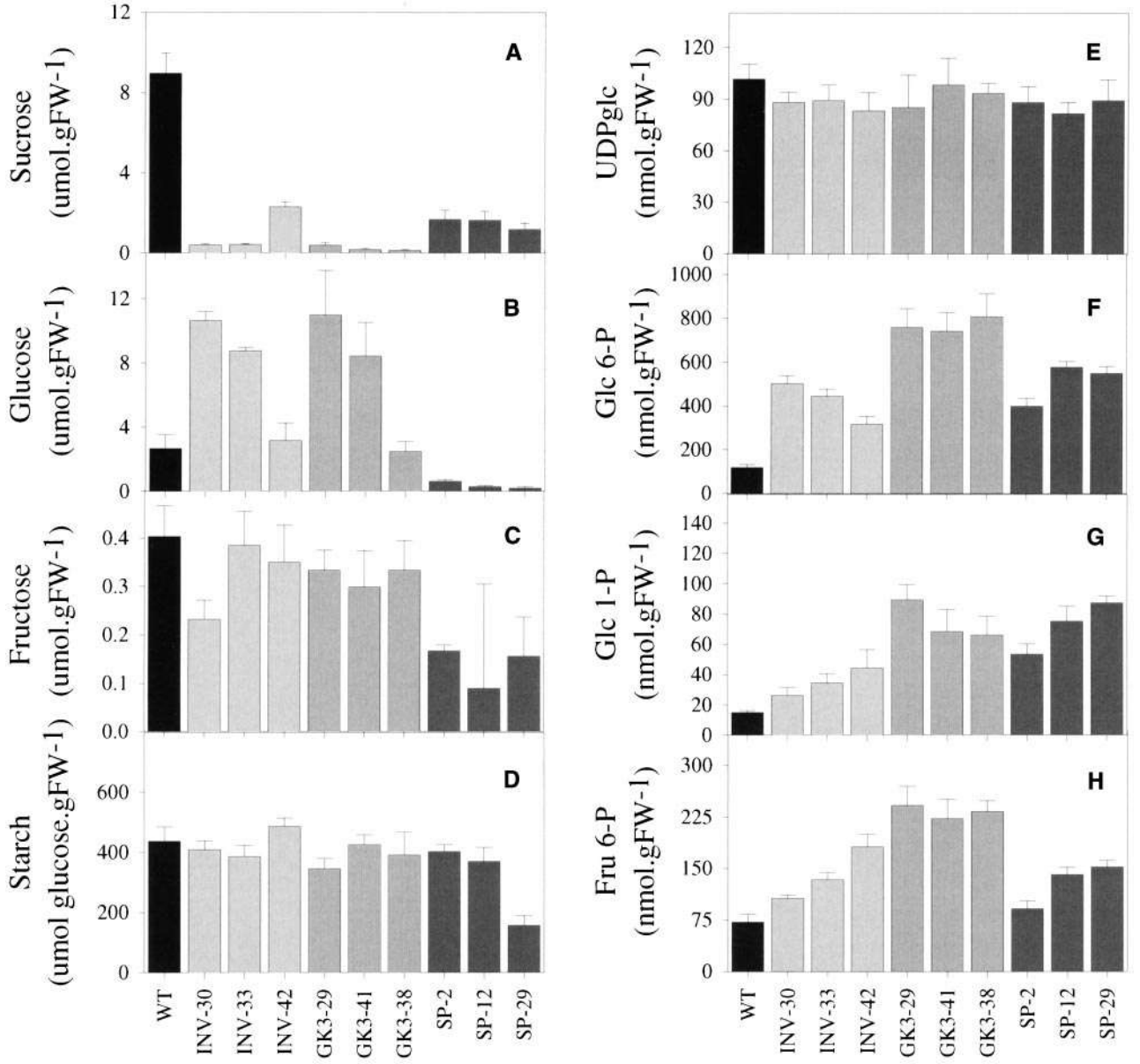

Figure 2. Sugar, Starch, and Sugar Phosphate Content of Transgenic Tubers.

Potato plants were grown in the greenhouse in 3.5-liter pots. Developing tubers were taken from plants harvested in the spring after 10 weeks of growth and while the plants were still fully green. Sucrose **(A)**, glucose **(B)**, fructose **(C)**, and starch content **(D)** were determined in extracts from six individual plants per line. UDP-Glc **(E)**, glucose-6-P **(F)**, glucose-1-P **(G)**, and fructose-6-P **(H)** were determined in extracts from four individual plants per line. All data are presented in μmol g^{-1} fresh weight and represent the mean $\pm$SE. FW, fresh weight.

Table 1; the data set contains 88 metabolites (61 of which were defined with respect to their chemical nature), including sugars, sugar alcohols, amino acids, organic acids, and several miscellaneous compounds.

The majority of the compounds detected were found to alter within the transgenic lines, in agreement with the data obtained using conventional spectrophotometric or HPLC methods (Figure 2; Trethewey et al., 1998, 1999b, 2001; Riedel, 1999). When taking mean values into consideration, we found that some interesting trends emerged (Table 1). In most

Table 1. Metabolite Levels in Wild-Type Developing Potato Tubers and in Tubers of Transgenic Potato Plants

	metabolites	WT	SE %	130	SE %	133	SE %	142	SE %	WT	SE %	GK 38	SE %
1	alanine	1.00	± 0.32	1.70	± 0.17	**2.43**	± **0.33**	2.06	± 0.35	1.00	± 0.16	**3.31**	± **0.16**
2	arginine	1.00	± 0.20	1.66	± 0.38	1.04	± 0.24	**1.99**	± **0.28**	1.00	± 0.20	**2.48**	± **0.39**
3	asparagine	1.00	± 0.19	1.31	± 0.14	1.06	± 0.09	1.57	± 0.20	1.00	± 0.05	1.21	± 0.07
4	aspartate	1.00	± 0.11	1.20	± 0.08	0.91	± 0.09	1.04	± 0.07	1.00	± 0.03	1.18	± 0.11
5	b-alanine	1.00	± 0.16	0.84	± 0.05	1.17	± 0.13	1.11	± 0.16	1.00	± 0.09	**1.35**	± **0.12**
6	cysteine	1.00	± 0.16	**2.17**	± **0.22**	**2.33**	± **0.41**	1.37	± 0.27	1.00	± 0.20	1.13	± 0.08
7	GABA	1.00	± 0.10	1.20	± 0.08	1.22	± 0.11	**1.40**	± **0.13**	1.00	± 0.13	0.79	± 0.05
8	glutamate	1.00	± 0.07	1.22	± 0.07	1.09	± 0.07	1.16	± 0.09	1.00	± 0.04	1.02	± 0.12
9	glutamine	1.00	± 0.26	0.39	± 0.17	0.76	± 0.20	1.17	± 0.22	1.00	± 0.16	0.65	± 0.14
10	glycine	1.00	± 0.19	0.87	± 0.07	0.93	± 0.13	0.88	± 0.10	1.00	± 0.06	**1.52**	± **0.12**
11	histidine		n.d.		n.d.		n.d		n.d.		n.d.	**585.33**	± **162.73**
12	*homocysteine*		n.d		n.d.		n.d		n.d		n.d		n.d.
13	*homoglutamine*		n.d		n.d.		n.d.		n.d.		n.d		n.d.
14	homoserine	1.00	± 0.12	**0.54**	± **0.09**	0.90	± 0.08	1.18	± 0.15	1.00	± 0.06	**0.46**	± **0.02**
15	isoleucine	1.00	± 0.19	1.00	± 0.14	0.98	± 0.14	1.07	± 0.05	1.00	± 0.23	0.93	± 0.19
16	leucine	1.00	± 0.32	1.22	± 0.23	1.11	± 0.19	1.03	± 0.06	1.00	± 0.44	1.27	± 0.22
17	lysine	1.00	± 0.16	**0.50**	± **0.11**	**0.51**	± **0.08**	0.94	± 0.06	1.00	± 0.25	0.70	± 0.14
18	methionine	1.00	± 0.13	0.84	± 0.10	0.84	± 0.11	1.26	± 0.11	1.00	± 0.14	0.89	± 0.13
19	norleucine	1.00	± 0.12	**0.60**	± **0.13**	**0.60**	± **0.08**	**0.51**	± **0.04**	1.00	± 0.24	0.77	± 0.14
20	norvaline	1.00	± 0.14	0.66	± 0.07	**0.57**	± **0.06**	**0.46**	± **0.05**	1.00	± 0.12	**0.62**	± **0.06**
21	ornithine	1.00	± 0.30	0.96	± 0.22	**1.17**	± **0.23**	2.04	± 0.32	1.00	± 0.13	**1.90**	± **0.28**
22	5-oxoproline	1.00	± 0.18	0.78	± 0.11	0.84	± 0.19	0.99	± 0.15	1.00	± 0.06	1.02	± 0.09
23	phenylalanine	1.00	± 0.20	**1.73**	± **0.16**	1.18	± 0.16	1.17	± 0.09	1.00	± 0.13	**1.69**	± **0.15**
24	proline	1.00	± 0.18	0.69	± 0.07	1.05	± 0.09	1.20	± 0.12	1.00	± 0.08	**1.53**	± **0.18**
25	serine	1.00	± 0.20	**2.84**	± **0.19**	**2.80**	± **0.22**	**2.44**	± **0.22**	1.00	± 0.08	**4.02**	± **0.48**
26	threonine	1.00	± 0.21	0.69	± 0.10	1.05	± 0.11	1.19	± 0.10	1.00	± 0.09	1.26	± 0.16
27	tryptophan		n.d	**459.83**	± **215.72**	**244.00**	± **28.56**	**390.50**	± **56.50**	1.00	± 0.45	**17.48**	± **4.26**
28	tyrosine	1.00	± 0.26	1.94	± 0.32	0.87	± 0.19	**1.34**	± 0.16	1.00	± 0.49	**5.04**	± **0.66**
29	valine	1.00	± 0.14	0.84	± 0.06	1.01	± 0.09	1.01	± 0.08	1.00	± 0.07	0.87	± 0.10
1	ascorbate	1.00	± 0.31	0.68	± 0.24	0.76	± 0.16	**1.46**	± 0.09	1.00	± 0.11	**2.39**	± **0.50**
2	citrate	1.00	± 0.03	1.07	± 0.05	1.12	± 0.06	**1.03**	± **0.03**	1.00	± 0.03	0.94	± 0.07
3	fumarate	1.00	± 0.31	0.30	± 0.03	**0.24**	± **0.02**	**0.23**	± **0.03**	1.00	± 0.12	**0.36**	± **0.05**
4	glucuronate		n.d		n.d.		n.d.		n.d.	1.00	± 0.11	**0.03**	± **0.00**
5	glutarate		n.d	**74.00**	± **5.70**	**38.83**	± **4.24**	**24.00**	± **1.75**		n.d.		n.d.
6	glycerate	1.00	± 0.08	**6.64**	± **0.44**	**5.69**	± **0.59**	**3.54**	± **0.74**	1.00	± 0.08	**6.33**	± **0.52**
7	isocitrate	1.00	± 0.10	0.73	± 0.06	1.04	± 0.19	**1.46**	± **0.13**	1.00	± 0.07	**0.42**	± **0.07**
8	malate	1.00	± 0.19	**1.92**	± **0.21**	**1.96**	± **0.30**	0.64	± 0.12	1.00	± 0.06	**1.85**	± **0.17**
9	oxalate		n.d		n.d		n.d.		n.d.	1.00	± 0.27	**11.28**	± **1.37**
10	quinate	1.00	± 0.12	**1.35**	± **0.09**	1.27	± 0.12	**1.51**	± **0.12**	1.00	± 0.10	0.78	± 0.03
11	shikimate	1.00	± 0.17	2.70	± 0.21	2.32	± 0.58	1.50	± 0.28	1.00	± 0.08	0.64	± 0.17
12	succinate	1.00	± 0.21	**2.24**	± **0.19**	2.14	± 0.58	1.63	± 0.26	1.00	± 0.18	**2.53**	± **0.39**
13	threonate	1.00	± 0.13	**1.38**	± **0.08**	1.16	± 0.11	0.91	± 0.10	1.00	± 0.06	1.24	± 0.14
1	fructose	1.00	± 0.44	1.82	± 0.52	5.67	± 3.80	0.81	± 0.13	1.00	± 0.19	6.01	± 2.55
2	galactose	1.00	± 0.35	0.60	± 0.17	0.63	± 0.16	0.25	± 0.09	1.00	± 0.16	**0.17**	± **0.03**
3	glucose	1.00	± 0.41	**4.23**	± **0.57**	**3.58**	± **0.62**	0.75	± 0.47	1.00	± 0.17	2.20	± 1.33
4	glycerol		n.d.		n.d		n.d.		n.d	1.00	± 0.12	**0.02**	± **0.00**
5	inositol	1.00	± 0.11	**0.16**	± **0.01**	**0.26**	± **0.04**	**0.49**	± **0.06**	1.00	± 0.20	**0.40**	± **0.06**
6	*ribonolactose*		n.d.	**17.00**	± **2.05**		n.d.		n.d.		n.d.		n.d.
7	*maltitol*		n.d.	**710.33**	± **105.64**	**384.00**	± **37.95**		n.d.		n.d.	**134.00**	± **40.13**
8	*maltose*		n.d.	**9256.83**	± **1107.27**	**3834.00**	± **621.48**		n.d		n.d	**1979.00**	± **1053.58**
9	mannitol	1.00	± 0.08	**3.22**	± **0.23**	**2.75**	± **0.38**	1.12	± 0.13	1.00	± 0.04	**6.00**	± **0.53**
10	mannose	1.00	± 0.38	**7.02**	± **0.88**	**4.24**	± **0.74**	0.85	± 0.18	1.00	± 0.11	1.19	± 0.66
11	sucrose	1.00	± 0.25	**0.13**	± **0.02**	**0.26**	± **0.06**	**0.27**	± **0.02**	1.00	± 0.09	**0.04**	± **0.01**
12	*trehalose*		n.d.	**223.33**	± **32.78**	**114.17**	± **17.36**		n.d		n.d	**32.33**	± **7.34**
1	fructose-6-P	1.00	± 0.08	**22.26**	± **2.77**	**17.64**	± **2.70**	**5.52**	± **1.30**	1.00	± 0.10	**40.66**	± **10.85**
2	glucose-6-P	1.00	± 0.21	**17.62**	± **2.12**	**15.04**	± **2.21**	**4.90**	± **1.09**	1.00	± 0.08	**30.52**	± **7.62**
3	phosphoethanolamine	1.00	± 0.16	1.02	± 0.08	1.13	± 0.15	0.74	± 0.05	1.00	± 0.18	**2.97**	± **0.62**
4	*3-PGA*		n.d.	**89.89**	± **14.41**	**61.19**	± **11.90**	**39.11**	± **11.53**		n.d	**75.67**	± **21.68**
5	*6-P-gluconate*		n.d.	**479.33**	± **95.00**	**347.17**	± **59.43**	**213.00**	± **47.67**		n.d.	**177.50**	± **25.80**
6	phosphate	1.00	± 0.02	0.94	± 0.04	0.96	± 0.07	**0.83**	± **0.05**	1.00	± 0.03	0.88	± 0.07
	spermidine	1.00	± 0.11	**1.88**	± **0.09**	**1.59**	± **0.09**	**1.69**	± **0.14**	1.00	± 0.08	**1.33**	± **0.06**
1	UNKNOWN SP		n.d		n.d.		n.d		n.d		n.d.		n.d.
2	PT01	1.00	± 0.05	0.74	± 0.05	0.85	± 0.04	**0.61**	± **0.04**	1.00	± 0.05	0.73	± 0.10
3	PT02	1.00	± 0.10	1.33	± 0.14	1.11	± 0.12	1.25	± 0.13	1.00	± 0.22	**5.54**	± **0.59**
4	PT04	1.00	± 0.07	0.88	± 0.09	1.21	± 0.12	**0.70**	± **0.04**	1.00	± 0.10	0.82	± 0.11
5	PT05	1.00	± 0.14	1.14	± 0.08	0.92	± 0.07	0.77	± 0.04	1.00	± 0.05	1.16	± 0.14
6	PT06	1.00	± 0.13	1.13	± 0.11	1.05	± 0.08	1.48	± 0.16	1.00	± 0.09	1.23	± 0.12
7	PT07	1.00	± 0.35	0.54	± 0.18	0.93	± 0.26	1.74	± 0.42	1.00	± 0.19	2.12	± 0.57
8	PT08	1.00	± 0.05	**0.76**	± **0.03**	**0.76**	± **0.05**	0.95	± 0.06	1.00	± 0.10	0.73	± 0.14
9	PT09	1.00	± 0.14	**1.73**	± **0.16**	1.26	± 0.12	1.18	± 0.06	1.00	± 0.19	**1.94**	± **0.11**
10	PT10	1.00	± 0.23	0.54	± 0.07	0.83	± 0.14	1.00	± 0.19	1.00	± 0.14	1.13	± 0.21
11	PT11	1.00	± 0.12	**1.82**	± **0.08**	**1.56**	± **0.20**	1.15	± 0.13	1.00	± 0.04	**1.47**	± **0.05**
12	PT12	1.00	± 0.24	1.23	± 0.25	1.56	± 0.30	0.73	± 0.09	1.00	± 0.19	0.87	± 0.15
13	PT14	1.00	± 0.05	**1.67**	± **0.10**	1.50	± 0.11	**1.38**	± **0.07**	1.00	± 0.09	1.32	± 0.12
14	PT15	1.00	± 0.18	1.48	± 0.16	**1.66**	± **0.20**	**2.90**	± **0.43**	1.00	± 0.10	**2.02**	± **0.22**
15	PT16	1.00	± 0.19	**8.35**	± **0.61**	**6.66**	± **0.68**	2.05	± 1.04	1.00	± 0.33	2.90	± 1.38
16	PT17	1.00	± 0.22	1.41	± 0.17	2.26	± 0.60	2.65	± 0.57	1.00	± 0.14	**2.65**	± **0.38**
17	PT18	1.00	± 0.11	0.80	± 0.06	0.90	± 0.09	**0.64**	± **0.09**	1.00	± 0.13	0.77	± 0.16
18	PT19	1.00	± 0.41	**9.51**	± **1.17**	**6.92**	± **1.49**	0.89	± 0.57	1.00	± 0.27	2.47	± 1.54
19	PT20	1.00	± 0.02	**1.38**	± **0.13**	**1.34**	± **0.13**	0.94	± 0.08	1.00	± 0.07	1.03	± 0.04
20	PT21	1.00	± 0.20	**2.82**	± **0.33**	**2.17**	± **0.32**	0.90	± 0.12	1.00	± 0.05	**2.62**	± **0.32**
21	PT23	1.00	± 0.19	**1.94**	± **0.19**	1.35	± 0.15	1.52	± 0.12	1.00	± 0.32	**3.32**	± **0.31**
22	PT24	1.00	± 0.17	**2.15**	± **0.24**	**2.21**	± **0.18**	**2.98**	± **0.54**	1.00	± 0.05	**1.78**	± **0.09**
23	PT25	1.00	± 0.04	**1.50**	± **0.08**	**1.22**	± **0.06**	1.05	± 0.06	1.00	± 0.07	**1.49**	± **0.05**
24	PT26	1.00	± 0.06	**0.64**	± **0.05**	**0.71**	± **0.08**	**0.54**	± **0.05**	1.00	± 0.06	**0.68**	± **0.09**
25	PT27	1.00	± 0.06	**1.68**	± **0.06**	**1.37**	± **0.09**	0.97	± 0.05	1.00	± 0.03	1.09	± 0.03
26	PT32	1.00	± 0.09	1.12	± 0.06	1.38	± 0.15	1.01	± 0.06	1.00	± 0.06	1.04	± 0.12
27	PT33	1.00	± 0.15	**0.35**	± **0.04**	**0.47**	± **0.02**	**0.53**	± **0.05**	1.00	± 0.12	**0.20**	± **0.03**

Continued

Table 1. (continued).

		GK 29	SE %	GK 41	SE %	WT	SE %	SP 2	SE %	SP 12	SE %	SP 29	SE %
1	alanine	**3.00**	± **0.17**	**3.70**	± **0.43**	1.00	± 0.18	**2.04**	± **0.14**	**1.73**	± **0.19**	**2.13**	± **0.06**
2	arginine	**3.04**	± **0.39**	**2.02**	± **0.26**	1.00	± 0.16	**2.71**	± **0.29**	**2.64**	± **0.44**	**2.73**	± **0.44**
3	asparagine	1.05	± 0.05	1.01	± 0.09	1.00	± 0.33	1.26	± 0.51	1.12	± 0.26	1.14	± 0.43
4	aspartate	0.80	± 0.08	0.89	± 0.13	1.00	± 0.05	**0.76**	± **0.04**	0.89	± 0.03	**0.91**	± **0.04**
5	b-alanine	1.26	± 0.15	1.18	± 0.07	1.00	± 0.15	0.89	± 0.10	1.03	± 0.21	0.97	± 0.08
6	cystaine	1.79	± 0.33	2.21	± 0.51	1.00	± 0.15	**2.39**	± **0.42**	**2.62**	± **0.81**	**1.61**	± **0.13**
7	GABA	1.10	± 0.13	1.04	± 0.14	1.00	± 0.04	1.04	± 0.12	0.93	± 0.12	1.02	± 0.08
8	glutamate	**0.69**	± **0.05**	**0.57**	± **0.12**	1.00	± 0.03	0.90	± 0.07	0.96	± 0.05	**0.84**	± **0.04**
9	glutamine	1.08	± 0.16	1.03	± 0.14	1.00	± 0.26	0.82	± 0.27	0.76	± 0.18	0.85	± 0.19
10	glycine	**1.36**	± **0.12**	**1.88**	± **0.12**	1.00	± 0.12	1.00	± 0.11	1.00	± 0.16	1.08	± 0.06
11	histidine	**751.83**	± **266.65**	n.d.		1.00	± 0.32	1.41	± 0.35	2.01	± 0.32	**1.52**	± **0.32**
12	*homocystathe*	n.d.		n.d.		n.d.		n.d.		**10.00**	± **1.70**	**5.00**	± **0.88**
13	*homoglutamine*	n.d.		n.d.		n.d.		n.d.		**17.50**	± **5.00**	**11.50**	± **3.34**
14	homoserine	**0.37**	± **0.02**	**0.01**	± **0.00**	1.00	± 0.24	**0.01**	± **0.00**	**0.01**	± **0.00**	**0.84**	± **0.03**
15	isoleucine	0.82	± 0.09	**2.09**	± **0.19**	1.00	± 0.20	1.15	± 0.31	1.44	± 0.23	1.58	± 0.29
16	leucine	1.27	± 0.14	**3.35**	± **0.34**	1.00	± 0.37	1.62	± 0.55	1.94	± 0.44	2.45	± 0.68
17	lysine	0.64	± 0.05	0.83	± 0.10	1.00	± 0.26	1.31	± 0.32	1.75	± 0.27	**2.04**	± **0.36**
18	methionine	0.91	± 0.08	1.14	± 0.06	1.00	± 0.15	1.09	± 0.15	1.21	± 0.09	1.19	± 0.11
19	norleucine	0.83	± 0.16	1.64	± 0.24	1.00	± 0.14	1.05	± 0.33	1.44	± 0.26	1.49	± 0.27
20	norvaline	0.64	± 0.13	0.75	± 0.11	1.00	± 0.07	0.80	± 0.11	0.92	± 0.07	0.91	± 0.08
21	ornithine	2.22	± **0.29**	**3.15**	± **0.24**	1.00	± 0.36	1.52	± 0.35	2.79	± **0.93**	**3.53**	± **0.82**
24	5-oxoproline	0.97	± 0.07	**2.00**	± **0.26**	1.00	± 0.04	**4.83**	± **0.30**	**5.27**	± **0.30**	**4.65**	± **0.87**
22	phenylalanine	**1.67**	± **0.25**	**2.88**	± **0.06**	1.00	± 0.16	1.46	± 0.21	1.56	± 0.22	**1.57**	± **0.17**
23	proline	0.91	± 0.07	0.98	± 0.14	1.00	± 0.13	0.83	± 0.05	**0.63**	± **0.05**	**0.66**	± **0.07**
25	serine	**2.81**	± **0.20**	**3.04**	± **0.18**	1.00	± 0.13	**2.33**	± **0.15**	**1.98**	± **0.14**	**2.13**	± **0.39**
26	threonine	1.14	± 0.09	**1.46**	± **0.07**	1.00	± 0.11	0.98	± 0.10	1.12	± 0.13	1.23	± 0.13
27	tryptophan	**12.79**	± **2.24**	**14.56**	± **5.25**	1.00	± 0.39	**360.03**	± **103.84**	**488.21**	± **136.51**	**380.82**	± **113.52**
28	tyrosine	**3.69**	± **0.56**	**5.55**	± **0.52**	1.00	± 0.26	**2.96**	± **0.24**	**2.50**	± **0.28**	**2.58**	± **0.22**
29	valine	0.80	± 0.06	**1.29**	± **0.10**	1.00	± 0.07	0.95	± 0.08	0.95	± 0.06	0.97	± 0.08
1	ascorbate	**2.42**	± **0.46**	0.91	± 0.26	1.00	± 0.33	**2.53**	± **0.36**	**2.91**	± **0.28**	**2.07**	± **0.35**
2	citrate	1.00	± 0.03	**0.69**	± **0.08**	1.00	± 0.03	**0.82**	± **0.13**	1.07	± 0.02	**1.31**	± **0.04**
3	fumarate	**0.37**	± **0.07**	**0.52**	± **0.07**	1.00	± 0.15	**0.27**	± **0.02**	**0.32**	± **0.03**	**0.22**	± **0.01**
4	glucuronate	**1.60**	± **0.11**	**0.03**	± **0.00**	n.d.		n.d.		n.d.		n.d.	
5	glutarate	n.d.		n.d.		n.d.		n.d.		n.d.		n.d.	
6	glycerate	**7.27**	± **0.89**	**12.06**	± **1.56**	n.d.		**1255.17**	± **147.32**	**1087.50**	± **167.15**	**772.33**	± **129.86**
7	isocitrate	**0.30**	± **0.09**	**0.16**	± **0.03**	1.00	± 0.08	0.84	± 0.05	0.93	± 0.10	**0.70**	± **0.05**
8	malate	**1.51**	± **0.10**	**2.15**	± **0.28**	1.00	± 0.08	0.97	± 0.08	0.71	± 0.13	0.76	± 0.11
9	oxalate	**13.56**	± **1.87**	**9.04**	± **1.02**	1.00	± 0.16	**0.48**	± **0.11**	**3.81**	± **0.37**	**2.63**	± **0.43**
10	quinate	**0.65**	± **0.07**	**0.62**	± **0.07**	1.00	± 0.05	0.98	± 0.06	1.04	± 0.08	1.19	± 0.15
11	shikimate	1.21	± 0.17	0.95	± 0.08	1.00	± 0.12	0.71	± 0.15	0.80	± 0.11	0.67	± 0.13
12	succinate	**3.94**	± **0.56**	**3.23**	± **0.69**	1.00	± 0.20	**1.72**	± **0.20**	0.95	± 0.08	1.05	± 0.07
13	threonate	1.79	± 0.34	**1.91**	± **0.16**	1.00	± 0.04	0.90	± 0.07	**0.78**	± **0.07**	**0.74**	± **0.07**
1	fructose	**9.72**	± **2.01**	**3.13**	± **1.07**	1.00	± 0.15	**2.54**	± **0.42**	0.58	± 0.13	0.85	± 0.24
2	galactose	**0.43**	± **0.09**	**0.01**	± **0.00**	1.00	± 0.46	2.09	± 0.60	0.13	± 0.03	0.22	± 0.04
3	glucose	**11.70**	± **1.68**	**9.58**	± **2.54**	1.00	± 0.29	**0.16**	± **0.04**	**0.01**	± **0.00**	**0.02**	± **0.00**
4	glycerol	**0.02**	± **0.00**	**0.02**	± **0.00**	1.00	± 0.08	0.92	± 0.02	**0.77**	± **0.05**	0.73	± 0.08
5	inositol	**0.19**	± **0.01**	**0.19**	± **0.05**	1.00	± 0.29	0.36	± 0.03	**0.20**	± **0.02**	**0.14**	± **0.01**
6	*isomaltose*	n.d.		n.d.		n.d.		n.d.		n.d.		n.d.	
7	*maltitol*	**331.17**	± **49.33**	**640.83**	± **39.29**	n.d.		n.d.		n.d.		n.d.	
8	*maltose*	**6216.00**	± **952.51**	**8136.00**	± **1456.91**	n.d.		n.d.		n.d.		n.d.	
9	mannitol	**4.03**	± **0.20**	**3.73**	± **0.38**	1.00	± 0.07	2.29	± 0.82	**3.64**	± **0.55**	**2.45**	± **0.11**
10	mannose	**5.50**	± **1.15**	**7.45**	± **1.44**	1.00	± 0.23	**0.26**	± **0.06**	**0.03**	± **0.00**	**0.03**	± **0.00**
11	sucrose	**0.04**	± **0.00**	**0.03**	± **0.00**	1.00	± 0.10	**0.13**	± **0.02**	**0.06**	± **0.01**	**0.09**	± **0.02**
12	trehalose	**149.00**	± **24.69**	**146.00**	± **16.74**	n.d.		n.d.		n.d.		n.d.	
1	fructose-6-P	**29.18**	± **1.26**	**11.77**	± **1.33**	1.00	± 0.08	**8.55**	± **1.06**	**4.38**	± **0.48**	**3.56**	± **0.33**
2	glucose-6-P	**23.49**	± **0.67**	**12.28**	± **0.68**	1.00	± 0.07	**14.96**	± **1.72**	**7.46**	± **0.79**	**7.18**	± **0.65**
3	phosphoethanolamine	**1.53**	± **0.13**	**1.57**	± 0.35	1.00	± 0.12	1.15	± 0.10	**1.35**	± **0.14**	0.95	± 0.07
4	3-PGA	**47.17**	± **8.84**	n.d.		1.00	± 0.04	**2.85**	± **0.16**	**3.82**	± **0.30**	**2.12**	± **0.13**
5	*6-P-gluconate*	**192.83**	± **41.72**	n.d.		n.d.		n.d.		**321.17**	± **31.60**	**197.33**	± **40.23**
6	phosphate	0.84	± 0.06	**0.57**	± **0.09**	1.00	± 0.03	**0.42**	± **0.06**	1.04	± 0.03	1.07	± 0.01
	spermidine	**1.49**	± **0.04**	0.77	± 0.08	1.00	± 0.01	1.07	± 0.06	0.90	± 0.08	**0.66**	± **0.04**
1	UNKNOWN SuPho	n.d.		n.d.		n.d.		**6405.83**	± **662.91**	**5114.50**	± **566.20**	**2987.17**	± **677.50**
2	PT01	**8.63**	± **0.02**	**0.88**	± **0.05**	1.00	± 0.07	**0.71**	± **0.03**	**0.43**	± **0.04**	**0.43**	± **0.03**
3	PT02	**6.65**	± **0.85**	**6.00**	± **0.54**	1.00	± 0.11	**3.38**	± **0.44**	**4.16**	± **0.49**	**9.17**	± **0.60**
4	PT04	**0.74**	± **0.04**	**1.47**	± 0.19	1.00	± 0.06	**0.82**	± **0.04**	**0.55**	± **0.02**	**0.49**	± **0.03**
5	PT05	**0.70**	± **0.06**	0.81	± 0.16	1.00	± 0.14	**0.34**	± **0.04**	**0.53**	± **0.09**	**0.41**	± **0.03**
6	PT06	1.05	± 0.07	**2.35**	± **0.27**	1.00	± 0.09	0.90	± 0.09	1.22	± 0.12	0.91	± 0.10
7	PT07	**2.39**	± **0.50**	**4.92**	± **0.32**	1.00	± 0.22	1.17	± 0.18	**2.86**	± **0.71**	**8.66**	± **1.67**
8	PT08	**0.54**	± **0.03**	**0.35**	± **0.03**	1.00	± 0.06	**0.01**	± **0.00**	**0.01**	± **0.00**	**0.01**	± **0.00**
9	PT09	**1.63**	± **0.22**	**3.92**	± **0.32**	1.00	± 0.12	**1.69**	± **0.26**	**1.86**	± **0.26**	**2.08**	± **0.22**
10	PT10	1.00	± 0.14	**1.94**	± **0.17**	1.00	± 0.08	**0.54**	± **0.06**	**0.55**	± **0.07**	**0.53**	± **0.07**
11	PT11	**1.89**	± **0.08**	**1.62**	± **0.14**	1.00	± 0.06	**1.59**	± **0.07**	**1.66**	± **0.07**	**1.02**	± **0.09**
12	PT12	1.39	± 0.11	0.77	± 0.12	1.00	± 0.15	**0.51**	± **0.08**	**0.56**	± **0.05**	**0.35**	± **0.03**
13	PT14	**1.43**	± **0.08**	**2.20**	± **0.22**	1.00	± 0.09	**1.30**	± **0.06**	1.23	± 0.10	1.11	± 0.10
14	PT15	**2.39**	± **0.25**	**7.21**	± **0.86**	1.00	± 0.12	**1.66**	± **0.17**	**5.07**	± **0.84**	**11.91**	± **1.76**
15	PT16	**20.10**	± **2.56**	10.59	± 4.41	1.00	± 0.28	0.53	± 0.16	**0.01**	± **0.00**	**0.01**	± **0.00**
16	PT17	**5.45**	± **1.10**	**9.24**	± **1.92**	1.00	± 0.24	0.52	± 0.10	0.99	± 0.13	**0.36**	± **0.06**
17	PT18	**0.58**	± **0.04**	**0.44**	± **0.02**	1.00	± 0.06	**0.65**	± **0.04**	**0.42**	± **0.04**	**0.41**	± **0.04**
18	PT19	**13.54**	± **2.94**	**25.79**	± **4.93**	1.00	± 0.14	**0.29**	± **0.02**	**0.14**	± **0.01**	**0.14**	± **0.03**
19	PT20	**1.32**	± **0.09**	1.16	± 0.08	1.00	± 0.03	1.14	± 0.08	1.14	± 0.09	0.96	± 0.11
20	PT21	**2.17**	± **0.12**	**2.74**	± **0.21**	1.00	± 0.08	**2.49**	± **0.24**	**1.48**	± **0.11**	1.21	± 0.10
21	PT23	**2.45**	± **0.31**	**7.29**	± **0.80**	1.00	± 0.21	**3.26**	± **0.46**	**3.42**	± **0.55**	**3.52**	± **0.40**
22	PT24	**2.32**	± **0.24**	**2.45**	± **0.59**	1.00	± 0.08	**1.74**	± **0.14**	**5.58**	± **0.43**	**4.67**	± **0.45**
23	PT25	**1.74**	± **0.24**	1.18	± 0.08	1.00	± 0.06	**1.33**	± **0.05**	1.34	± 0.14	0.91	± 0.05
24	PT26	**0.53**	± **0.04**	**0.42**	± **0.02**	1.00	± 0.05	0.91	± 0.04	**0.66**	± **0.06**	**0.66**	± **0.04**
25	PT27	**1.38**	± **0.06**	0.92	± 0.09	1.00	± 0.04	0.92	± 0.03	**0.79**	± **0.06**	**0.59**	± **0.04**
26	PT32	0.99	± 0.07	0.95	± 0.06	1.00	± 0.05	0.98	± 0.07	1.07	± 0.08	0.93	± 0.03
27	PT33	**0.32**	± **0.04**	0.23	± **0.04**	1.00	± 0.07	**0.95**	± **0.03**	**0.29**	± **0.02**	**0.21**	± **0.01**

Metabolites were determined using the same samples from developing tubers as those used to measure starch, sugars, and sugar phosphates, as presented in Figure 2. Data are normalized to the mean response calculated for the wild type (WT) of each measured batch. (So that measured batches could be compared, individual wild-type values were normalized in the same way.) Values presented are the mean ±SE of six independent determinants. Those that are significantly different from the wild type are identified in boldface. n.d. indicates compounds that were not determined in a particular set of chromatograms.

instances, metabolite levels in the transgenics increased, which was consistent with the increased respiratory flux observed in these transgenics (Trethewey et al., 1998, 2001). Strikingly, but perhaps not surprisingly, the metabolite levels within several pathways tended to increase in tandem. Such concerted increases were exemplified by the amino acids, that is, the aromatic amino acids (phenylalanine, tryptophan, and tyrosine), all of which derive from shikimate, and also those deriving from 3-PGA (cysteine and serine). A further example was the coupled increase between arginine and ornithine; however, in this instance, the trend was not absolute. In contrast, when the data set for intermediates of the tricarboxylic acid cycle was considered, the novel finding that changes in the individual metabolites do not correlate became apparent. Succinate and malate levels generally increased, whereas the levels of citrate, isocitrate, and fumerate generally decreased. Because these trends are observable in the mean values, it is clear that a nonbiased correlation analysis that takes into account every single value within an independent sample may prove more revealing.

Appearance of Novel Metabolites in Chromatograms from Transgenic Tubers

On first glance at the chromatograms, it became clear that several compounds were present in the transgenic lines that had not been detected in the chromatograms of wild-type tissue (data not shown). On inspection of the calibrated data, this observation was confirmed: nine of the 88 metabolites presented in Table 1 were below the level of detection in wild-type tubers. Some of these metabolites were observed in all of the transgenic types studied, whereas others were only present for a certain transgenic manipulation or even for a single transgenic line. In the first category are gluterate and 6-phosphogluconate. In contrast, maltose, trehalose, and maltitol become detectable in only INV and GK lines, whereas homoglutamine and homocysteine become detectable exclusively within SP lines. Isomaltose was only detected in line INV-30. In addition, an unknown peak, PT00, which is bigger in magnitude than that of sucrose, appears in the SP lines. It is conceivable that this peak is the result of a side reaction catalyzed by sucrose phosphorylase, and the mass spectrum suggests that it contains a glucosyl residue. This observation is consistent with the findings of Kitao and co-workers, who performed detailed characterization of the side reactions of sucrose phosphorylase from *Leuconostoc mesenteroides* (Kitao and Sekine, 1994a, 1994b) and found that this enzyme was also capable of transferring glycosyl residues to a wide range of acceptors. Unfortunately, when we analyzed the following commercially available compounds (found to be products or constituents of products of the sucrose phosphorylase in *L. mesenteroides*)—arbutin, catechin-glucosides, kojic acid, kojibiose, and nigerose—none of them co-eluted with the unknown peak. The final elucidation of the exact chemical structure therefore requires further study.

Hierarchical Cluster Analysis and Principle Component Analysis of Steady State Metabolite Concentrations in the Transgenic Tubers

It is clear from the preceding paragraphs that analysis of such a large data set is a daunting task. It is even more so when the genetic diversity in question is centered around primary carbohydrate metabolism and the number of changes in steady state metabolite pool size is as large as that observed here (Figure 2 and Table 1). For this reason, we decided to apply bioinformatic tools to our data set. Given that there is a fair degree of natural variation between samples for many of the metabolites in question, we chose to plot all individual chromatograms rather than the mean values presented in Table 1 to assess whether individual transformants and/or transgenics exhibited similar behavior with respect to their total metabolic profile. When we applied hierarchical cluster analysis (HCA) to our data set, as shown in Figure 3, we found that all 18 wild-type samples clustered as a single distinct group; likewise, all the GK3 and SP lines clustered by both the nature of the transformation and the magnitude of the introduced activity. In contrast, the INV lines did not cluster in the same manner; rather, INV-30 and INV-33 formed a single cluster that was closer to the GK3 lines than to the wild type, whereas INV-42 was closest to the wild type. The fact that INV-42 is the line closest to the wild type is interesting in that it is also the line that exhibits the lowest invertase activity.

We then took a second, complementary approach of applying principle component analysis (PCA) to our data set. PCA uses an *n*-dimensional vector approach to separate samples on the basis of the cumulative correlation of all metabolite data and then identifies the vector that yields the greatest separation between samples. The results from the chosen vector were then displayed in two dimensions (Figure 4A). Once again, wild-type tubers constituted a single cluster, and INV-42 samples clustered independently of all other lines. Furthermore, the SP lines formed a distinct cluster, and differences between individual samples of the SP lines appeared to be related to the activity of the introduced enzyme. However, contrary to the observations made using HCA, the GK lines and INV-33 and INV-30 were not too distinct, and considerable overlap between INV-30 and all the GK3 lines (to which it served as a parental line) exists. That said, within each cluster of transgenics, subclusters that represent individual transgenic plants can be easily recognized. When taken together, the results from both types of cluster analysis are in close agreement, with the exception of the resolution of INV-30, INV-33, and GK3 lines, and indicate that despite the fact that sucrose phosphorylase acts on the same target molecule as does invertase, plants ex-

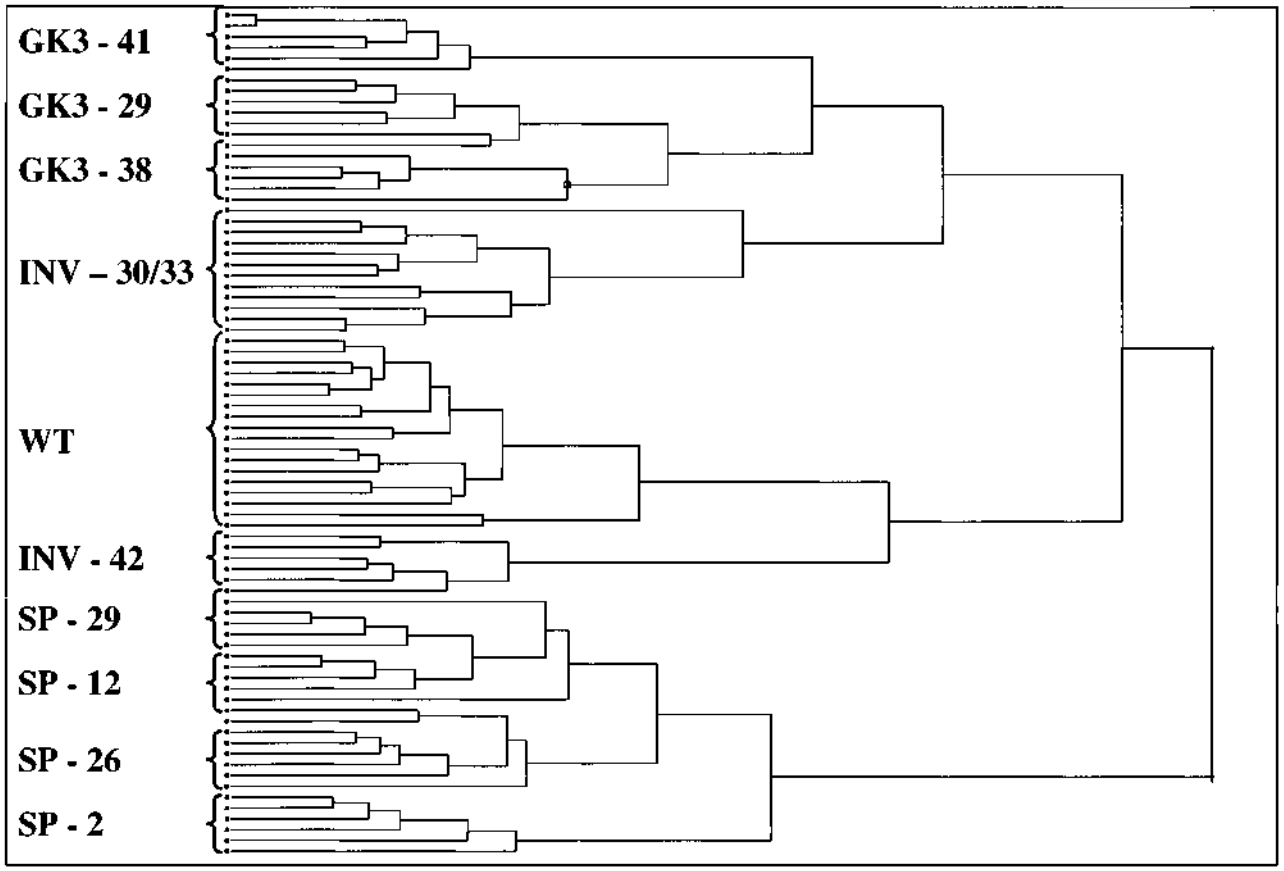

Figure 3. Dendogram Obtained after HCA of the Metabolic Profiles of the Analyzed Transgenic Systems.

The distances between these populations were calculated as described in Methods, using the normalized data of the single measurements from which the means presented in Table 1 are derived. In addition, data from a further line, SP-26, are included that were not presented previously. Wherever possible, individual branches are grouped in brackets for ease of reading. WT, wild type.

pressing sucrose phosphorylase have a clearly distinct metabolic profile.

Assessment of the Metabolites Exerting the Largest Influence on Cluster Formation

Using the vector-based approach of PCA, it is possible to distinguish the compounds that exhibit the greatest variance within a population and thereby distinguish the contribution of these compounds to the formation of distinct clusters. When the steady state levels of metabolites within these four genotypes were compared, the main contributors to the cluster formation were determined to be sugars or closely related compounds, including the aforementioned PT00, maltose, maltitol, trehalose, glucose and mannose, glycerate, both glucose-6-P and fructose-6-P, and unknowns PT08 and PT16 (Figure 4B). Given that the novel unknown PT00, which was detectable only in the SP lines, is a major contributor to PCA, we also calculated a vector in which this component was omitted from the PCA. This omission resulted in no changes in the clusters formed by either HCA or PCA. Further studies performed that removed all novel components of the metabolite profiles also did not result in gross changes in the clustering patterns produced by either method of component analysis (data not shown). These data demonstrate that our approach indeed takes into account the entire spectrum of metabolites detailed; it does not merely compare the behavior of a single, or a few, metabolite(s) within these lines, and thus, it provides validation of these analyses.

Correlation of Metabolite Levels and Analysis of Dependencies

These methods exemplify how interpretations can be made on the basis of the entire metabolic complement of a system.

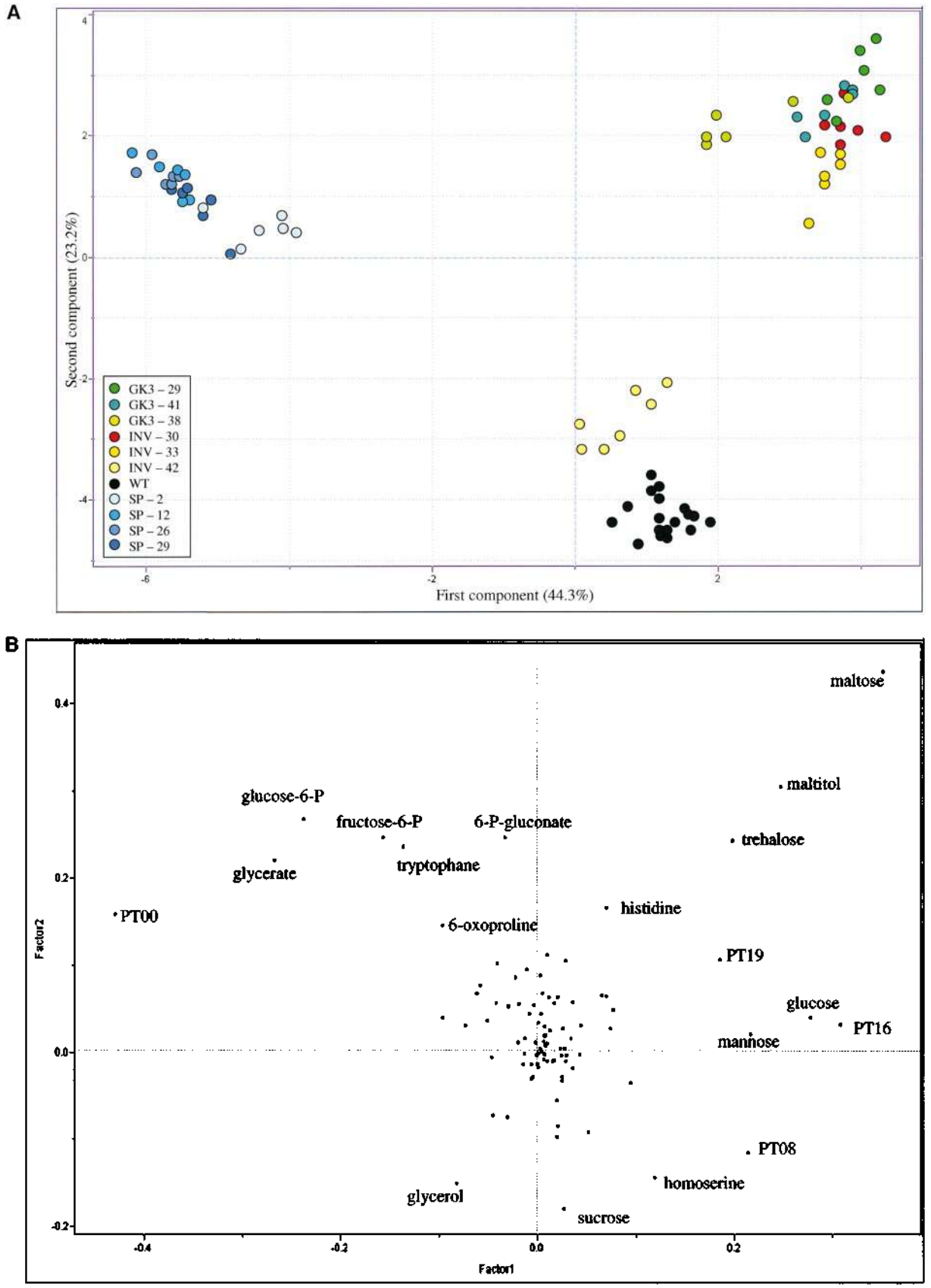

Figure 4. PCA of the Metabolic Profiles of the Analyzed Transgenic Systems.

Specifically, they show how genetically distinct systems can be identified and how the most important component(s) of this phenotype can be determined. Although this technique is clearly very powerful, we decided also to look at the trends within the individual metabolites by plotting the level of every metabolite in individual samples of the wild type and various transgenic lines against every other metabolite within that sample. We analyzed a total of 3872 such plots. The observed dependencies could be classified into three major groups: those exhibiting no dependency (i.e., scatter), those exhibiting linear correlation, and those exhibiting a more complex correlation. As would perhaps be expected, most plots were of metabolite levels that were independent of each other; however, several interesting results came to light during this analysis. (A complete list of metabolites exhibiting correlations with a coefficient >0.7 is presented on our web page at http://www.mpimp-golm.mpg.de/willmitzer/metabolic-profiling-e.html.) For discussion of these data, we have presented a few examples of some of the trends (Figure 5). An obvious example of a linear correlation between metabolites is that observed for fructose-6-P and glucose-6-P (Figure 5A), which are separated by only a single enzyme, phosphoglucose isomerase, which catalyzes a near-equilibrium reaction. This correlation holds for all lines, confirming that the potato tuber has a very high capacity for equilibrating these two metabolites. However, this relationship was also observed in situations in which metabolites are not consecutive within a pathway, for example, between leucine and isoleucine (Figure 5B). When we consider that the pathways for the biosynthesis of these amino acids share the same terminal enzyme activity, branched chain amino acid transaminase, and the same cofactor, glutamate, the reason for the close relationship between the metabolites becomes apparent. Methionine and lysine (Figure 5C) display a nonlinear correlation, which is most pronounced in GK3 and SP lines; this correlation seems to be in agreement with the relationship that one would predict from proposed models of feedback regulation (Bartlem et al., 2000; see Discussion for detailed explanation). Perhaps even more exciting are cases in which the relationship between metabolites *a* and *b* is different in different genotypes. One example of this is shown in Figure 5D, in which the glycine level is plotted against sucrose. However, this example is trivial because in each case, the genetic modification introduced is targeted at sucrose, and therefore a different linear regression would be expected between transgenic lines and the wild type. A more informative example is provided in Figure 5E, in which PT07 is plotted against PT15; here, it can be clearly seen that in GK3 and SP lines, the metabolites show a different dependency than they do in wild-type and INV lines. This type of analysis may also prove crucial in identifying unknown compounds, because in several instances (e.g., as shown in Figure 5F, in which unknown PT19 is plotted against mannose), the observation that the level of an unknown exhibits strong positive correlation with the increase in level of a known metabolite provides hints about the biosynthesis or subsequent metabolism of that compound.

Effect of Environmental Perturbation on the Steady State Metabolite Levels in Wild-Type Tuber Discs

As a further example of the use of metabolic profiling, we investigated the metabolite levels of wild-type tuber discs incubated for 2 hr in 0, 20, 50, 100, 200, or 500 mM glucose, corresponding to cellular glucose levels of 1.7, 8.0, 9.4, 18.1, 30.2, and 68.2 μM g fresh weight^{-1}, respectively (mean, $n = 4$), as measured by GC-MS. The levels of more than half of the 86 compounds we measured were found to decrease on incubation in comparison with the nonincubated controls, irrespective of the presence or absence of glucose (experimental data are available at http://www.mpimp-golm.mpg.de/willmitzer/metabolic-profiling-e.html). Despite the large changes caused by incubation, when the levels of compounds in discs incubated in glucose were contrasted with the levels of those found in samples incubated in buffer (10 mM Mes-KOH, pH 6.5) alone, a different picture emerged. Only samples that were incubated in 200 and 500 mM glucose exhibited significant differences. The exceptions to this include malate and glucose-6-P, whose levels significantly increased on incubation in 100, 200, or 500 mM glucose and mannitol, and of course glucose, whose levels increased after incubation in glucose at all concentrations tested. Again, several of the unknown compounds displayed patterns of change similar to those for

Figure 4. (continued).

(A) The distances between these populations were calculated as described in Methods, using the log-transformed, normalized data of the single measurements from which the means presented in Table 1 are derived. In addition, data from a further line, SP-26, are included that were not presented previously. PCA vectors span a 10-dimensional space to give best sample separation, with each point representing a linear combination of all the metabolites from an individual sample. Vectors 1 and 2 were chosen for best visualization of differences between genotypes and include 67.5% of the information derived from metabolic variances. WT, wild type.

(B) The contribution of individual metabolites to the PCA vector calculation by linear combination. The closer to the origin, the smaller the influence a given metabolite has on the linear combination. The most important metabolites for separation of the differently treated samples are labeled.

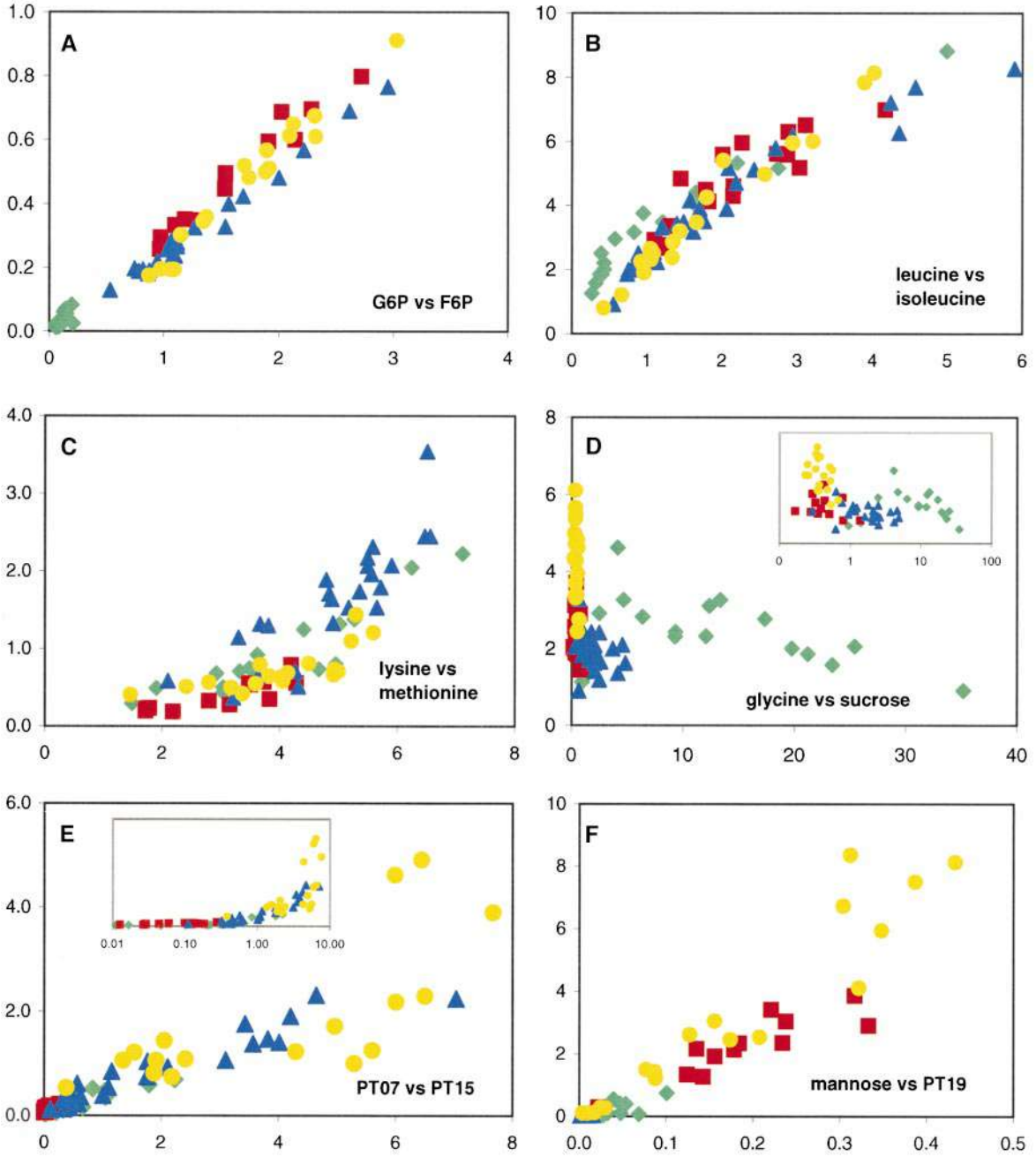

Figure 5. Correlation between Metabolite Levels of the Analyzed Transgenic Systems.

Correlations between the relative response ratios of each of the 88 metabolites with those of all other metabolites were assessed, and several interesting trends were observed. Examples of these trends are shown. Symbols are as follows: green diamonds, wild type; red squares, INV; yellow circles, GK3; blue triangles, SP.

(A) Glucose-6-P (G6P) versus fructose-6-P (F6P).

(B) Leucine versus isoleucine.

(C) Lysine versus methionine.

(D) Glycine versus sucrose. The insert shows sucrose values plotted on a logarithmic scale.

(E) PT07 versus PT15. The insert shows PT07 values plotted on a logarithmic scale.

(F) Mannose versus PT19.

compounds for which we know the chemical nature. This is in itself interesting, but it may also indicate chemical similarity between the correlating metabolites and thus may help in identifying the unknown metabolites.

HCA and PCA of the Metabolic Complement of Glucose-Incubated Samples

Applying cluster analysis to the data from glucose incubation (i.e., using wild-type steady state metabolite concentrations) revealed interesting results. HCA showed that the wild-type tuber discs incubated in buffer alone had the most similar metabolite complement to the steady state wild-type levels (Figure 6). Furthermore, the glucose-fed samples formed a distinct cluster that was more similar to the wild-type steady state complement than to that of any of the transgenics, and the metabolic profile of the discs fed with 500 mM glucose was distinct from the profile of the discs fed with lower concentrations of glucose. The relationship between the transgenic lines shown in Figure 6 is different from that shown in Figure 4; however, this is an inherent feature of this type of component analysis, because a new hierarchy is established.

PCA revealed very similar trends (Figure 7). Furthermore, when we used this method of clustering, the buffer-incubated samples were indistinct from the wild-type steady state levels. In addition, the 20 to 200 mM glucose-fed samples form an independent cluster, as do the 500 mM glucose-fed samples, and these clusters are closer to the wild-type steady state cluster than to any of those of the transgenics. Moreover, when glucose-fed samples and their respective controls were clustered independently of the transgenic lines, the same clustering pattern was formed (data not shown). Figure 8 reveals that the compounds that exhibited the greatest variance when the metabolic profiles of the glucose-fed samples were considered alone were asparagine, glucose, maltose, proline, tryptophan, PT10, PT14, PT16, and PT19. In contrast, the most important components for the clustering when both genetically and environmentally modified systems were compared were mainly sugars and sugar derivatives, including glucose, maltose, mannose, maltitol, trehalose, 6-phosphogluconate, both of the hexose-6-phosphates, and the unknown PT00 (Figure 9). For both analyses, we reevaluated the data sets, this time omitting the novel compounds; however, the observed clustering was remarkably similar in both instances (data not shown).

When the glucose-feeding region of the PCA was expanded (Figure 10A) and the individual incubations were highlighted, a clear trend of increased distance from the wild type (steady state) occurred with increased concentration of glucose in the incubation medium. One of the primary aims of this experiment was to attempt to phenocopy the metabolic complement of the transgenics by using environmental manipulation. This was clearly not possible in this instance because all situations formed distinct clusters. Thus, we decided to broaden our analyses by comparing the metabolic profile of transgenic potatoes expressing invertase at an apoplastic location that we had previously measured (Roessner et al., 2000) with that of the glucose-fed samples by using both methods of cluster analysis. We were fascinated to find that PCA showed that the apoplastic invertase samples co-clustered with the glucose-fed samples (Figure 10B); furthermore, both HCA and an in-depth search of the changes in the chromatograms confirmed this result (data not shown). To our knowledge, this result in which a genetically modified system has been phenocopied by modification of environmental conditions is novel. When the data from the apoplastic invertase-expressing potatoes were considered alongside the data from the other transgenics and the wild-type and glucose-fed samples, the most important components for the clustering turned out to be identical to those when only the INV, GK3, and SP lines were compared with the wild-type and glucose-fed samples, except that fructose became marginally more important (see Figure 9). Once again, we reevaluated the cluster analysis by omitting novel compounds to determine whether the clustering pattern observed was reflective of the entire metabolic complement or whether the control of cluster formation was vested in merely a few compounds. As in other cases reported here, the clustering pattern that resulted from this PCA was essentially the same as the one obtained when all metabolites were considered.

DISCUSSION

This study investigated the potential of metabolic profiling, using GC-MS for phenotyping and comprehensive characterization of plant systems. We selected the particular transgenic lines because they have already been fairly well characterized at the metabolite level, and they differ only slightly in the biochemical activity that is always targeted at enhancing sucrose cleavage. The similarity of the data obtained using the GC-MS protocol compared with that previously obtained using conventional HPLC and spectrophotometric methods (Trethewey et al., 1998, 1999b, 2001; Riedel, 1999) validates the authenticity of the measurements obtained using this protocol, and therefore confirms the protocol's suitability for use in this study.

Although a major purpose of this study was to combine multiparallel metabolite analysis with bioinformatic tools for data analysis, the comprehensive analysis achieved by metabolite profiling alone allowed some important conclusions to be made. For example, the fact that so many amino acids increased in the lines investigated in this study is in itself fascinating. There are two possible mechanisms for these increases: either an increased synthesis in source tissues and an increased transport of amino acids to the tubers or an elevated rate of amino acid biosynthesis within the

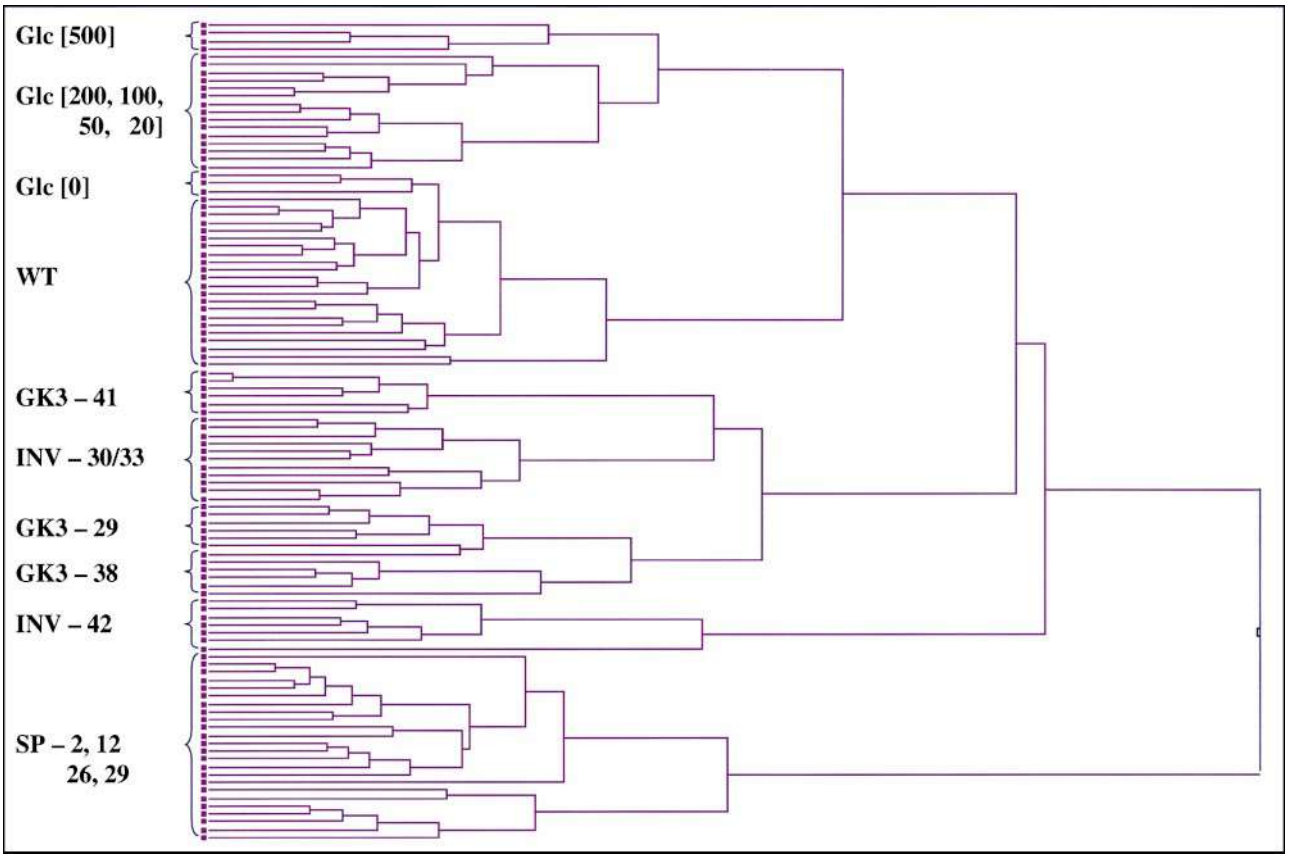

Figure 6. Dendogram Obtained after HCA of the Metabolic Profiles of both Genetically and Environmentally Modified Systems.

The vector for the HCA described in Figure 3 was recalculated to include the metabolic profiles achieved after incubation of wild-type (WT) potato tuber tissue in a range of glucose concentrations. Thus, the full data set used was the individual measurements of samples from all transgenic lines as well as individual measurements from glucose-fed wild-type tissue (from which the mean data, presented on our web page at http://www.mpimp-golm.mpg.de/willmitzer/metabolic-profiling-e.html, were derived). Wherever possible, individual branches are grouped in brackets for ease of reading. Note that the relationship between the various transgenic lines is different from that observed in Figure 4. This is an inherent feature of this form of cluster analysis because a new hierarchy is established.

potato tuber. GC-MS analysis revealed that the amino acid levels in the leaves of the transgenic plants did not change (data not shown). These data are what would be expected given the use of a tuber-specific promoter for transgene expression, and they indicate that the later hypothesis is the more likely. Amino acid biosynthesis in potato tubers in particular and in storage tissues in general is poorly understood. Although recently several genes for amino acid biosynthesis have been cloned from the potato tuber (Muday and Herrmann, 1992; Riedel et al., 1999; Casazza et al., 2000; Maimann et al., 2000), it is not known whether tubers possess the necessary machinery to synthesize all amino acids. The data presented in this study, although indirect, provide the first evidence that the potato tuber is likely to contain the required machinery to produce all amino acids de novo. This example illustrates clearly the power of metabolic profiling in functional genomics in that compounds are identified that imply the presence and influence of gene products involved in their synthesis. A further example is that of ascorbate because little is known about the location of synthesis of this vitamin (Smirnoff and Wheeler, 2000). The data presented here indicate that ascorbate can also be synthesized de novo within the tuber: ascorbate is increased in the tubers in several of the transgenic lines studied but not in their leaves (data not shown). Ascorbate also increased after incubation of wild-type tuber tissue in glucose, so ascorbate synthesis is possible in the tuber, at least under conditions in which glucose is plentiful. These examples therefore return our attention to searching for genes. Furthermore, we anticipate that once the chemical nature of the unknowns is established, clear new targets for gene discovery will be identified.

A further example of the type of conclusions that can be drawn from such a broad-based profiling method involves differences in metabolic profiles that can be assigned on the basis of difference in the genetic manipulation imposed. Interestingly, several compounds, namely, maltose, trehalose, isomaltose, maltitol, malate, PT16, PT19, and PT20, increase starkly only in the INV and GK lines that also exhibit elevated glucose. This observation fits with recent results suggesting the operation of sugar-sensing mechanisms within plants (Jang et al., 1997; Smeekens, 2000). However, although these changes can be correlated directly to glucose levels, they are limited to only a few metabolites; thus, these data seem to argue against a major signaling role for glucose within the tuber system. These findings are therefore in agreement with previous studies in which we directly modified the levels of glucose and of glucose-using enzymes by using a transgenic approach (Veramendi et al., 1999; Fernie et al., 2000).

The above examples clearly illustrate the power of a nonbiased metabolic screen to help us draw conclusions from our data that have both breadth and novelty. However, analysis at the level of single metabolites is an ominous task, particularly when ~11,000 data points must be assessed. We therefore applied bioinformatic tools for data mining to our results. The four initial genotypes analyzed (wild type, INV, GK3, and SP potato lines) had distinct metabolic profiles, despite the fact that the target of the genetic manipulation was the same in each instance. Both methods of cluster analysis independently led to the same interpretation and gave a high level of resolution between the genotypes. Moreover, reanalysis of the data sets when the most influential contributing metabolites of the individual clusters were

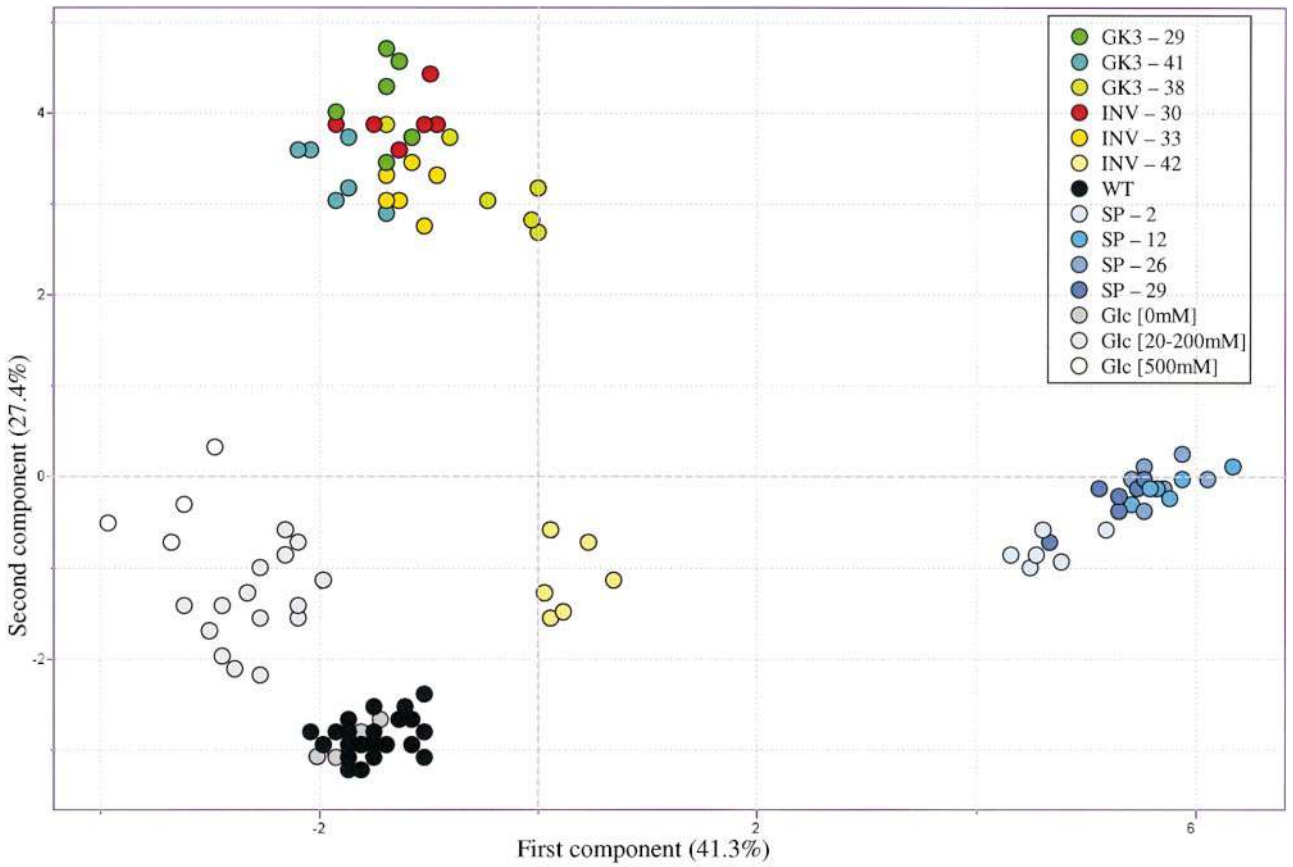

Figure 7. PCA of the Metabolic Profiles of Both Genetically and Environmentally Modified Systems.

The distances between these populations were calculated as described in Methods by using the log-transformed, normalized data of the single measurements from which the means presented on our web page (http://www.mpimp-golm.mpg.de/willmitzer/metabolic-profiling-e.html) were derived. PCA vectors span a 10-dimensional space to give best sample separation, with each point representing a linear combination of all the metabolites from an individual sample. Vectors 1 and 2 were chosen for best visualization of differences between genotypes and include 68.7% of the information derived from metabolic variances. WT, wild type.

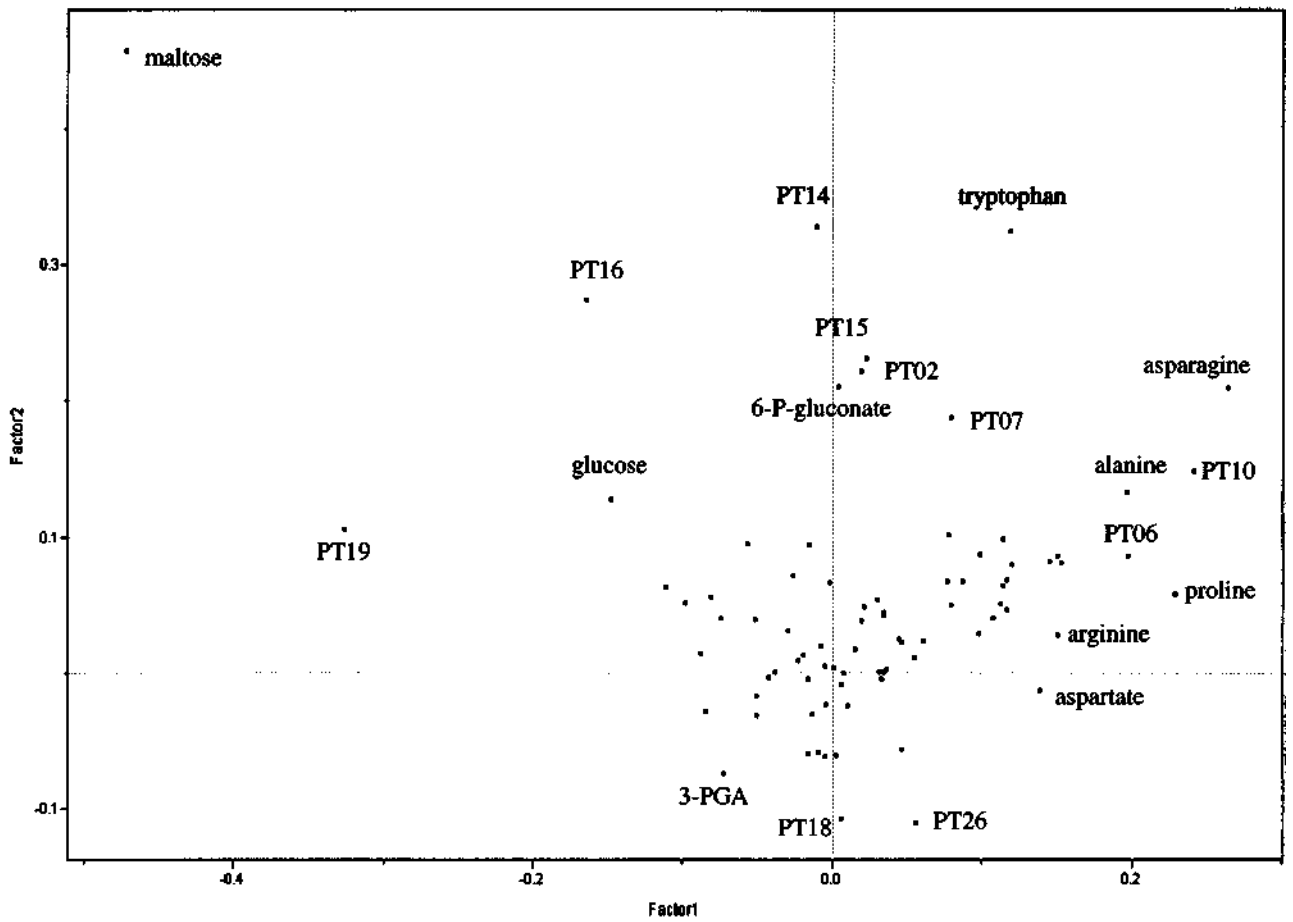

Figure 8. Assessment of the Metabolites Exerting the Largest Cluster Formation When Only Glucose-Fed Samples Are Considered.

Shown is the contribution of individual metabolites to the PCA vector calculation by linear combination. The closer to the origin, the smaller the influence a given metabolite has on the linear combination. The most important metabolites with respect to the separation of the differently treated samples are labeled.

removed yielded very similar clusters in all instances. We believe that this allows us to have a high level of confidence in interpreting these clusters because it demonstrates that the cluster formation is not dependent on merely a few metabolites or even a single metabolite. That the combination of metabolic profiling and cluster analysis allows resolution of very similar situations suggests that it is of general use for phenotyping diverse genetically or environmentally modified plant systems.

A further advantage of using a multiparallel approach is that because all metabolites are analyzed within a single extract, relationships between the levels of the various metabolites can be determined. By plotting all possible correlations, we were able to assess which metabolite concentrations were strongly linked. Although some of these linkages have been reported previously for plants (e.g., Hatzfeld and Stitt, 1990; Fernie et al., 2001a), and some are probably trivial, these analyses also gave insight into regulation of metabolism within the tuber. The hyperbolic nature of the curve obtained when lysine was plotted against methionine fits models of feedforward and feedback regulation of the aspartate family biosynthetic pathway in Arabidopsis, as outlined by Bartlem et al. (2000). These authors suggest that under conditions of high flux, the methinine-threonine branch point is tightly regulated such that when methionine accumulates, its feedback inhibits expression of cystathione γ-synthase mRNA, but feedforward activitates the competing branch point catalyzed by threonine synthase. If such control were operating in the potato tuber, it would follow that methionine would only accumulate to a threshold level, whereas lysine would continue to increase with increasing flux through the pathway. Thus, a hyperbolic relationship between these metabolites indicates that the biosynthetic pathway of the potato tuber aspartate family is regulated in

a manner analogous to that of Arabidopsis. That these plots can indicate metabolic regulation at a certain locus is very exciting, because the screening of, for example, mutant populations for individuals lines that do not fit these relationships have the potential to allow identification of component genes of regulatory factors at these loci. A further function of these plots is that the high degree of correlation between the unknown compounds and those for which the chemical nature is established may aid in the identification of these compounds and hence to improvements in the efficacy of our protocol.

As a first example of the power of metabolic profiling, we demonstrated its use in identifying phenocopies of certain genetic modifications—an approach that obviously will be useful in functional genomics. For this purpose, we incubated tuber discs in various concentrations of glucose and determined their subsequent metabolic profile. This manipulation led to metabolic profiles that formed distinct clusters from the transgenic lines we initially chose for our study (INV, GK3, and SP). However, when the metabolic profiles of the glucose-incubated samples were compared with transgenics we had profiled previously (Roessner et al., 2000), we were able to phenocopy one of them—potato plants expressing a yeast invertase within the tuber at an apoplastic location. A possible explanation for the phenocopying of these situations is the presence of a factor on the plasma membrane that has been implicated to sense the carbohydrate status of the cell wall space and mediate effects on

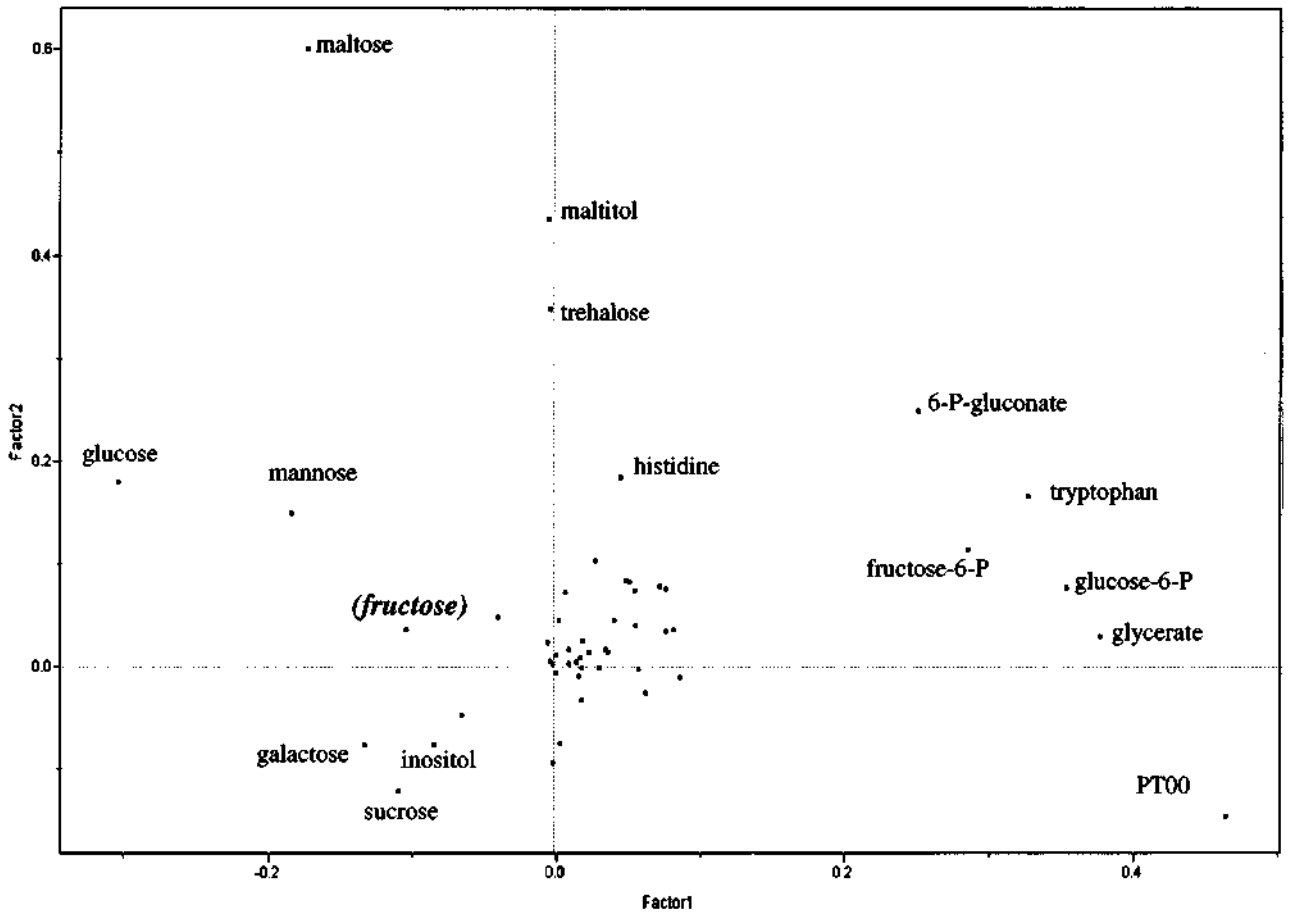

Figure 9. Assessment of the Metabolites Exerting the Largest Cluster Formation When Both Genetically and Environmentally Modified Systems Are Considered.

Shown is the contribution of individual metabolites to the PCA vector calculation by linear combination. The closer to the origin, the smaller the influence a given metabolite has on the linear combination. The most important metabolites with respect to the separation of the differently treated samples are labeled. The metabolite that appears in brackets, fructose, only has this degree of influence when glucose feeding profiles are considered.

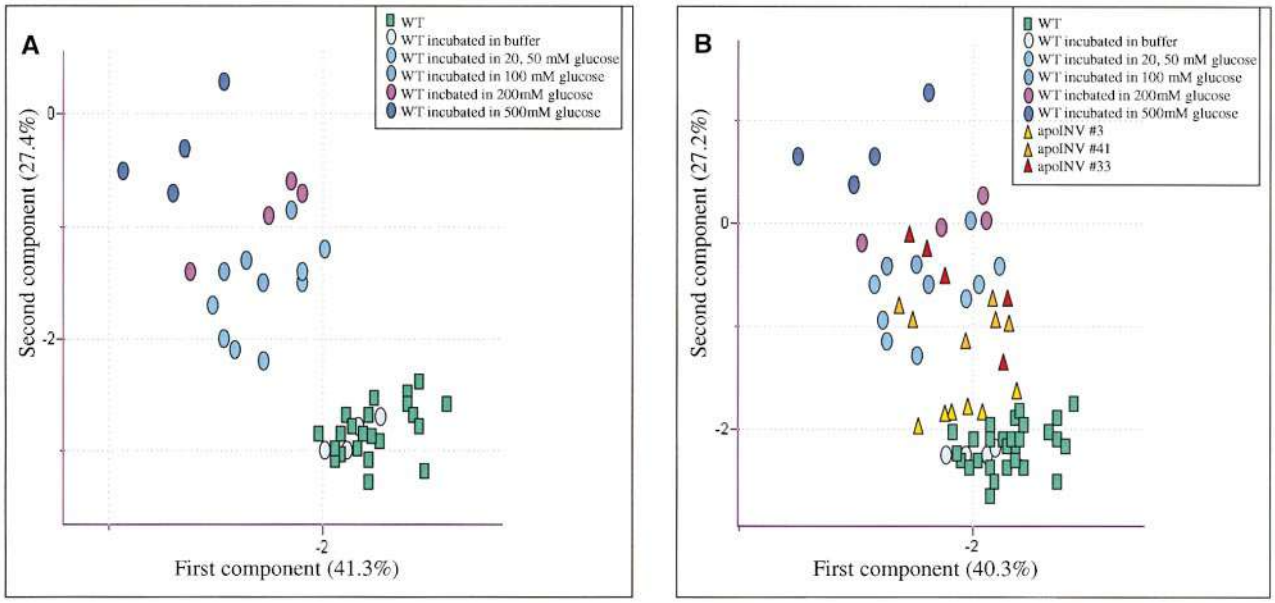

Figure 10. PCA of the Metabolic Profiles of Genetically and Environmentally Modified Systems in Combination with the Metabolic Profiles of Previously Profiled Transgenic Plants.

(A) Expansion of the glucose-feeding cluster region presented in Figure 7.
(B) Relationship between apoplastic invertase-expressing tubers and glucose-fed wild-type tubers.
The distances between these populations were calculated as described in Methods by using the log-transformed, normalized data from both environmentally and genetically modified systems. PCA vectors span a 10-dimensional space to give best sample separation, with each point representing a linear combination of all the metabolites from an individual sample. Vectors 1 and 2 were chosen for best visualization of differences between genotypes and/or different environmental conditions and include 67.5% of the information derived from metabolic variances. WT, wild type.

cellular metabolism (Lalonde et al., 1999; Fernie et al., 2001b, 2000). The fact that certain environmental conditions can phenocopy genetic modifications, even when many parameters are considered, proves the general utility of this approach.

Conclusion and Perspectives

The work presented in this article demonstrates that metabolic profiling coupled with bioinformatic tools represent an additional exciting approach to the analysis of complexity within plant systems. We believe that the data herein illustrate that our protocol allows the phenotyping of diverse plant systems and gives multiple insights into regulation and relationships of metabolite levels within plant cells. The exact number of chemical compounds present in the combined plant kingdoms is unknown; however, estimates range from 90,000 to 200,000 different molecules, with a single species such as Arabidopsis having a complexity in excess of 5000 compounds. However, a large proportion of this enormous diversity results from compounds of secondary metabolism. It is therefore obvious that the approach described here, in which we essentially limit ourselves to ~80 compounds, does not represent the end of this development. Unpublished data from our group suggest that applying different data extraction algorithms (using peak deconvolution software) to the original chromatograms increases the number of distinct compounds detected by a factor of three. A further extension of the metabolic-profiling approach is in the development of similar, automated technologies for the nonvolatile or highly fragile compounds; liquid chromatography coupled to MS represents one such approach. The biggest hurdle is probably determination of the exact chemical structure of the individual compounds seen. Here, a multitude of approaches such as MS, nuclear magnetic resonance, and other techniques will be useful. It is our belief that only the combination of many analytical techniques will allow a full description of the metabolome status of an organism and thus create a third level of multiparallel approaches. When taken together with RNA and protein analyses, the metabolic complement will allow a full picture of the complexity of the biological entity under study.

METHODS

Plant Materials

Solanum tuberosum cv Desiree was obtained from Saatzucht Lange AG (Bad Schwartau, Germany). The generation and selection of the transgenic lines used here have been described previously by Sonnewald et al. (1997) and Trethewey et al. (1998, 2001). Plants were maintained in tissue culture with a 16-hr-light/8-hr-dark regime on Murashige and Skoog (1962) medium that contained 2% sucrose. In the greenhouse, plants from all transgenic lines and wild-type controls were grown in parallel under the same light regime with a minimum of 250 μmol photons m^{-2} sec^{-1} at 22°C. In this article, the term "developing tubers" is used for tubers (>10 g fresh weight) harvested from healthy 10-week-old plants.

Chemicals

All chemicals and pure standard substances were purchased from either Sigma-Aldrich Chemie GmbH (Deisenhofen, Germany) or Merck KGaA (Darmstadt, Germany).

Confirmation of Preliminary Biochemical Characteristics of Transgenic Lines

Extraction and assaying of invertase and glucokinase were performed according to Trethewey et al. (1998), and those of sucrose phosphorylase were performed following the protocol of Trethewey et al. (2001). Carbohydrate levels were determined exactly as described in Morrell and ap Rees (1986), whereas phosphorylated intermediates were measured according to protocols described in Fernie et al. (2001a). Recoveries of metabolites in the trichloroactetic acid extracts have been documented previously (e.g., Trethewey et al., 1998; Veramendi et al., 1999; Fernie et al., 2001a).

Extraction, Derivatization, and Analysis of Potato Tuber Metabolites Using Gas Chromatography–Mass Spectrometry

Potato tuber tissue (100 mg) was extracted in 1400 μL of methanol, as described by Roessner et al. (2000); 50 μL of internal standard (2 mg of ribitol in mL^{-1} water) was added for quantification. The mixture was extracted for 15 min at 70°C, mixed vigorously with 1 volume of water, centrifuged at 2200*g*, and subsequently reduced to dryness in vacuo. The residue was redissolved and derivatized for 90 min at 30°C (in 80 μL of 20 mg mL^{-1} methoxyamine hydrochloride in pyridine) followed by a 30-min treatment at 37°C (with 80 μL of *N*-methyl-*N*-[trimethylsilyl]trifluoroacetamide). Forty microliters of a retention time standard mixture (3.7% [w/v] hepatonic acid, 3.7% [w/v] nonanoic acid, 3.7% [w/v] undecanoic acid, 3.7% [w/v] tridecanoic acid, 3.7% [w/v] pentadecanic acid, 7.4% [w/v] nonadeanoic acid, 7.4% [w/v] tricosanoic acid, 22.2% [w/v] heptacosanoic acid, and 55.5% [w/v] hentriacontanoic acid dissolved in 10 mg mL^{-1} tetrahydrofuran) was added before trimethylsilylation. Sample volumes of 1 μL were then injected with a split ratio of 25:1, using a hot needle technique.

The gas chromatography–mass spectrometry (GC-MS) system was composed of an AS 2000 autosampler, a GC 8000 gas chromatograph, and a Voyager quadrole mass spectrometer (ThermoQuest, Manchester, UK). The mass spectrometer was tuned according to the manufacturer's recommendations, using tris-(perfluorobutyl)-amine (CF43). GC was performed on a 30-m SPB-50 column with 0.25-μm film thickness (Superlco, Bellfonte, CA). The injection temperature was set at 230°C, the interface at 250°C, and the ion source adjusted to 200°C. Helium was used as the carrier gas at a flow rate of 1 mL min^{-1}. The analysis was performed under the following temperature program: 5 min of isothermal heating at 70°C, followed by a 5°C min^{-1} oven temperature ramp to 310°C, and a final 1 min of heating at 310°C. The system was then temperature equilibrated for 6 min at 70°C before injection of the next sample. Mass spectra were recorded at 2 scan sec^{-1} with a scanning range of 50 to 600 m/z. Both chromatograms and mass spectra were evaluated using the MASSLAB program (ThermoQuest). A retention time and mass spectral library for automatic peak quantification of metabolite derivatives were implemented within the MASSLAB method format. Substances were identified by comparison with authentic standards, as described in Roessner et al. (2000). The recovery of small representative amounts of each metabolite through the extraction, derivatization, storage, and quantification procedures has been documented previously (Roessner et al., 2000). Data sets measured at different times are not directly comparable because of varying tuning parameters of the GC-MS machine over time; we therefore normalized the data by using the wild-type control of each measured batch as a reference. To include all the specific ions used for quantification of the metabolites (Roessner et al., 2000), we averaged all response numbers for the wild-type control and divided all data from a measured batch by the calculated factor.

Glucose Incubation of Potato Tuber Slices

Glucose incubations were performed essentially as described by Geiger et al. (1998). Discs were cut directly from developing tubers from nonsenescent wild-type plants and washed three times in 10 mM Mes-KOH. They were then placed in 100-mL flasks (eight discs per flask) containing 5 mL of incubation medium (10 mM Mes-KOH, pH 6.5), supplemented with 0, 20, 50, 100, 200, or 500 mM glucose, and incubated with shaking (at 150 rpm) for 2 hr. An aliquot of the incubation media then was immediately frozen in liquid N_2 for subsequent analysis. Samples were washed three times in 10 mM Mes-KOH, pH 6.5, before they were dried and frozen in liquid N_2 for subsequent analysis. Analysis of the tuber extracts was performed as described above, except that the glucose level of the sample was quantified by calibration, as described previously (Fernie et al., 2001b; Roessner et al., 2000).

Cluster Analysis

Hierarchical cluster anaylsis (HCA) and principle component analysis (PCA) were performed with the S-Plus system, as detailed by Venables and Ripley (1999). For an independent confirmation of the results obtained by this method, we also used the informatic program Pirouette 2.6 (Infometrix, Woodinville, WA). HCA allows the presentation of cluster results in a dendogram, where the similarity of two samples can be determined from the value on the distance axis at which they join in a single cluster (the smaller the distance, the more similar the sample). All HCAs described in this article were transformed by log 10 to allow better comparison of large and small numbers. We used the Euclidean distance to calculate the matrix of all samples. The

complete linkage method was then used in the assignment of clusters. For PCA, the *n*-dimensional data set was transformed into a second *n*-dimensional data set in which what was designated as the most important information of the original data set was stored in the first few dimensions. These transformations allowed the reduction of the original data set to only the most important dimensions, hence allowing more distinct cluster formation. The results of these analyses were then presented as a two-dimensional graphical display of the data in which a single sample is represented by a point in three-dimensional space.

Statistical Analysis

If two observations are described in the text as different, this means that their difference was determined to be statistically significant by the performance of *t* tests using the algorithm incorporated into Microsoft Excel 7.0. (Microsoft, Seattle, WA).

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Use of genomics tools to isolate key ripening genes and analyse fruit maturation in tomato

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Abstract

Development, maturation and ripening of fruits has received considerable experimental attention, primarily due to the uniqueness of such processes to plant species and the importance of fruit as a significant aspect of human dietary intake and nutrition. Molecular and genetic analysis of fruit development, and especially ripening of fleshy fruits, has resulted in significant gains in knowledge over recent years, especially with respect to understanding ethylene biosynthesis and response, cell wall metabolism and, to a lesser extent, environmental cues which impact ripening. Tomato has proved to be an excellent model system for the analysis of fruit ripening and development, in part due to the availability of well characterized ripening mutants. Especially interesting are the non-allelic *ripening-inhibitor* (*rin*) and *non-ripening* (*nor*) mutations which result in non-ripening fruit. Fruit from both mutants are deficient in climacteric respiration and the associated burst in ethylene biosynthesis. Exogenous ethylene does not restore ripening yet does induce expression of ethylene-regulated ripening genes, suggesting both mutations block necessary aspects of ripening outside the realm of ethylene's influence. Both mutations therefore represent genes upstream of ethylene control and additional non-ethylene mediated aspects of ripening. Both genes have recently been isolated through positional cloning strategies and it was shown that ripening is regulated, in part, by a MADS-box transcription factor at the *rin* locus. Recent development of tools for tomato genomics summarized here have further expanded the potential of the tomato system for the elucidation of genetic regulatory components impacting fruit development, ripening and nutritional quality.

Key words: ESTs, map-based cloning, microarrays, mutant complementation.

Introduction

Ripe fruit demonstrate a wide range of diversity in form, pigmentation, texture, aroma, flavour, and nutrient composition. Fruit of many species undergo modification of cell wall ultrastructure and texture, conversion of starch to sugars, increased susceptibility to post-harvest pathogens, alterations in pigment biosynthesis/accumulation, and heightened levels of flavour and aromatic volatiles during the maturation and ripening processes (for reviews see Rhodes, 1980; Seymour *et al*., 1993).

From a practical viewpoint, a number of ripening characteristics result in negative quality attributes including decreased shelf-life and high input harvest, shipping and storage practices. Particularly important, in this respect are the changes in firmness and the overall decrease in resistance to microbial infection brought about by the ripening process and associated tissue deterioration. Significant advances in understanding the molecular regulation of individual ripening parameters, especially cell wall metabolism and ethylene biosynthesis and response have occurred in the last 15 years (reviewed in Giovannoni, 2001). The resulting knowledge has contributed to a more complete view of molecular ripening control and has, additionally, yielded molecular tools for addressing problems in fruit production and quality.

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Two major classifications of ripening fruit, climacteric and non-climacteric, have been used to distinguish fruit on the basis of respiration and ethylene biosynthesis rates. Climacteric fruit (e.g. tomato, avocado, apple, banana) are distinguished from non-climacteric fruits (e.g. strawberry, grape, citrus) by their increased respiration and ethylene biosynthesis rates during ripening (Lelievre *et al*., 1997). While non-climacteric fruits do not require ethylene for ripening of their fruits, ethylene has been shown to be necessary for the co-ordination and completion of ripening in climacteric fruit. This has been demonstrated in a number of ways including the analysis of inhibitors of ethylene biosynthesis and perception (Tucker and Brady, 1987; Yen *et al*., 1995), transgenic plants altered in ethylene biosynthesis (Klee *et al*., 1991; Oeller *et al*., 1991; Picton *et al*., 1993), and through the analysis of the tomato *Never-ripe* (*Nr*) ethylene receptor mutant (Lanahan *et al*., 1994; Wilkinson *et al*., 1995).

Fruit are an important component of the human diet. Ripening has an impact on fibre content and composition, lipid metabolism, and the levels of vitamins and various antioxidants (Ronen *et al*., 1999). The ability to understand and manipulate, through breeding or biotechnology, key control points in the global control of ripening or regulatory points of specific ripening process such as carotenoid, flavonoid, vitamin, and flavour volatiles, will allow the manipulation of nutrition and quality characteristics associated with ripening. Possibly the most convincing argument for the promotion of plant genetic engineering will be the development of modified plants or plant-derived products with direct consumer appeal such as increased quality and nutrition.

Tomato as a model system for fruit ripening

Tomato has long served as the most studied model for fruit ripening, in part because of its importance as a food crop species. This practical importance combined with diploid inheritance, ease of seed and clonal propagation, efficient sexual hybridization, a relatively short generation period, and year-round growth potential (in greenhouses) has fostered tomato as the primary model for ripening research. From the standpoint of genetic and molecular investigations tomato has the additional advantages of a relatively small genome (0.9 pg/haploid genome; Arumuganathan and Earle, 1991) on which nearly 2000 molecular markers have been mapped (Tanksley *et al*., 1992; Solanaceae Genome Network http://www.sgn.cornell.edu/). High molecular weight insert genomic libraries are available in both YAC (Martin *et al*., 1992; Bonnema *et al*., 1996) and BAC (Budiman *et al*., 2000) vector systems to facilitate positional cloning. A recently added tool to the repertoire of tomato and other plant science researchers is the National Science Foundation sponsored development of a tomato EST database. 23 cDNA libraries from various tissues have been created, followed by single-pass 5′ sequencing of over 150 000 clones resulting in approximately 28 000 non-redundant sequences (http://www.tigr.org/tdb/lgi/). The database includes approximately 40 000 sequences derived from fruit at various stages of development with an emphasis on ripening. In addition, years of breeding and focus on tomato as an agricultural crop have resulted in a valuable germplasm resource representing genes influencing multiple aspects of fruit development and ripening. A summary of ripening mutants of tomato is listed in Table 1.

Table 1. *Tomato germplasm altered in ripening*

The dashed line separates mutants for which the corresponding gene has been cloned (top) from those which have not (bottom).

Genotype	Activity	Function	Reference
rin; *ripening-inhibitor*	MADS-box gene	Comprehensive ripening	Vrebalov *et al*., 2002
nor; *non-ripening*	Transcription factor	Comprehensive ripening	[a]
Nr; *Never-ripe*	C2H4 receptor	Ethylene signalling	Wilkinson *et al*., 1995
hp-2; *high-pigment-2*	DET1 homologue	Light signalling	Mustilli *et al*., 1999
cr; *crimson*	Lycopene cyclase	Carotenoid metabolism	Ronen *et al*., 2000
B; *Beta*	Lycopene cyclase	Carotenoid metabolism	Ronen *et al*., 2000
R; *Phytoene Synthase*	Phytoene synthase	Carotenoid metabolism	Fray and Grierson, 1993
t; *tangerine*	Carotenoid isomerase	Carotenoid metabolism	Isaacson *et al*., 2002
hp-1; *high-pigment-1*	NA	Light signalling	Yen *et al*., 1997
alc; *alcobaca*	NA	Comprehensive ripening	Kopeliovitch *et al*., 1981
Nr-2; *Never-ripe-2*	NA	Comprehensive ripening	Kerr, 1982
Gr; *Green-ripe*	NA	Comprehensive ripening	Kerr, 1981
Cnr; *Coulorless non-ripening*	NA	Comprehensive ripening	Thompson *et al*., 1999
gf; *green-flesh*	NA	Comprehensive ripening	Akhtar *et al*., 1999
at;apricot	NA	Carotenoid metabolism	Jenkins and Mackinney, 1955
gs; green stripe	NA	Fruit pigmentation	Rick and Butler, 1956

[a] J Vrebalov *et al*., unpublished data.

Ethylene and non-ethylene ripening control

Considerable research has been based on the tomato system specifically for the analysis of ethylene synthesis and signalling during ripening. The role of ethylene in facilitating climacteric ripening has been shown through the analysis of ethylene-inducible gene expression in tomato fruit (Lincoln *et al*., 1987; Maunders *et al*., 1987; Zegzouti *et al*., 1999). Reduced ethylene evolution resulted in ripening inhibition in fruit of ACC synthase and ACC oxidase antisense lines (Oeller *et al*., 1991; Hamilton *et al*., 1990) and the mutation of the *Nr* ethylene receptor results in non-ripening, ethylene-insensitive fruit (Wilkinson *et al*., 1995). Furthermore, the introduction of a dominant mutant allele of the *NR* ethylene receptor resulted in tomato, *Arabidopsis* and petunia plants inhibited in virtually every measurable ethylene response including fruit ripening (Wilkinson *et al*., 1997).

Careful analysis of transgenic and mutant tomato lines inhibited in ethylene biosynthesis or perception suggests that climacteric ripening represents a combination of ethylene regulation and developmental control. The term 'developmental control' is used here to signify aspects of ripening regulation operating independently from ethylene. For example, the gene encoding the rate-limiting activity in ethylene biosynthesis, ACC synthase, is itself initially induced during ripening by a signalling system other than ethylene (Theologis *et al*., 1993; Barry *et al*., 2000). Gene expression analysis indicates that 'developmental'or 'non-ethylene mediated' regulation has an impact on a number of ripening-related genes in tomato (Giovannoni, 2001).

Tomato ripening-inhibitor and non-ripening mutants

The strongest evidence for non-ethylene-mediated ripening control comes from the analysis of gene expression in fruit of the *rin* (*ripening-inhibitor*) and *nor* (*non-ripening*) tomato mutants that fail (a) to produce autocatalytic ethylene, (b) to ripen, and (c) to ripen in response to exogenous ethylene, yet display signs of ethylene sensitivity and signalling, including the induction of some ethylene-regulated genes (Tigchelaar *et al*., 1978; Yen *et al*., 1995). These results have been interpreted to indicate that higher order regulatory constraints are placed on climacteric fruit maturation in addition to general ethylene biosynthesis and signalling. Such regulatory mechanisms could include fruit-specific regulation of certain subsets of ethylene-regulated genes or regulatory mechanisms that operate separately and in addition to ethylene. Genes corresponding to both the *rin* and *nor* mutations have been recently cloned, and while unrelated at the level of DNA or peptide sequence, both have features suggestive of roles in regulation of gene transcription (Vrebalov *et al*., 2002; J Giovannoni *et al*., unpublished results). Both genes were isolated via positional cloning strategies. The details of *NOR* gene isolation are preliminary and will not be discussed further.

The *rin* locus was mapped to high resolution in an F_2 population resulting from an initial cross between *L. esculentum* (*rin/rin*) and the wild relative of tomato *L. cheesmannii* (*Rin/Rin*). *L. cheesmannii* was selected over the more divergent (and thus more likely to be polymorphic at marker loci) *L. pennellii* used in the development of the tomato genetic map, as F_2 progeny derived from *L. esculentum* by *L. pennellii* crosses have a high incidence of sterility resulting in few ripe fruit (Tanksley *et al*., 1992). Tightly linked RFLP markers were used both to isolate and to map a high molecular weight tomato genomic clone harbouring the targeted *rin* locus. This clone was subsequently labelled in total and used as a hybridization probe to identify cDNA sequences derived from this cloned segment of the tomato genome. Specifically, a breaker fruit cDNA library was screened and several classes of independent sequences were isolated. Two cDNAs resulting from this screen yielded different size RNA gel-blot hybridization signals when RNA from normal and nearly isogenic *rin* fruit were compared (Fig. 1). This result was the first clue that sequences derived from the mutant locus had indeed been isolated (Vrebalov *et al*., 2002).

RT-PCR and subsequent DNA sequencing of the two cDNAs which yielded alternate mRNA transcript sizes in *rin* fruit indicated that these sequences were fused into a chimeric gene in the *rin* mutant as a result of a genome deletion. Both genes are members of the MADS-box

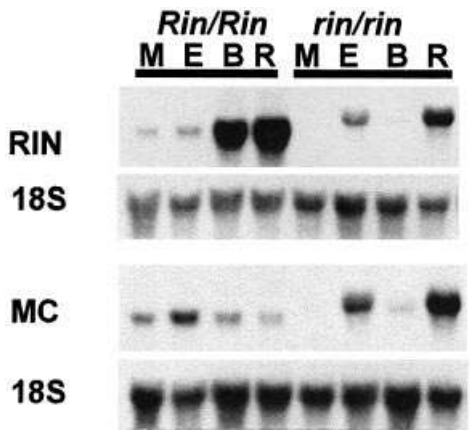

Fig. 1. Expression of the RIN and MC genes in maturing fruit. RNA gel-blot analysis of LeMADS-RIN (RIN) and LeMADS-MC (MC) transcript accumulation in mature green (MG), 12 h 20 ppm ethylene-treated mature green (E), breaker (B) and ripe (R) fruit tissues of wild-type (*Rin/Rin*) and mutant (*rin/rin*) fruit. Filters were stripped and hybridized to an 18R rRNA probe (18S) as control.

family of transcriptional regulators (Fig. 2). A combination of mutant complementation and antisense gene expression in *rin/rin* and *Rin/Rin* genotypes, respectively, indicated that one gene (*LeMADS-RIN*) regulates ripening while the other (*LeMADS-MC*) is responsible for the large sepal (*macrocalyx*) phenotype associated with the *rin* mutation (Vrebalov *et al*., 2002).

Phylogenetic analysis combined with detailed phenotypic characterization indicates that LeMADS-MC is likely to be the tomato orthologue of the *AP1* and *SQUA* genes of *Arabidopsis* and *Anthirhinum*, respectively (Fig. 2). *LeMADS-RIN* is most similar to the *SEP1* and *AGL3* genes of *Arabidopsis* (Fig. 2), but the expression patterns of these latter genes, and the phenotype attributed to SEP1 (there is no reported phenotype for an AGL3 mutation), are inconsistent with *LeMADS-RIN* expression or function. To assess whether LeMADS-RIN is likely to represent a conserved function among diverse fruit species a strawberry cDNA library was screened with the tomato cDNA and a gene (FvMADS-23) was recovered which demonstrates ripening-related gene expression (Fig. 2; Vrebalov *et al*., 2002). This result is especially interesting in that strawberry is a non-climacteric fruit with very different fruit morphology and development compared with tomato.

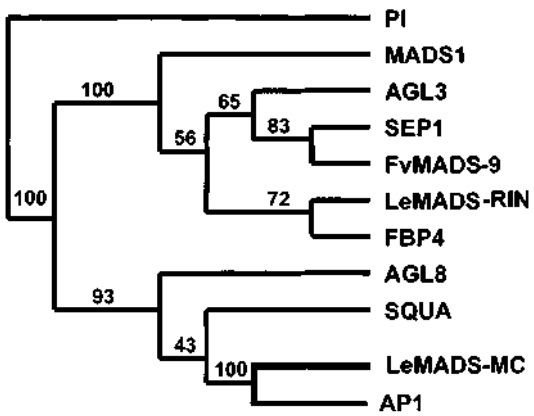

Fig. 2. Most parsimonious phylogenetic tree of MADS-box genes from tomato and additional plant species. Predicted MIK domain amino acid sequences (1–170) were derived from the LeMADS-RIN, LeMADS-MC, *Arabidopsis* (AP1, SEP1, AGL3, AGL8, PI), *Antirrhinum* (SQUA), petunia (FBP4), pepper (MADS1), tobacco (NAP1-2), and strawberry (FvMADS-9) MADS-box gene sequences and analysed with PYLIP3.5c (Phylogeny Inference Package). Specifically, the maximum parsimony, distance matrix and likelihood methods of the Protpars and Seqboot programs were used to estimate phylogenies (Felsenstein, 1995). The non-rooted phylogenetic tree was generated using the PYLIP3.5c program Consense with PI designated at the out group. The single most parsimonious tree obtained in a heuristic search following 100 random sequence addition replicates is shown. Bootstrap percentage supports are indicated at branches of the tree. Genbank accession numbers for sequences utilized in this phylogenetic analysis can be found in Vrebalov *et al*. (2002) and Alvarez-Buylla *et al*. (2000) and references therein, except for FvMADS-9 (J Vrebalov and J Giovannoni, unpublished results).

The cloning of these ripening regulatory genes should now foster analysis of steps in the ripening regulatory hierarchy preceding ethylene. These discoveries should also permit an assessment of whether or not such genes represent regulatory mechanisms common to both climacteric and non-climacteric fruit species. In addition, as many of the ripening-related genes which have undergone promoter analysis are impacted by the *rin* and *nor* mutations, the recent cloning of these putative transcription factors will provide opportunities to test for specific interactions of the RIN and NOR proteins with functionally characterized regulatory sequences. The tools for gene expression profiling described below will also facilitate characterization of the unique and overlapping regulatory effects of the *RIN* and *NOR* genes.

Tools for gene expression profiling

The increasing availability of efficient, high-throughput methodologies for cloning and sequencing have driven the development of novel discovery platforms able to exploit the increasing amounts of available genome data (Rounsley and Briggs, 1999, and references therein). Until recently, significant gene sequence and functional data for a given biological system was virtually non-existent or the result of painstakingly piecing together studies conducted over many years using classical approaches. New methodologies now allow for the expansion of the traditional platforms of using forward and reverse genetics to those that facilitate the examination of the behaviour of hundreds or thousands of genes simultaneously. In tomato, a collaborative NSF-funded effort has resulted in the construction and sequencing of cDNA libraries from a multitude of tissues and conditions, and the creation of a tomato EST database (Fig. 3; Quackenbush *et al*., 2000; Van der Hoeven *et al*., 2002). This information provides the foundation for parallel gene studies for the detection and quantitation of gene expression levels**.** Parallel studies can provide both static (e.g. examination of gene expression in a single tissue) and dynamic (comparative) information. There are multiple methodologies to achieve parallel analysis, ranging from traditional RNA gel blots and RT-PCR to those providing a more global view including differential display (Liang and Pardee, 1992), serial analysis of gene expression (SAGE, Velculescu *et al*., 1995), and microarrays (Schena *et al*., 1995),

Microarrays allow for the analysis of expression patterns of thousands of genes within the confines of a single experiment (Fig. 4). Arrays are descendants of DNA gel-blot (Southern)-based assays that capitalize on interactions between complementary strands of DNA (Southern, 1975). The inclusion of a solid glass substrate, precision robotics, and fluorescence-based detection methods provide expres-

sion arrays with increased accuracy, speed, and scale over their filter- and radioactivity-based relatives.

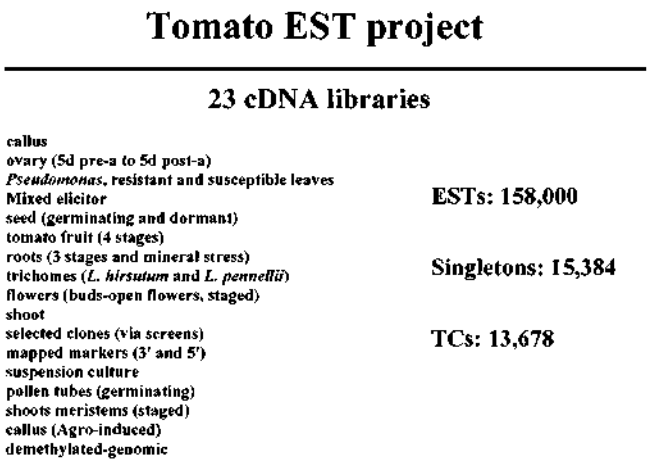

Fig. 3. Origins and summary of tomato EST collection.

Microarrays can be constructed using either PCR-amplified cDNAs or oligonucleotides. Arrays based on amplified expressed sequence tags (ESTs) are the most popular candidates for micro-spotting. ESTs are usually generated by single-pass sequencing 300–900 bases from the 5′ end of cDNA clones. EST sequence and homology information provide a distinct and obvious advantage in expression studies compared with the use of anonymous clones, as immediate functional implications can often be made based on sequence homologies.

Unique DNAs are printed onto chemically coated glass microscope slides to create microarrays. Glass provides an excellent platform with low inherent fluorescence resulting in negligible intrinsic background levels. Glass also presents a non-porous surface important for preventing diffusion of deposited samples and thus allowing utilization of minimum hybridization volumes. Glass slides also allow for miniaturization and the easy storage of arrays (Schena, 1999; Duggan and Bittner, 1999; Zammatteo *et al*., 2000).

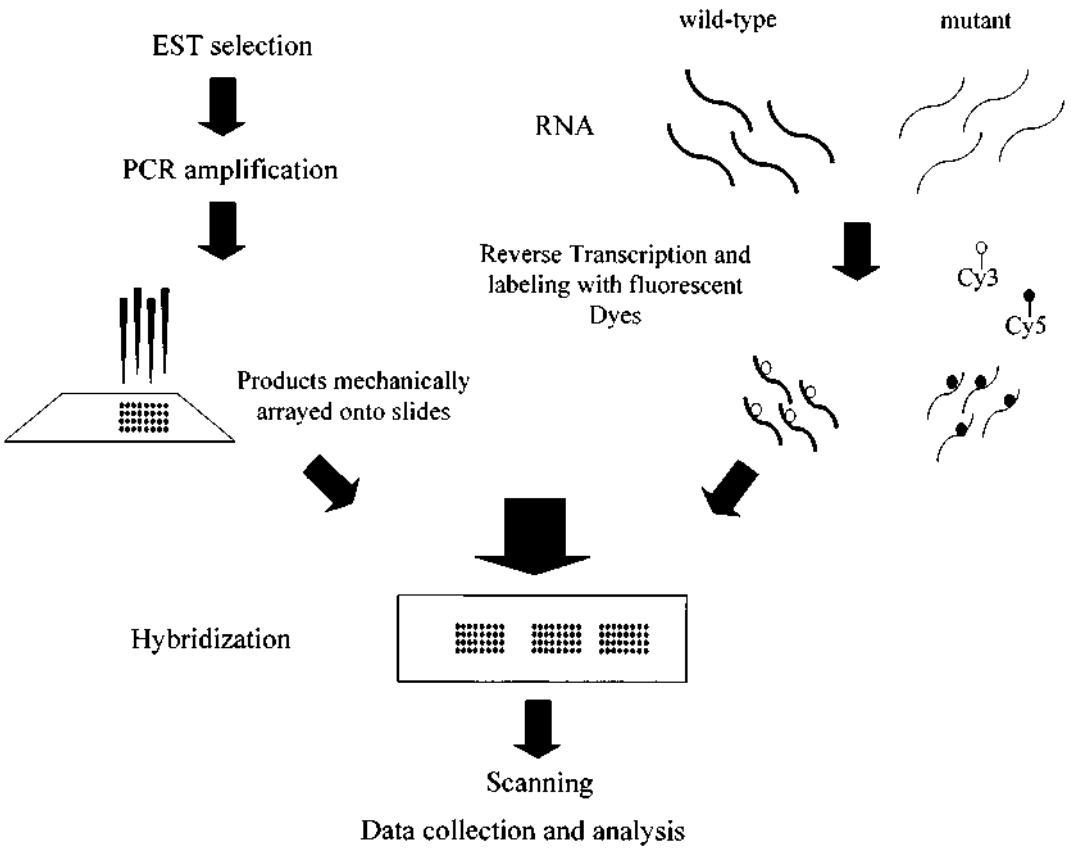

Fig. 4. Tomato microarrays. ESTs were sequenced from cDNA libraries (Fig. 3) and sequences were aligned to determine redundancy using TIGR assembler software (TIGR). Selected ESTs were re-arrayed into 96 well plates, clones were amplified by PCR and then robotically arrayed onto poly-L-lysine-coated glass microscope slides. Fluorescently labelled cDNA probes were prepared using the 3DNA Expression Array kit from Genisphere, Inc. Probes were synthesized from 50 μg of total RNA isolated from tissues of interest, labelled with either Cy3 or Cy5, and simultaneously hybridized at high stringency to arrayed EST sequences. Hybridization intensities are measured with a GenScan 5000 laser scanning (GSI Lumonics, CA) and data analysis is performed utilizing Imagene and Gene Sight software (Biodiscovery, CA).

Table 2. *Examples of differentially expressed genes recovered by microarray analysis*

The expression profiles of several previously characterized genes were utilized to validate successful performance of our cDNA microarray experiments. The genes are listed with their corresponding EST numbers and the normalized expression ratios from two experiments, Breaker fruit (BB)/mature green fruit (MG) and red ripe (RR)/mature green fruit.

	EST	BB/MG	RR/MG	Reference
Phytoene synthase (PSY)	412510	8.4	1.6	Giuliano *et al*., 1993
E8	357397	28.6	6.2	Cordes *et al*., 1989
Expansin	319975	5.5	2.0	Rose *et al*., 2000
Polygalacturonase-2a	299443	16.2	3.4	Osteryoung *et al*., 1990

Probes for transcript analysis are constructed by incorporating fluorescent molecules into cDNAs created from a single round of reverse transcription (Schena *et al*., 1995; DeRisis *et al*., 1996). Our group utilizes protocols and procedures provided by Genisphere Inc. Probes from two tissues to be compared (e.g. wild type and mutant or +/– a given treatment) are labelled with different fluorescent dyes and applied simultaneously to the array. Visualizing hybridized arrays requires excitation of bound fluorochromes by a laser source, collection of the emitted fluorescence through a series of filters which block reflected and scattered excitation energy, and conversion of the focused energy to an electrical signal by a photomultiplier (Montagu and Weiner, 1999; Brignac *et al*., 1999).

The output from scanning a hybridized array is typically a simple TIFF or bitmap image. Perhaps the most difficult and challenging aspect of microarray experiments is data analysis, as a single experiment appropriately replicated can typically produce thousands of data points. There are currently multiple software programs available and many more under development. Many available programs are variations of similar themes and have features to facilitate the following data manipulations, locate spots, normalize signal, quantify intensities, subtract out background, and generate a report which can be downloaded in a simple format for subsequent analysis in general or customized software packages (Ermolaeva *et al*., 1998; Chen *et al*., 1997; Bard, 1999; Baldwin *et al*., 1999; Bowtell, 1999).

Expression profiling of tomato fruit ripening

Important new resources that are available for tomato include substantial sequence information, the EST database, and microarray technology (http://www.sgn.cornell.edu/). These tools are now allowing tomato and Solanaceae researchers to expand the platforms available for answering general biological questions. A cDNA microarray has recently been constructed with the purpose of answering questions about fruit development and ripening. A time-course of ten intervals has been established, spanning fruit development from 7 d post anthesis to 15 d past breaker. The time-points were selected to represent biologically significant stages in the fruit developmental process (e.g. cell division, cell expansion, onset and continuation of ripening). Initially, the focus was on using Ailsa Craig (Ac) to establish a baseline of wild-type gene expression. However, an investigation into multiple ripening-related mutants has been started in order to expand information on their specific functions and effects. Mutations targeted for comparative analysis to the normal expression profile include those known to be altered in their perception to light (*hp-1*), ethylene (*Nr*) and other aspects of ripening (*rin, nor*) (Table 1; Giovannoni, 2001, and references therein).

Probes for array experiments were constructed for each stage and used in step-wise dual hybridizations (e.g. 1 d versus 10 d, 10 d versus 20 d, etc). The hybridizations were performed in multiple replications and included 'dye-swap' experiments in an attempt to compensate for any variability in signal intensity due solely to the characteristics of the individual fluorochrome. The resulting data has allowed a comparative analysis of genome-wide transcript accumulation during fruit ripening and development for a subset of genes to begin. Although there are defined patterns of differential expression for each stage in development, there is also a dramatic increase in the number of differentially expressed genes that corresponds with the onset of ripening. This set includes ESTs with putative homology to genes known to be involved in ethylene synthesis, carotenoid accumulation and cell wall modifications, in addition to others known to be ripening regulated (Table 2). As analysis of the initial developmental profile is completed, it may become possible to make predictions about ESTs with little or no known homology, based upon their expression patterns and how they relate to genes that have been extensively characterized. By developing expression profiles and co-ordinating them with other tools such as analysis of the tomato proteome, further elucidation of the underlying genetic and molecular events contributing to fruit development and ripening phenomenon will be possible.

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Differential Gene Expression in Response to Mechanical Wounding and Insect Feeding in Arabidopsis

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Wounding in multicellular eukaryotes results in marked changes in gene expression that contribute to tissue defense and repair. Using a cDNA microarray technique, we analyzed the timing, dynamics, and regulation of the expression of 150 genes in mechanically wounded leaves of Arabidopsis. Temporal accumulation of a group of transcripts was correlated with the appearance of oxylipin signals of the jasmonate family. Analysis of the coronatine-insensitive *coi1-1* Arabidopsis mutant that is also insensitive to jasmonate allowed us to identify a large number of *COI1*-dependent and *COI1*-independent wound-inducible genes. Water stress was found to contribute to the regulation of an unexpectedly large fraction of these genes. Comparing the results of mechanical wounding with damage by feeding larvae of the cabbage butterfly (*Pieris rapae*) resulted in very different transcript profiles. One gene was specifically induced by insect feeding but not by wounding; moreover, there was a relative lack of water stress–induced gene expression during insect feeding. These results help reveal a feeding strategy of *P. rapae* that may minimize the activation of a subset of water stress–inducible, defense-related genes.

INTRODUCTION

Wounding is a continual threat to the survival of all organisms. Responses to wounding have been extensively studied in plants, which in the wild seldom escape some degree of damage from environmental stresses such as wind, sand, hail, and rain. An open wound caused by mechanical wounding is a potential infection site for pathogens; thus, expression of defense genes at the wound site is a barrier against opportunistic microorganisms. Plants respond to mechanical wounding with the induction of numerous genes. The first identified wound-inducible defense proteins in plants include proteinase inhibitors I and II from potato and tomato (Graham et al., 1986; Ryan, 1990).

In Arabidopsis, many genes have been shown to be induced by mechanical wounding (reviewed in Reymond and Farmer, 1998). The expression of many of these genes is induced by treatment with jasmonic acid (JA) or with its precursor oxophytodienoic acid (OPDA); these compounds, which are both members of the jasmonate family (Creelman and Mullet, 1997; Farmer et al., 1998), are essential in vivo regulators of defense gene expression (Reymond and Farmer, 1998). Other signals and stimuli also lead to the expression of genes in wounded plant tissues, although the relative contribution of molecules such as ethylene (O'Donnell et al., 1996; Rojo et al., 1999) and abscisic acid (Pena-Cortés et al., 1989; Birkenmeier and Ryan, 1998) and of electrical signals (Wildon et al., 1992) is still unclear. The importance of water stress/hydraulic pressure changes to gene expression during wounding has received even less attention (Malone and Alarcon, 1995).

A large proportion of multicellular eukaryotes eat plants, and a particularly common source of injury to plants is insect herbivory. Inevitably, insect feeding causes wounding of the plant, but little is known about how plants distinguish and respond to the very different threats posed by mechanical wounding and herbivory. Although reports show that some genes or proteins can be activated by both mechanical wounding and insect challenge (Howe et al., 1996; Stratmann and Ryan, 1997), other observations have revealed responses that are induced specifically or activated more rapidly by damage from insects. Differences have been observed in the expression of several wound-induced genes (Korth and Dixon, 1997) and also in the release of volatiles (Paré and Tumlinson, 1997). A study of insect damage to plants has led to the discovery of volicitin, a factor in insect saliva that elicits the production of plant volatiles, which then attract predatory insects to the herbivore insects (Alborn et al., 1997). As occurs with mechanical wounding, in which jasmonates play important roles in gene expression, the ability of plants to produce or perceive members of the jasmonate family of regulators is essential for their defense against

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tobacco hornworm (Howe et al., 1996) and fungus gnats (McConn et al., 1997).

In this study, our goal was to better understand how plant responses to mechanical wounding differ from those to insect feeding. An answer to this question is important because insects have probably evolved strategies to avoid activating the expression of at least some plant defense processes. We first studied gene expression dynamics in mechanically wounded Arabidopsis leaves by using a cDNA microarray that included 150 defense-related genes. We then dissected the signal requirements for the expression of wound-inducible genes, using Arabidopsis mutants impaired in the jasmonate and ethylene perception pathways. From these results, we determined which signal pathways are selectively activated by a feeding insect and which categories of genes escape activation during feeding. Our results illustrate fundamental differences in responses to damage caused by mechanical wounding and to damage from insect feeding; they also help to link feeding strategy to molecular responses in the plant.

RESULTS

Construction of a cDNA Microarray Containing Arabidopsis Defense-Related Genes

We used a previously described method (Eisen and Brown, 1999) to array a total of 150 polymerase chain reaction (PCR)–amplified double-stranded expressed sequence tags (ESTs) onto glass slides. Data on the ESTs that were used, the layout of the microarray, as well as extensive technical details can be found at http://www.unil.ch/ibpv. The array contained many of the commonly studied genes implicated in Arabidopsis defense and included many genes for which we only recently collated data on inducible expression (Reymond and Farmer, 1998). Genes of potentially related function are displayed in five separate domains: pathogenesis-related (PR) genes; general defense and stress-related genes (e.g., those encoding components of the myrosinase system as well as oxidative stress-related genes); genes involved in fatty acid signaling and metabolism; genes of aromatic amino acid metabolism; and genes involved in signal transduction, regulatory functions, or other (unknown) functions.

We included 16 genes for which the expression was unlikely to vary greatly during experiments (e.g., tubulin, actin, and translation elongation factors); these allowed us to calibrate the signal output and correct for sample-to-sample variability. In some cases, a so-called control gene showed a more than twofold variation in expression after wounding and thus could not be used for calibration. This speaks for the use of as many control genes as possible for data normalization.

Finally, three animal genes having no substantial homology to any sequence in the Arabidopsis database were printed on the microarray to assess for nonspecific hybridization. One of them, the peroxisome proliferator-activated receptor (*PPAR*α) gene, consistently produced a hybridization signal well above background and might have some degree of homology to an as yet unknown Arabidopsis sequence. The other two clones always produced a signal close to the background level (data not shown).

Dynamics of Wound-Inducible Gene Expression

The temporal program of transcription was studied in mechanically wounded Arabidopsis leaves. Leaves of 6- to 7-week-old plants were wounded with a forceps across the apical 40% of the lamina surface. At seven time points up to 24 hr after the wounding, leaves were detached and mRNA was purified. The cDNA made from each sample was labeled with the fluorescent dye Cy5 and mixed with a reference probe consisting of cDNA made from mRNA from unwounded plants and labeled with a second fluorescent dye, Cy3. The two populations of labeled cDNAs were simultaneously hybridized with the cDNA microarray; after scanning each fluor, the signal intensity for each gene was integrated. A pseudocolor image of the results obtained for one time point (60 min after wounding) is shown in Figure 1. Here, marked changes in transcript levels relative to those in the control plants are visible. The expression of each gene was calculated for the complete time course, and a hierarchical clustering program (Eisen et al., 1998) was used to analyze a subset of 91 genes for which expression changed substantially in response to wounding.

Figure 2 illustrates that use of this clustering program allowed grouping of genes with similar expression profiles during the time course. Various patterns of gene expression were observed, including early, mid-, and late gene induction as well as early repression of gene expression. By 15 min after wounding, the expression of 20 genes was already induced, including, for example, *PR-1, PR-2, PR-5*, touch genes (*TCH2, TCH3,* and *TCH4*), and genes encoding mitogen-activated kinases (*MPK3* and *MEKK1*). In several cases (e.g., *PR-1* and *MPK3*), the increase in transcript abundance was short-lived and fell rapidly to the base value. The number of upregulated genes increased to 39 at 90 min but was only 13 at 9 hr after wounding and seven by 24 hr after wounding.

One measure of the reproducibility of the changes we observed in gene expression is exemplified in Figure 2, in which, for most genes, we could see a gradual change over a few time points. This effectively provided independent measurements for all of the observations. To better assess the reproducibility of the microarray technique under our laboratory conditions, we performed nine independent replications of the same experiment. Arabidopsis leaves were wounded, RNA was isolated after 90 min, and labeled

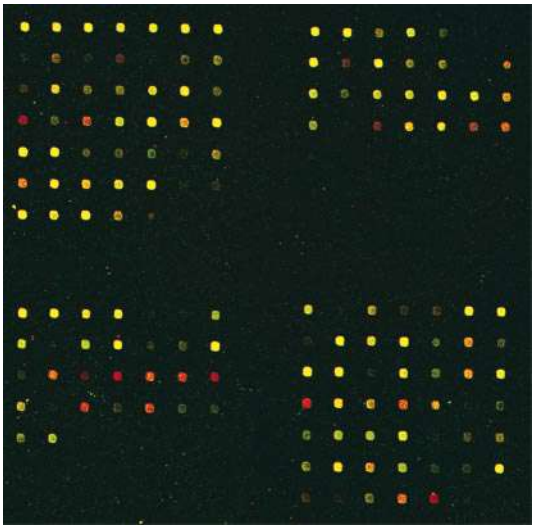

Figure 1. cDNA Microarray Analysis of Gene Expression after Mechanical Wounding.

A fluorescently labeled cDNA probe was prepared from mRNA isolated from control Arabidopsis leaves by reverse transcription in the presence of Cy3-dCTP. A second probe, labeled with Cy5-dCTP, was prepared from leaves that were mechanically wounded (60 min). After the simultaneous hybridization of both probes with a cDNA microarray containing 150 defense-related Arabidopsis ESTs and scanning of the array, a pseudocolor image was generated. Genes induced or repressed after mechanical wounding are represented as red or green signals, respectively. Genes expressed at approximately equal levels between treatments appear as yellow spots. The intensity of each spot corresponds to the absolute amount of expression of each gene. The actual size of the array is 8 × 8 mm. Control genes are in the first row of top left, top right, and bottom left quadrants.

mRNA samples from control and treated plants were hybridized with a microarray. The average expression ratios calculated for the nine independent experiments are shown in Figure 3 for a set of representative genes and illustrate the small variability in the measurements. In some cases in which duplicate genes were included, highly similar values were obtained (Figure 3). In addition, hybridization of different microarrays with the same mRNA samples indicated good correlation (data not shown).

The time-course analysis of gene expression revealed groups of genes with similar behavior (Figure 2). One implication of a common temporal pattern of expression is that genes might share similar or related roles in cellular processes, or they might be regulated by the same signal molecules. Figure 4A shows the mean expression ratios of a group of 17 transcripts that had similar temporal expression profiles. Among these are two genes (*LOX2* and *AOS;* Table 1) implicated in the synthesis of JA as well as a gene known to be induced by jasmonate, *JR3*. Moreover, JA and its

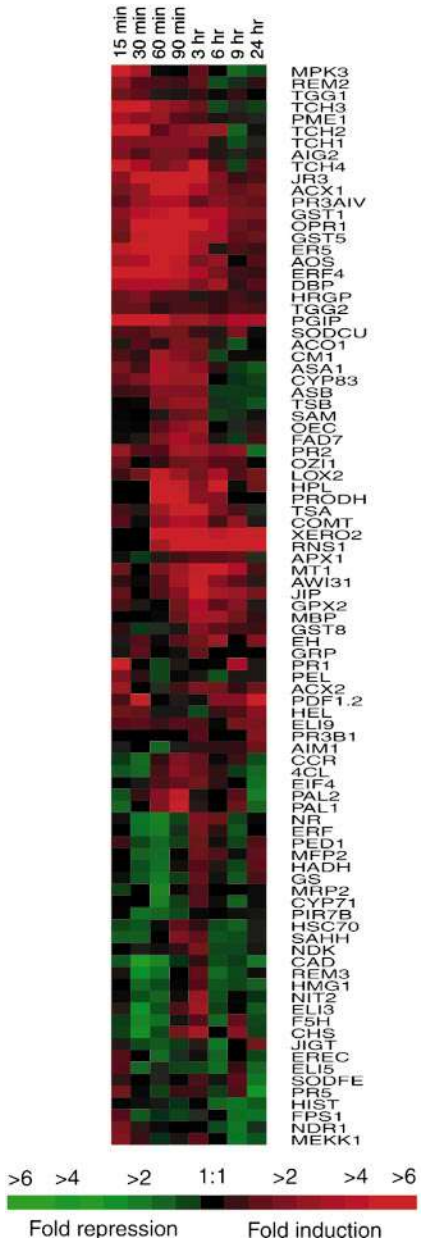

Figure 2. Clustered Display of Data from the Time Course of Mechanical Wounding.

A time course of wound-inducible gene expression in Arabidopsis leaves was constructed using cDNA microarrays. For simplicity, only those genes for which the transcript levels changed substantially as a result of wounding are included. Genes were ordered using a clustering program (see Methods) so that those with similar expression patterns would be grouped together. Each gene is represented by a single row of colored boxes, and each time point is represented by a single column. Induction (or repression) ranges from pale to saturated red (or green). The numbers of independent experiments were as follows: 15 min, 2; 30 min, 1; 60 min, 2; 90 min, 9; 3 hr, 3; 6 hr, 2; 9 hr, 1; and 24 hr, 1.

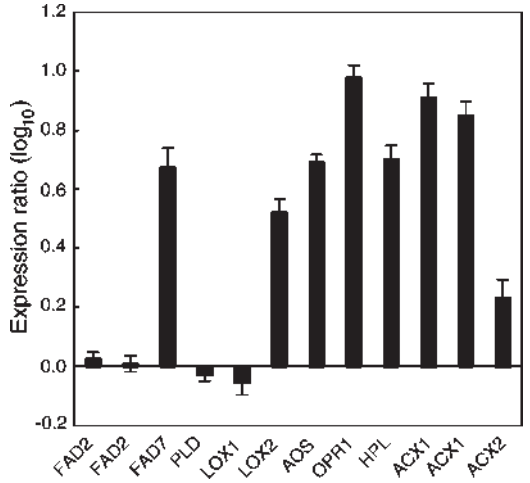

Figure 3. Reproducibility of cDNA Microarray Experiments.

mRNA samples (2 μg) from Arabidopsis leaves harvested 90 min after wounding or from control Arabidopsis leaves were labeled with Cy5 or Cy3, respectively, and hybridized with a cDNA microarray. After scanning each fluor separately, the fluorescent signal intensity was integrated and corrected for local area background. Expression ratios between treated and control samples were calculated. Results are shown for a set of representative wound-inducible genes. Values ±SE represent the average of nine independent experiments. Genes shown in duplicate (*FAD2* and *ACX1*) are represented by two different ESTs on the microarray, which show highly similar expression ratios.

precursor OPDA as well as its C_{16} carbon homolog dinor OPDA are known to accumulate in wounded plant tissues (Albrecht et al., 1993; Parchmann et al., 1997; Weber et al., 1997). By using the oxylipin signature technique (Weber et al., 1997), we were able to measure simultaneously the concentrations of OPDA, dinor OPDA, and JA throughout the time course of the wounded Arabidopsis leaves and to compare these contents with the induction of a subset of genes likely to be controlled by jasmonates. Figure 4B shows that JA reached a peak 2 hr after wounding, in striking agreement with the rise of the transcript levels shown in Figure 4A. In contrast, both OPDA and dinor OPDA levels rose more slowly, peaking ~6 hr after wounding.

Several Signal Pathways Regulate Wound-Inducible Gene Expression

To assess the in vivo role of jasmonates in wound-induced gene expression, we conducted experiments using jasmonate-insensitive mutants. The well-characterized coronatine-insensitive *coi1-1* mutant is insensitive to JA (Feys et al., 1994). Wound-inducible gene expression was analyzed in wild-type and *coi1-1* Arabidopsis plants. As Figure 5A shows, half of the genes that are normally induced after wounding in wild-type plants were no longer induced in the mutant, and two transcripts (*NPR1* and *MPK;* Table 1) were induced only in *coi1-1* plants. This latter finding was confirmed by RNA gel blot analysis for *MPK3* (Figure 5B). Results from microarray experiments allowed us to define two basic classes of wound-inducible genes, as shown in Table 1: a group of *COI1*-dependent genes for which induction, or repression, by wounding depends strictly on the ability of

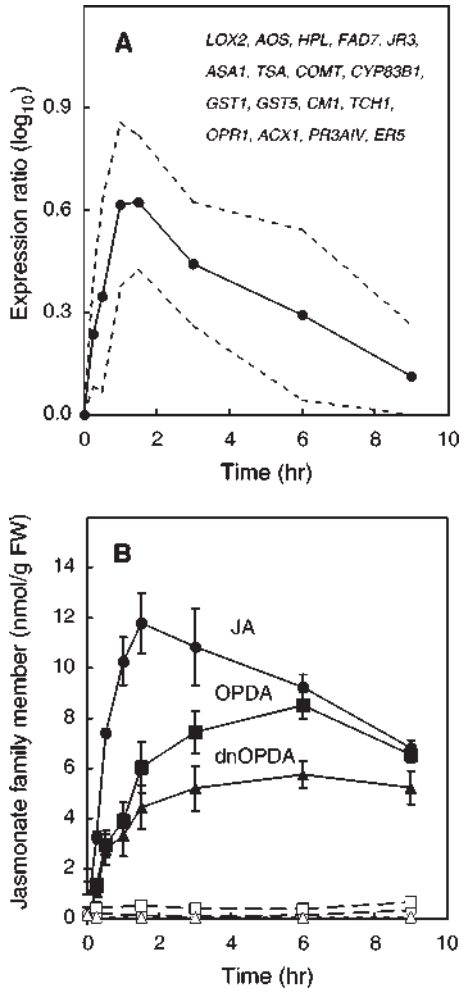

Figure 4. Comparison between the Expression of a Subset of Genes and the Levels of Jasmonate Family Members after Mechanical Wounding.

(A) The average expression profile of a cluster of genes showing a similar temporal expression profile is represented. Dashed lines indicate standard deviation. For experimental details, see Figure 2.

(B) Arabidopsis leaves were extracted at different times, and the tissues were analyzed for JA (circles), OPDA (squares), and dinor OPDA (dnOPDA, triangles) content in both wounded (solid lines) and control (dashed lines) plants. Mean values ±SE were calculated for three plants. FW, fresh weight.

Table 1. Relative Transcript Abundance after Wounding, Dehydration, or Insect (*Pieris rapae*) Feeding[a]

		Wounding		Dehydration	*P. rapae*
Gene	Description[b]	Wild Type	*coi1-1*	Wild Type	Wild Type
COI1-dependent genes[c]					
ACO1	Aminocyclopropane–carboxylic acid oxidase	2.2	1.8	1.2	1.5
ASA1	Anthranilate synthase (α subunit)	3.1	1.0	2.7	1.7
ASB	Anthranilate synthase (β subunit)	2.3	1.2	2.5	1.7
AOS	Allene oxide synthase	4.8	0.6	4.8	2.1
AWI31	Unknown	2.7	1.7	2.2	1.8
CCR	Cinnamoyl–coA reductase	2.1	1.2	2.4	1.3
CHS	Chalcone synthase	2.0	1.0	3.0	2.1
4CL	4-Coumarate:coA ligase	2.8	1.5	2.0	1.3
COMT	*O*-methyltransferase	4.7	1.6	3.6	1.4
CYP83B1	Cytochrome P450	2.9	1.0	4.4	1.8
FAD7	Fatty acid desaturase	4.7	1.2	2.7	1.5
HEL	Hevein-like protein	1.1	1.2	0.7	2.8
HPL	Hydroperoxide lyase	4.8	1.0	7.1	2.2
JIP	Jasmonate-inducible protein	2.9	1.6	2.5	3.1
JR3	Aminohydrolase	9.3	1.9	8.9	3.6
LOX2	Lipoxygenase	3.2	0.7	4.9	2.3
MBP	Myrosinase binding protein	2.6	1.0	2.2	2.1
MPK3	Mitogen-activated protein kinase	0.9	2.2	1.1	1.5
MT1	Metallothionein	2.2	1.5	1.9	2.1
NPR1	Transcription factor inhibitor	1.2	2.4	0.9	1.0
PAL2	Phenylalanine ammonia-lyase	5.6	1.4	1.1	0.3
PR-2	β-1-3-Glucanase	3.0	1.5	3.8	1.6
SAHH	*S*-adenosyl-L-homocysteine hydrolase	2.2	1.4	1.2	1.0
TSA	Tryptophan synthase (α subunit)	6.3	1.0	3.7	2.0
TSB	Tryptophan synthase (β subunit)	2.7	1.3	2.6	1.8
COI1-independent genes[c]					
ACX1	Acyl-coA oxidase	8.3	2.4	12.6	1.7
CM1	Chorismate mutase	2.1	2.1	2.6	1.7
DBP	Oligogalacturonide binding protein homolog	2.7	2.6	2.3	1.4
ER5	Late embryogenesis abundant-like protein	6.6	13.8	11.2	2.4
ERF4	Ethylene-responding factor	4.0	3.1	4.6	2.2
GPX2	Glutathione peroxidase	2.0	2.3	4.9	1.7
GST1	Glutathione *S*-transferase	9.2	12.0	2.2	2.1
GST5	Glutathione *S*-transferase	6.2	2.7	11.5	2.9
OEC	Oxygen-evolving protein	3.0	2.5	2.1	1.2
OPR1	OPDA reductase	9.3	7.7	1.5	1.7
PAL1	Phenylalanine ammonia-lyase	3.8	2.1	3.5	1.6
PGIP	Polygalacturonase-inhibiting protein	2.9	7.3	4.5	1.8
PME1	Pectin methyl esterase	2.0	2.2	0.7	1.1
PR3AIV	Chitinase	2.9	7.6	0.7	1.8
PRODH	Proline dehydrogenase	11.6	10.4	0.03	2.4
TCH1	Calmodulin	2.4	5.2	1.4	1.6
TCH2	Calmodulin-related protein	2.4	4.5	0.8	1.3
TCH3	Calmodulin-related protein	2.4	4.6	0.3	1.3
TCH4	Endotransglycosylase	3.7	3.7	1.0	1.9
RNS1	RNase	64.6	52.4	22.1	2.3
XERO2	Dehydrin-like protein	23.8	83.4	13.9	3.1

[a] Samples from wounded (90 min), dehydrated (120 min), or insect-challenged (180 min) Arabidopsis leaves were fluorescently labeled with Cy5-dCTP, and respective control samples (untreated) were labeled with Cy3-dCTP. After hybridization with a cDNA microarray and scanning, expression ratios were calculated. Ratios correspond to fluorescent values from treated plants relative to untreated plants.

[b] For further details, see http://www.unil.ch/ibpv.

[c] Genes induced (having a ratio >2.0) in wild-type plants after wounding as well as the *P. rapae*–inducible *HEL* and two genes (*MPK3*, *NPR1*) only induced in the wounded *coi1-1* mutant are included. Genes that are induced after wounding in both wild-type and *coi1-1* plants are considered independent of the *COI1* pathway. Our classification of *COI1*-dependent or -independent genes simplifies data analysis; we do not imply that this simplification exists in nature.

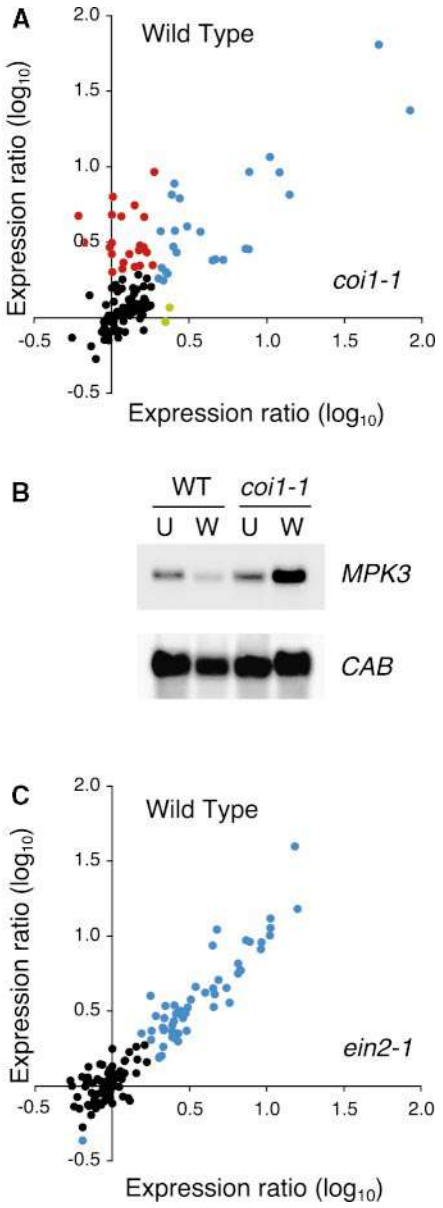

Figure 5. Contribution of Jasmonates and Ethylene to Wound-Inducible Gene Expression.

Relative changes in Arabidopsis gene expression after wounding of leaves for 90 min were studied in mutants. Expression ratios calculated from experiments comparing unwounded with wounded wild-type plants are plotted against expression ratios from experiments comparing unwounded with wounded mutant plants (**[A]** and **[C]**). Black dots represent genes that did not substantially change expression after wounding in both the wild type and mutants (based on the threshold of a twofold change). Blue dots represent genes that were induced (or repressed) in both wild-type and mutant plants. Red dots represent genes that were induced only in wild-type plants. Green dots represent genes (*NPR1* and *MPK3*) that were induced only in mutant plants.

(A) Jasmonate-insensitive mutant *coi1-1.*

(B) RNA gel blot analysis of *MPK3* mRNA accumulation 90 min after wounding of wild-type (WT) or *coi1-1* plants. A chlorophyll *a/b* binding protein probe (*CAB*) was used as a control for equal RNA loading. U, unwounded; W, wounded.

(C) Ethylene-insensitive mutant *ein2-1*.

Each scatter plot represents the mean of two independent experiments.

the plant to respond to JA; and a group of *COI1*-independent genes that are induced in the absence of JA signal transduction. Among the *COI1*-independent genes were some transcripts that had a temporal pattern of expression similar to the changes in JA concentrations (Figures 4A and 4B).

To find a potential signal involved in the induction of the *COI1*-independent group of genes, we investigated the role of ethylene in wounding. Ethylene is essential for the wound induction of proteinase inhibitors in tomato (O'Donnell et al., 1996), and the induction of a transcript encoding an ethylene-responding factor (*ERF4*) during wounding was noted in our experiments. Therefore, we investigated the effects of wounding the leaves of an Arabidopsis *ein2-1* mutant, which is insensitive to ethylene (Guzman and Ecker, 1990). Surprisingly, in plants from two different batches of *ein2-1* seeds, wounding induced the same sets of genes as those induced in wild-type plants, and the degree of induction was very similar in both cases, as depicted in Figure 5C. This implies that none of the wound-inducible genes represented on this microarray requires ethylene to respond to wounding under the experimental conditions described in this study.

Searching for another potential stimulus responsible for the induction of *COI1*-independent genes, we noticed the strong wound activation of genes (*XERO2* and *ER5;* Table 1) that are also induced by water stress (Rouse et al., 1996; Zegzouti et al., 1997). Therefore, we investigated the possible contribution of water stress to the expression of wound-inducible genes. Intact rosettes were gently cut away from their roots and were allowed to dehydrate in the air until they had lost 20% of their water (2 hr). Gene expression profiles were compared with those in control plants. Water stress was found to have a powerful effect on transcript levels: 58 genes on the array more than doubled their expression, and 31 of those were wound inducible (Table 1), including 13 *COI1*-independent genes. An interesting case was the gene encoding proline dehydrogenase (*PRODH*), which is repressed by water stress but induced by wounding.

Transcript Signatures in Wounding, Dehydration, and Insect Feeding

To investigate differences between mechanical damage and insect feeding, we allowed the larvae of the cabbage butterfly *Pieris rapae* to feed on the leaves of wild-type Arabidopsis plants until ~40% of the leaf surface had been removed.

At this point, a range of abandoned and newly started feeding sites was observed on the leaves. Insects were removed, and mRNA was extracted from the leaves for analysis. Figure 6A shows a direct comparison of gene expression in leaves damaged by *P. rapae* and in mechanically wounded leaves. Many transcripts were induced by both treatments, but generally, they were induced to higher levels in the mechanically wounded leaves. Many wound-inducible genes were not induced by the insect feeding (e.g., *PGIP, COMT, TCH1, OPR1,* and *ASA1*; Table 1). Only one gene, encoding a hevein-like protein (*HEL*), was induced by *P. rapae* but not by mechanical wounding. This observation was confirmed by RNA gel blot analysis (Figure 6B). Experiments with larvae of the closely related pierid *P. brassicae* yielded remarkably similar results (data not shown). Again, *HEL* was specifically induced by the insect.

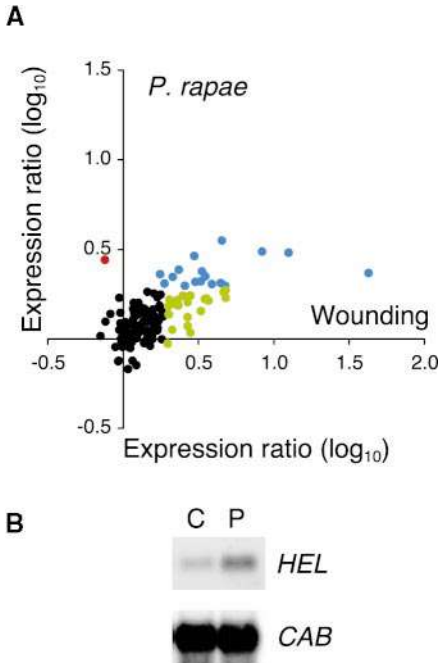

Figure 6. Comparison between Effects of Mechanical Wounding and Insect Feeding.

(A) Relative changes in gene expression were measured 3 hr after wounding Arabidopsis leaves and after challenging leaves with *P. rapae* larvae for 3 hr. Expression ratios calculated from experiments comparing unwounded with wounded plants are plotted against expression ratios from experiments comparing unchallenged with insect-challenged plants. Black dots represent genes that showed no marked change in expression after wounding or insect challenge (based on the threshold of a twofold change). Blue dots represent genes that were induced in both treatments. The red dot represents a gene (*HEL*) that was induced only in insect-challenged plants. Green dots represent genes that were induced only after mechanical wounding.

(B) RNA gel blot analysis of *HEL* mRNA accumulation in leaves challenged for 3 hr with *P. rapae* larvae. A chlorophyll *a/b* binding protein probe (*CAB*) was used as a control to assess equal RNA loading. C, unchallenged; P, *P. rapae*.

A comparison of data sets from mechanical wounding, dehydration, and insect feeding allowed us to recognize different patterns of gene expression, as illustrated in Figure 7 with a set of representative genes. We observed that some genes were induced in all treatments, some induced transcripts were common to mechanical wounding and dehydration, and others were unique to each treatment. Some of these marker genes (Figures 7A and 7C) will provide a good tool for the further analysis of signaling pathways specifically involved in the responses to mechanical wounding or insect damage. We found no examples of genes that were induced by both dehydration and insect feeding but not by mechanical wounding. The transcript signature of mechanical wounding was more similar to that of dehydration than to that of insect feeding (Figure 7).

DISCUSSION

In this study, we used cDNA microarrays to identify a number of Arabidopis genes for which we were unable to find reports of wound induction in the literature. The data also confirmed previous studies of other genes for which activation by wounding was described (Reymond and Farmer, 1998). Mechanical wounding of Arabidopsis leaves initiated important and dynamic changes in gene expression (Figures 1 and 2). In response to a punctual mechanical wound, the transcript levels for many genes increased to maximum values 90 to 120 min after wounding and then began to subside toward the baseline. Several families of transcripts showed coordinated induction, including genes from the tryptophan pathway (*ASA1, ASB, TSA,* and *TSB*), touch genes (*TCH1, TCH2, TCH3,* and *TCH4*), or genes implicated in aromatic metabolism (*CHS, CCR, 4CL COMT,* and *PAL*). The concerted induction of metabolic cassettes implies tight control of expression among genes with potentially related functions and opens the door for comparative studies using conserved elements in the regulatory regions of these genes.

Another example is provided by genes involved in the synthesis or metabolism of members of the jasmonate family (*FAD7, LOX2,* and *AOS*), which are coordinately induced during wounding (Figure 4A). Concomitantly with changes in gene expression, the amounts of three members of the jasmonate family—OPDA, dinor OPDA, and JA—transiently increased (Figure 4B). The results revealed that temporal changes in JA content correlate tightly with the induction of a group of genes, including genes involved in JA biosynthesis. Moreover, the relative proportion of JA to the cyclopentenones OPDA and dinor OPDA constantly changed during wounding. Shortly after the wound stimulus, molar amounts of JA exceeded the combined quantities of OPDA and dinor

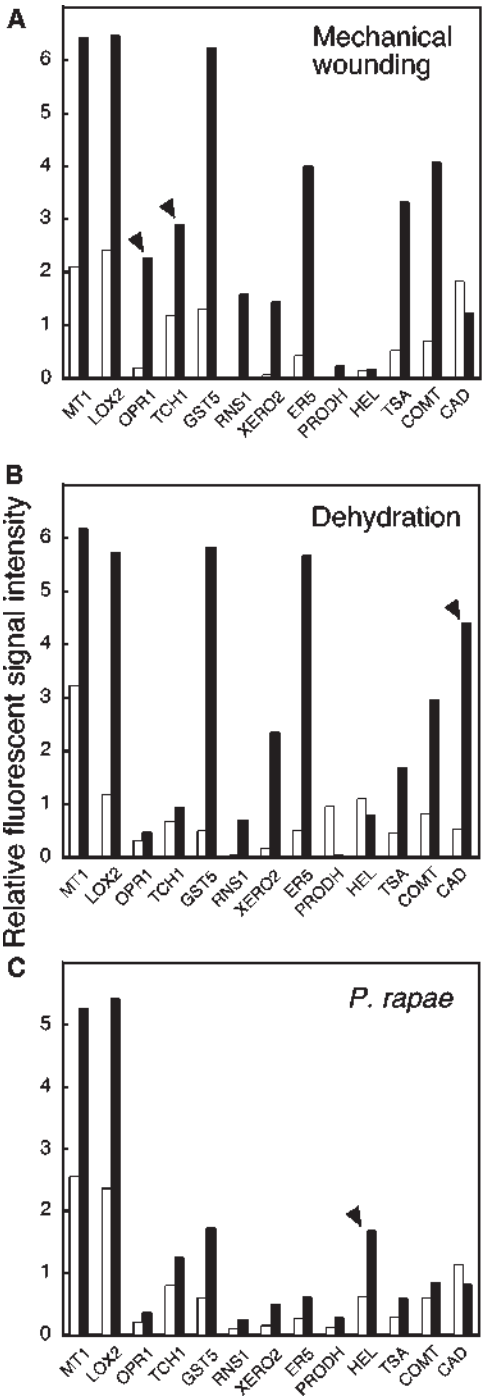

Figure 7. Transcript Signatures for Mechanical Wounding, Dehydration, and Insect Feeding.

Arabidopsis leaves were mechanically wounded (90 min), dehydrated (120 min), or challenged with *P. rapae* larvae (180 min). Cy3- or Cy5-labeled cDNA probes were prepared with mRNA samples from control (open columns) or treated (filled columns) plants, respectively, and were hybridized with a cDNA microarray. After scanning each fluor separately, the fluorescent signal intensity was integrated and corrected for local area background. Results are shown for a set of genes illustrating typical patterns of expression. Genes marked with an arrowhead were induced in only one treatment.

(A) Mechanical wounding.

(B) Dehydration.

(C) *P. rapae*.

OPDA. However, 2 to 3 hr after wounding, the combined amounts of the cyclopentenone oxylipins exceeded those of JA. This crossover point might be relevant to regulation of gene expression by different jasmonates. Future work should address the specific role of each of these molecules in gene expression as determined with cDNA microarrays. The experiment shown here highlights the potential of combining "oxylipin signatures" with "transcript signatures"; it will be interesting to make comparisons in larger databases containing more values for gene expression and more complex pools of oxylipins.

The fact that genes showed similar expression profiles when wounded does not imply that they are regulated by the same signal. Indeed, we found several genes (e.g., *GST1, TCH1,* and *ER5*) for which the temporal expression profile was similar to that of JA-related genes (Figure 4A) but that were still induced by wounding in JA-insensitive *coi1-1* plants (Table 1). Surprisingly, one of these was *OPR1*, which possibly participates in the synthesis of JA (Schaller and Weiler, 1997). The reason that *OPR1* induction is independent of the JA perception, whereas two other genes in the same pathway (*LOX2* and *AOS*) are dependent on an intact JA signaling pathway, is not known. The exact role of *OPR1* induction in wounding requires additional studies.

The use of the *coi1-1* mutant yielded two broad categories of wound-inducible genes: *COI1*-dependent and *COI1*-independent genes (Table 1). It is important to note that a gene defined as *COI1*-dependent or -independent in this study might be controlled differently under other conditions, and we used these two categories only for the present study. We assume that most, if not all, *COI1*-dependent genes are jasmonate dependent and that their expression is altered by a direct or indirect effect of the loss of a functional *COI1* gene. Additionally, the category of *COI1*-independent genes contains genes that were differentially expressed in wounded wild-type and *coi1-1* plants. Some genes were more highly induced in wild-type plants (e.g., *ACX1* and *GST5*), whereas others (e.g., *ER5* and *PGIP*) were more highly induced in *coi1-1* plants. These results merit further attention because they indicate that *COI1* might play subtle roles as a positive or negative regulator of other signal pathways controlling wound-inducible gene expression.

Interestingly, the transcript levels of two genes (*NPR1* and

MPK3; Figure 5A) were induced in wounded *coi1-1* plants after 90 min but not in wounded wild-type plants. *MPK3* shows an early induction after wounding of wild-type plants, but its transcript level returns to the control value 60 min after wounding (Figure 2). These two genes have been implicated in the signaling pathway that leads to resistance to bacterial and fungal pathogens (Cao et al., 1997; Ligterink et al., 1997; Ryals et al., 1997). This observation indicates that sensitivity to endogenous JA might downregulate gene expression. Similarly, exogenous JA has been shown to downregulate the amounts of various transcripts (Wasternack and Parthier, 1997). Our results demonstrate a possible case of signal pathway interaction (cross-talk) in which a wounding pathway might override a pathogen defense pathway.

Our finding that many genes (21) are regulated in a *COI1*-independent manner (genes that are wound-regulated in both the wild-type and the *coi1-1* plants) is in strong agreement with the literature, and several wound-inducible but jasmonate-independent genes are known (Titarenko et al., 1997; Leon et al., 1998; Rojo et al., 1998). We concentrated on the *COI1*-independent genes, because little information is available in the literature on how this large group of genes is regulated during wounding (Rojo et al., 1998), and tested the role of ethlyene as a signal during mechanical wounding. The observation that the lack of ethylene sensitivity did not affect the wound-inducible expression of several genes in the Arabidopsis mutant *ein2-1* is somewhat surprising (Figure 5C). Ethylene has been shown to be necessary for the wound induction of the proteinase inhibitor II gene in tomato (O'Donnell et al., 1996), but touch genes (*TCH2, TCH3,* and *TCH4*) are known to respond to mechanical stimulation even in *ein* mutants (Johnson et al., 1998). A recent study has implicated ethylene in the downregulation of a subset of wound-inducible, JA-dependent genes in Arabidopsis (Rojo et al., 1999). Thus, a more complete picture of apparently complex roles of ethylene in wound-inducible gene expression awaits the analysis of cDNA microarrays containing a larger number of genes.

Water Stress Is an Important Component in the Response to Mechanical Wounding

Because ethylene perception was not required for the expression of the *COI1*-independent genes in our study, we decided to determine whether other factors might contribute to the expression of these genes during wounding. Sensitivity to touch is one factor, and not surprisingly, four of these genes were touch genes (*TCH1, TCH2, TCH3,* and *TCH4*), which are known to be regulated by signal networks involving calcium flux (Braam and Davis, 1990). This left 17 genes for which the inducing stimulus was unclear. Because some of the genes are known to be induced by drought, we looked at gene expression in dehydrating leaves that had lost 20% of their water content. For these experiments, *PRODH*, a gene known to be strongly downregulated during water stress (Kiyosue et al., 1996), served as an excellent control, and in our experiments, transcript levels for *PRODH* were reduced 33-fold (relative to controls) as a consequence of rosette detachment (Table 1). We found that the expression of many wound-inducible genes was induced by dehydration (Table 1), including 13 *COI1*-independent genes. This result implies that water stress might play a pivotal role during the response to the mechanical wounding we used, which generated crushed tissue.

Exactly how water stress leads to changes in gene expression is not clear. In tomato, at least two wound-inducible genes are upregulated by water deficit, abscisic acid, and salinity (Chao et al., 1999). For *COI1*-independent genes described in this study, several factors might contribute to changes in gene expression, for example, the decrease in hydraulic pressure resulting from wounding tissue or from dehydration itself. From our results, we cannot distinguish which of these factors, or others, are associated with gene activation, and we did not assess the contribution of abscisic acid to the regulation of gene expression. Several *COI1*-dependent genes were also induced by dehydration (Table 1), and JA contents are known to increase in tissues undergoing water stress. JA or its precursors may thus mediate at least some drought stress signaling events (Creelman and Mullet, 1997). Because the treatment we used to induce water stress (detachment of rosettes from the root system) may have itself resulted in a wound stimulus, the increase in some transcripts might also be due to this distal wound stress in addition to a water stress.

Finally, for four genes (*PME1, PR3AIV, OPR1,* and *PRODH*), the signal or stimulus that controls their induction during wounding is not known. Possible candidates would be oxylipins (different from jasmonates), cell wall–derived oligosaccharides (Rojo et al., 1999), touch, ion fluxes, or plant hormones. Reactive oxygen intermediates involved in plant defense (Alvarez et al., 1998) could also be envisaged.

In summary, our results lead to a more comprehensive view of gene expression in response to mechanical wounding. Several factors, including tissue damage and water loss, lead to a complex, dynamic pattern of transcript levels in which waves of gene expression involving groups of similarly behaving transcripts were observed. Underlying these patterns is the complex interplay of stimuli that control gene expression, in which one input (e.g., wounding) can override another (e.g., water stress), as demonstrated by the interesting behavior of *PRODH*, which was strongly upregulated by mechanical wounding and downregulated by water stress (Table 1).

Reduced Water Stress–Inducible Gene Expression during *P. rapae* Feeding

Having characterized the expression of an array of genes during mechanical wounding, we then compared the effect of insect damage, asking whether insects preferentially

induce *COI1*-dependent or *COI1*-independent genes. We also estimated the contribution of water stress to the induction of gene expression during insect feeding. The lepidopteran *P. rapae* is a common and economically important insect pest, and the association between members of the Brassicaceae and cabbage butterflies, in particular *P. rapae* and *P. brassicae*, has long been used as a model plant–insect system (Renwick, 1995). On Arabidopsis, we observed that the sharp mouth parts of *P. rapae* larvae successively removed tissue from the edge of the leaf, leaving an oval, semioval, or semicircular hole in the leaf without cutting the midvein. Once the feeding site approached the midvein, the larvae moved to another leaf or to a different site on the same leaf (often on the opposite side of the midvein). This behavior probably not only requires the least amount of movement for the insect but also allows a larva to efficiently and successively remove strips of already wounded tissue at the cut leaf edge while exposing the least amount of damaged surface to the air. When we allowed larvae of *P. rapae* to feed on Arabidopsis leaves until ~40% of the leaf area had been removed, we found that insects induced gene expression in a manner very different from mechanical wounding.

As our results definitively show, many genes that were strongly induced by mechanical damage were less or not at all induced when a plant was attacked by *P. rapae*. The fact that the insect did not induce the expression of many wound-inducible genes is likely to be to the insect's advantage. Several genes that were not induced by insect feeding include *PR* genes (e.g., *PR-2* and *PAL*) or genes involved in the synthesis of aromatic metabolites (e.g., *CCR* and *COMT*), which might reduce insect fitness. On the other hand, the defense gene *HEL* was reproducibly induced by *P. rapae* larvae but not by mechanical wounding. *HEL* is known to be induced by microbial pathogens by way of a JA-dependent pathway (Potter et al., 1993; Thomma et al., 1998), but we found that this gene is also induced by insect feeding. *HEL*, which might be induced by an elicitor released from the insect, thus provides a good marker for further studies of insect interaction with Arabidopsis.

Use of cDNA microarrays containing many more genes might reveal a new class of insect-specific genes that might be useful in developing biotechnological tools for insect control. Although our array contained only 150 genes, it was already large enough to permit the detection of a gene (*HEL*) induced by feeding *P. rapae* larvae but not by mechanical wounding. Our results illustrate the advantages of using small boutique arrays. First, the quality of each clone on the array can be controlled and printing errors can be rapidly rectified. Second, assembly of boutique arrays is possible in small laboratories that currently lack the resources to print genome-scale arrays.

Concerning the signal pathways activated by feeding *P. rapae,* several *COI1*-dependent genes (e.g., *LOX2, MT1, TSA,* and *JIP*) as well as several *COI1*-independent genes (e.g., *GST1, ERF4, RNS1,* and *PRODH*) were induced. Thus, the insect did not appear to preferentially activate either jasmonate-dependent or -independent genes. It is remarkable that the feeding of *P. rapae* had little effect on genes such as *XERO2*, *RNS1*, *ER5*, *TSA,* and *COMT* (Table 1), all of which are water stress inducible. Perhaps *P. rapae* minimizes the effects of water stress on gene expression when feeding by reducing the crushing of tissue and by keeping to a minimum the cut edge of the lamina while removing the maximum tissue mass. In other words, it might not be a coincidence that cabbage butterfly larvae often leave circular or semicircular holes in host plant leaves in contrast to following a feeding strategy that might expose a greater length of ragged or crushed leaf edge to the air. Indeed, some specialist insects use elaborate vein-cutting strategies to cut the flow of defense chemicals to the feeding site (Dussourd and Eisner, 1987). Our results are consistent with the idea that the larvae of cabbage butterflies, such as *P. rapae*, may utilize feeding approaches designed to minimize the activation of a subset of host defense genes.

METHODS

Plant Materials and Growth Conditions

Seeds from plants (*Arabidopsis thaliana* ecotype Columbia) were sown on potting compost and vernalized for 4 days at 4°C. After 17 days of incubation in a growth chamber (10 hr of light at 150 μmol m^{-2} sec^{-1}) at 23°C during the day and 18°C at night, the young plants were transferred to pots (7 cm in diameter, with two plants per pot) containing potting compost and were grown for 3 to 4 weeks in a growth room (20°C at 70% relative humidity and with 10 hr of light at 100 μmol m^{-2} sec^{-1}). The jasmonate response mutant *coi1-1* (Feys et al., 1994) was obtained from J. Turner (University of East Anglia, Norwich, UK). Because this mutation is recessive and causes male sterility, we identified *coi1-1* mutants in F_2 plants grown from self-fertile F_1 plants. Seeds were germinated on Murashige and Skoog medium (Sigma, Buchs, Switzerland) containing 3% sucrose and 30 μM jasmonate and incubated under light (150 μmol m^{-2} sec^{-1}) for 10 days in a growth chamber. Homozygous *coi1-1* mutants showing normal greening of leaves and no inhibition of root growth (Feys et al., 1994) were transferred to pots, as described earlier. The presence of the mutation was confirmed in all plants by using a described cleaved amplified polymorphic sequence marker (Xie et al., 1998). Two separate batches of the ethylene-insensitive *ein2-1* mutants were obtained from the Nottingham Arabidopsis Stock Centre (Nottingham, UK).

Plant Treatments

For wounding treatments, we crushed all rosette leaves of Arabidopsis plants several times across the apical lamina with a forceps, which effectively wounded ~40% of the leaf area. Plants were incubated for various periods, after which the leaves were harvested and immediately immersed in liquid nitrogen. For dehydration experiments, we detached whole Arabidopsis rosettes from the roots by cutting with a clean razor blade; we then weighed them and placed them on chromatography paper (3MM; Whatman, Maidstone, UK) at

20°C and 70% humidity. After 2 hr, plants were weighed again to estimate water loss and were then immediately immersed in liquid nitrogen. For feeding experiments, *Pieris rapae* and *P. brassicae* larvae collected near Lausanne were maintained on cabbage (*Brassica oleracea*) plants in a greenhouse. Fourth and fifth instar larvae were placed on Arabidopsis plants (three larvae per plant) and were allowed to feed under light (100 μmol m^{-2} sec^{-1}) for 3 to 4 hr at 20°C until ~40% of the leaf surface was removed. Larvae were then removed, and all plant leaves were immediately frozen in liquid nitrogen. Mechanical wounding experiments designed to damage leaves in patterns similar to those of feeding insects, including wounding the lamina but not the midribs, were performed. All gene expression patterns were similar to those found in response to normal wounding treatments (data not shown).

Quantitative Analysis of Jasmonate Family Members

Extraction and quantitative analyses of jasmonic acid (JA), oxophytodienoic acid (OPDA), and dinor OPDA were performed with 1 g of leaf material, as previously described (Weber et al., 1997).

cDNA Clones and Microarray Preparation

Arabidopsis cDNA clones (expressed sequence tags [ESTs]) were obtained from the Arabidopsis Biological Resource Center (Columbus, OH). Inserts of cDNA clones were amplified by polymerase chain reaction (PCR) in 100-μL reaction volumes by using primers that were complementary to vector sequences flanking both sides of the cDNA insert. At the end of each reaction, 5 μL of product was electrophoresed on agarose gels to confirm amplification quality and quantity. PCR products were purified on QIAquick-96 columns (Qiagen, Basel, Switzerland), lyophilized, and resuspended in 8 μL of 3 × SSC (1 × SSC is 0.15 M NaCl and 0.015 M sodium citrate) in a 384-well microtiter plate. Final insert concentration was >500 ng/μL.

Microarray fabrication was performed according to published methods (Schena et al., 1995; Shalon et al., 1996). Briefly, PCR products were arrayed onto silylated microscope slides (CEL Associates, Houston, TX) by using a high-precision gridding robot (GeneMachines, San Carlos, CA) equipped with four printing tips (TeleChem International, San Jose, CA). After printing, silylated slides were allowed to dry, and nonbound DNA was removed with 0.2% SDS and double-distilled H_2O; covalently bound DNA was denatured for 2 min in boiling water. Free aldehydes were reduced by soaking slides for 5 min in 68 mM sodium borohydride (dissolved in PBS containing 25% ethanol). Several washing steps were performed with 0.2% SDS and double-distilled H_2O; then slides were dried by centrifugation (model MSE Mistral 2000R; Kleiner, Wohlen, Switzerland) at 500*g* for 5 min and stored at room temperature for further hybridizations. For full details, see http://www.unil.ch/ibpv.

mRNA Isolation and Preparation of Fluorescent Probes

Total leaf RNA was extracted with 2:1 (v/v) extraction buffer (0.5 M Tris-HCl, pH 8.2, 0.25 M EDTA, and 5% SDS):phenol solution, followed by two washes with chloroform and overnight precipitation with LiCl (3 M final concentration). The RNA pellet was resuspended in H_2O and precipitated with 0.1 volume of 3 M sodium acetate and 2 volumes of ethanol. The pellet was rinsed with 70% ethanol, air dried, and resuspended in H_2O. Poly(A)$^+$ mRNA was prepared by using an Oligotex Midi kit (Qiagen) according to the manufacturer's instructions.

Each mRNA sample (one control and one treated sample) was reverse-transcribed in the presence of Cy3-dCTP or Cy5-dCTP (Amersham Pharmacia Biotech, Dübendorf, Switzerland). Each reaction was performed in a 30-μL volume containing 2 μg of mRNA, 2 μg of oligo(dT) 21-mer, 500 μM each for dATP, dGTP, and dTTP, 200 μM dCTP, 100 μM Cy3-dCTP or Cy5-dCTP, 30 units of RNase inhibitor (Life Technologies, Basel, Switzerland), 10 μM DTT, and 400 units of SuperScriptII reverse transcriptase (Life Technologies) in SuperScript buffer (Life Technologies). After incubation at 42°C for 1 hr, the sample tubes containing Cy3 and Cy5 labeling were pooled and treated with 2.65 μL of 25 mM EDTA and 3.3 μL of 1 M NaOH for 10 min at 65°C to degrade the RNA. After the addition of 3.3 μL of 1 M HCl and 5 μL of 1 M Tris-HCL, pH 6.8, labeled single-stranded DNA was precipitated with 0.1 volume of 3 M sodium acetate and 2 volumes of ethanol, and the pellet was washed with 80% ethanol, dried under vacuum, and resuspended in 10 μL of hybridization solution containing 3 × SSC, 0.2% SDS, and 0.02% yeast tRNA (Life Technologies). Probes were purified by Millipore (Volketswil, Switzerland) Ultrafree-MC filters.

Hybridization Reaction and Microarray Analysis

Before hybridization, the probe solution was boiled for 1 min and then rapidly applied to the microarray under a cover slip. Slides were placed in hybridization chambers (TeleChem International), and 20 μL of 3 × SSC was placed inside each chamber before sealing. Slides were incubated for 14 to 16 hr in a water bath at 64°C and then were sequentially washed in the following solutions: 2 × SSC, 0.1% SDS twice for 5 min, 0.2 × SSC twice for 1 min, and 0.1 × SSC twice for 1 min. Slides were dried by centrifugation at 900*g* for 2 min (MSE Mistral 2000R) before they were scanned.

Microarrays were scanned with a scanning laser microscope (ScanArray3000; GSI Lumonics, Watertown, MA). Separate images were acquired for each fluor at a resolution of 10 μm per pixel. To normalize the two channels with respect to signal intensity, we adjusted photomultiplier and laser power settings such that the signal ratio of the majority of control genes was as close to 1.0 as possible. The average fluorescence intensity for each fluor and for each gene was determined by using the ScanAlyze program (written by M. Eisen, Stanford University; available at http://rana.stanford.edu/software). Background fluorescence was calculated as the median fluorescence signal of nontarget pixels around each gene spot. Genes showing a signal value <1000 (which was typically twice the mean background value) in both Cy3 and Cy5 channels were not considered for the analyses. For all of the experiments, we defined induction or repression of a gene as a minimum twofold change in its transcript level. Gene-clustering analysis was performed as described previously (Eisen et al., 1998).

RNA Gel Blot Analysis

Two micrograms of poly(A)$^+$ mRNA was electrophoresed in formaldehyde-containing agarose gel and transferred to nylon membrane (Hybond N$^+$; Amersham). ESTs for *HEL*, *MPK3*, and chlorophyll *a*/*b* binding protein were labeled with digoxigenin (Roche Molecular Biochemicals, Rotkreuz, Switzerland) by PCR amplification and used as

probes. Hybridization and detection of digoxigenin-labeled probes were performed according to the manufacturer's instructions.

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Correlated clustering and virtual display of gene expression patterns in the wheat life cycle by large-scale statistical analyses of expressed sequence tags

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Summary

Compared to rice, wheat exhibits characteristic growth habits and contains complex genome constituents. To assess global changes in gene expression patterns in the wheat life cycle, we conducted large-scale analysis of expressed sequence tags (ESTs) in common wheat. Ten wheat tissues were used to construct cDNA libraries: crown and root from 14-day-old seedlings; spikelet from early and late flowering stages; spike at the booting stage, heading date and flowering date; pistil at the heading date; and seeds at 10 and 30 days post-anthesis. Several thousand colonies were randomly selected from each of these 10 cDNA libraries and sequenced from both 5′ and 3′ ends. Consequently, a total of 116 232 sequences were accumulated and classified into 25 971 contigs based on sequence homology. By computing abundantly expressed ESTs, correlated expression patterns of genes across the tissues were identified. Furthermore, relationships of gene expression profiles among the 10 wheat tissues were inferred from global gene expression patterns. Genes with similar functions were grouped with one another by clustering gene expression profiles. This technique might enable estimation of the functions of anonymous genes. Multidimensional analysis of EST data that is analogous to the microarray experiments may offer new approaches to functional genomics of plants.

Keywords: hexaploid wheat, large-scale EST analysis, correlation clustering of expression patterns, virtual display, gene search in wheat, functional genomics.

Introduction

Plants control gene expression in response to environmental conditions, inducing the development of distinct tissues and cell types during the life cycle of the plant and allowing adaptation to diverse environments. Although tissue and cellular differentiation of plants is triggered by various modular genes, developmental transitions are considered to be accompanied by global changes induced by those modular genes (Doebley and Lukens, 1998). A large number of examples of temporal and spatial regulation of gene expressions in higher plants have been accumulated using traditional approaches, such as Northern hybridization. However, traditional approaches are limited by the number of transcripts that can be simultaneously analyzed. Recent developments in functional genomics, such as a hybridization system for arrayed cDNA clones or synthesized oligonucleotide chips now allow systematic monitoring of expression profiles for thousands of genes (Brown and Botstein, 1999; Schaffer *et al.*, 2001; Seki *et al.*, 2001).

Unlike these analog methods of analysis, digital analysis of gene expression profiling can be achieved by analyzing expressed sequence tags (ESTs) in cDNA libraries and monitoring of transcript abundance can be inferred from

EST frequencies. Considerable accumulation of EST data from various cDNA libraries in various tissues (Yamamoto and Sasaki, 1997) combined with rigorous statistical analysis can therefore allow digital gene expression profiling in each tissue to be assessed (Ewing *et al.*, 1999).

Recent innovations in genomics of model plants have established fundamental tools for individual gene analyses. In addition to the availability of DNA sequence data of entire genomes of *Arabidopsis* (The Arabidopsis Genome Initiative, 2000) and rice (Goff *et al.*, 2002; Yu *et al.*, 2002), full-length cDNA libraries have also been constructed (Seki *et al.*, 2002), and cDNA microarrays are available to monitor gene expression patterns (Schaffer *et al.*, 2001; Seki *et al.*, 2001; Yazaki *et al.*, 2000). Genome research is therefore entering a new era of functional analyses of individual genes and the associated gene networks. In fact, comparative genomics among related and distinct plants is reported to have come of age as a field of research (Bennetzen, 2002; Paterson *et al.*, 2000).

Within the family Gramineae, wheat, unlike rice, shows some characteristic growth habits. Wheat originating from temperate zones is a long-day plant (Zohary and Hopf, 2001), while rice cultivated in tropical or subtropical areas is a short-day plant (Oka, 1988). Genomically, wheat possesses large chromosomes containing considerable amounts of DNA (5000 Mb per single genome; Arumuganathan and Earle, 1991), whereas rice displays a small genome (450 Mb). Differences in genome size between the two species are largely attributed to the inclusion of repetitive sequences (Feuillet and Keller, 2002). Wheat can also be characterized by a polyploid nature, although polyploidy is common in plants (Wendel, 2000). In fact, about 70% of angiosperms were polyploid at some stage during their evolution (Masterson, 1994). Even in model plants, such as *Arabidopsis* and rice, extensive duplication and rearrangement of the genomes can be found as remnants of polyploidy (Blanc *et al.*, 2000; Goff *et al.*, 2002; Yu *et al.*, 2002). Wheat species (*Triticum–Aegilops* group) can provide a model system to study the genomics of polyploid plants, as most progenitors of polyploid species have been determined and the genetic relationships among wheat species have been extensively characterized (Tsunewaki, 1993). In addition, allopolyploids are easily synthesized (Ozkan *et al.*, 2001). Wheat and rice therefore represent good model systems for investigating the comparative genomics of higher plants.

The present study aimed to produce a body map of ESTs in typical tissues during the wheat life cycle. A large body of EST data represents a convenient starting point for investigating functional genes in wheat, and multidimensional analysis of ESTs that is analogous to microarray experiments (Eisen *et al.*, 1998; Ewing *et al.*, 1999) may offer a new monitoring system for functional annotation of anonymous genes.

Results and discussion

Number of sequenced EST clones from various wheat tissues

The cDNA libraries were constructed from 10 tissues found in the wheat life cycle. The range of colony-forming units (cfu) was estimated between 7.1×10^5 cfu in the library of spikelet at early flowering (Wh_yf) and 1.7×10^6 cfu in the library of root (Wh_r). Because those libraries were merely cultured for stabilization, expressed gene members in these libraries more or less reflected the original populations of mRNAs in these tissues. From the several thousand cDNA clones from each tissue sequenced (Table 1), more than 5000 individual sequences were obtained. Consequently, 116 232 items of sequence information were obtained from

Table 1 Number of contigs from 10 wheat cDNA libraries grouped by the PHRAP method

Tissue	Number of forward sequences	Number of reverse sequences	Total number of sequences	Total number of contigs after PHRAP analysis	Number of contigs with duplicated members	Number of singlets (%)
Crown of seedling	4958	5111	10069	3753	1976	1777 (47.3)
Root	5180	5322	10502	4196	2346	1850 (44.1)
Spikelet at early flowering	5488	5584	11072	4679	2477	2202 (47.1)
Spikelet at late flowering	5837	6193	12030	4813	2637	2176 (45.2)
Spike at booting stage	7283	7487	14770	5547	3047	2500 (45.1)
Spike at heading date	5529	5756	11285	4731	2575	2156 (45.6)
Pistil at heading date	5108	5241	10349	4915	2489	2426 (49.4)
Spike at flowering	6040	6260	12300	4977	2726	2251 (45.2)
Seed DPA10	5578	5704	11282	3877	2160	1717 (44.3)
Seed DPA30	6296	6277	12573	3390	2201	1189 (35.1)
Total	57297	58935	116232	25971	15934	10037 (38.6)

EST clones. In Table 1, sequence directions are indicated as the position of the sequence primer: the forward primer principally provides information on the 3′ region of mRNA, and the reverse primer provides information about the 5′ region. The 3′ sequence reading is quite informative, as the 3′ region of mRNA contains information specific to genes and/or genomes. Our data set represents the largest set of wheat ESTs for sequence information derived from both ends in a single wheat strain.

Sequences were grouped by the phragment assembly program (PHRAP) method. In total, 25 971 contigs were classified. Grouping with PHRAP was so rigid that each contig represented individual gene groups, thus distinguishing the genes from multiple loci and/or different homoeologous loci (Mochida *et al.*, unpublished data). Contigs standing alone were grouped as singlets (Table 1). Three possible explanations for the production of singlets were considered:

(1) Only sequences from one direction were obtained. In practice, sequence numbers from forward and reverse directions were not always consistent among cDNA libraries (Table 1).
(2) The length of cDNAs was too long to overlap sequences from both ends. Mean sequence length was approximately 600 nucleotides. Thus, contigs of cDNAs exceeding 1.2 kbps must be separated from each other.
(3) Sequence quality of clones was not sufficiently high for PHRAP to connect the sequences. All contigs except singlets were used for further analysis.

Virtual display of expression profiles of abundant ESTs in 10 wheat tissues

To assess expression profiles of ESTs in different tissues, contigs showing abundant expression were selected; based on preliminary simulations (Ewing *et al.*, 1999), this comprised of contigs with five or more members (Table 2). In total, 5199 contigs were listed where about half had five to nine members and the other half had 10–99 members. Highly expressed contigs with more than 100 members were present as minor fractions.

Expression profiles were derived from each of the 5199 contigs with five or more members. The number of EST constituents assigned to 10 cDNA libraries was scored for each contig, producing a two-way expression profile, i.e. contig versus library. This matrix table represented the primary data for further computations. Based on Pearson's correlation coefficient for the EST constituent matrix, hierarchical clustering was constructed according to the method of Eisen *et al.* (1998). Virtual display of the expression profile is shown in Figure 1. A noticeable property of the clustered image in Figure 1 is the presence of large contiguous patches of genes showing abundant expression in each of the 10 tissues. In addition to these gene clusters expressed in a tissue-specific manner, genes commonly expressed throughout the 10 tissues were identified. Based on these expression patterns of ESTs, contigs were classified into nine major groups (A–I, Figure 1). Expression patterns for each major group, on average, are shown in Figure 2. Groups A, C, E, G, H, and I contained genes preferentially expressed in seeds DPA30 and DPA10, root, pistil at heading date, and spikes at heading and flowering dates, respectively. Group B contained genes commonly expressed in almost all tissues. Although the overall expression pattern of group F did not appear in a tissue-specific manner, this group comprised of four subgroups whose preferential expressions were found in crown tissue of seedlings, spikelet at early flowering, spikelet at late flowering, and spike at booting stage (Figures 1 and 2). Group D was unique in that it comprised only one member, showing specific expression patterns distinct from those of other EST groups. A BLAST search indicated that the group D contig is a gene encoding a translation initiation factor (Shen and Gigot, 1999). Expression of the gene was barely detected in the spikelet at early flowering and the spike at booting stage, but was relatively abundant in other tissues (Figure 2). These contiguous patches contained genes expressed in a tissue-specific manner. A list of contigs specifically expressed in each of 10 tissues along with those showing other expression patterns is presented in Table 3. From the 5199 contigs examined here, about 30–50% of genes were expressed in individual tissues: slightly more genes were expressed in the spike at booting stage (*c.* 50%), while expression of genes in seed DPA30 was restricted (*c.* 30%). In relation to the expression pattern scored in Figure 2, contigs specifically expressed in each of 10 tissues were counted (Table 3). Less than 10% of genes (0.2–7.3%) were specifically expressed in each tissue. In total, 456 of 5199 contigs (8.8%) demonstrated specific expression patterns in individual tissues. Conversely, 104 contigs (2.0%) were commonly expressed in all 10 tissues and constituted members of subgroup B (Figures 2 and 3). The other contigs (*c.* 90%) were found in a range of two to nine tissues (Table 3). From our analyses, we were able to construct a gene catalog or body map expressed in 10 tissues during the wheat life cycle. Although functional annotation of wheat gene sequences is poor, functional roles of genes can be estimated somewhat by expression patterns of

Table 2 Constitution of contigs with multiple members

Classification	Number of contigs
Contigs with more than 500 members	1
Contigs with between 100 and 499 members	48
Contigs with between 10 and 99 members	2198
Contigs with between 5 and 9 members	2952
Contigs with 5 or more members	5199

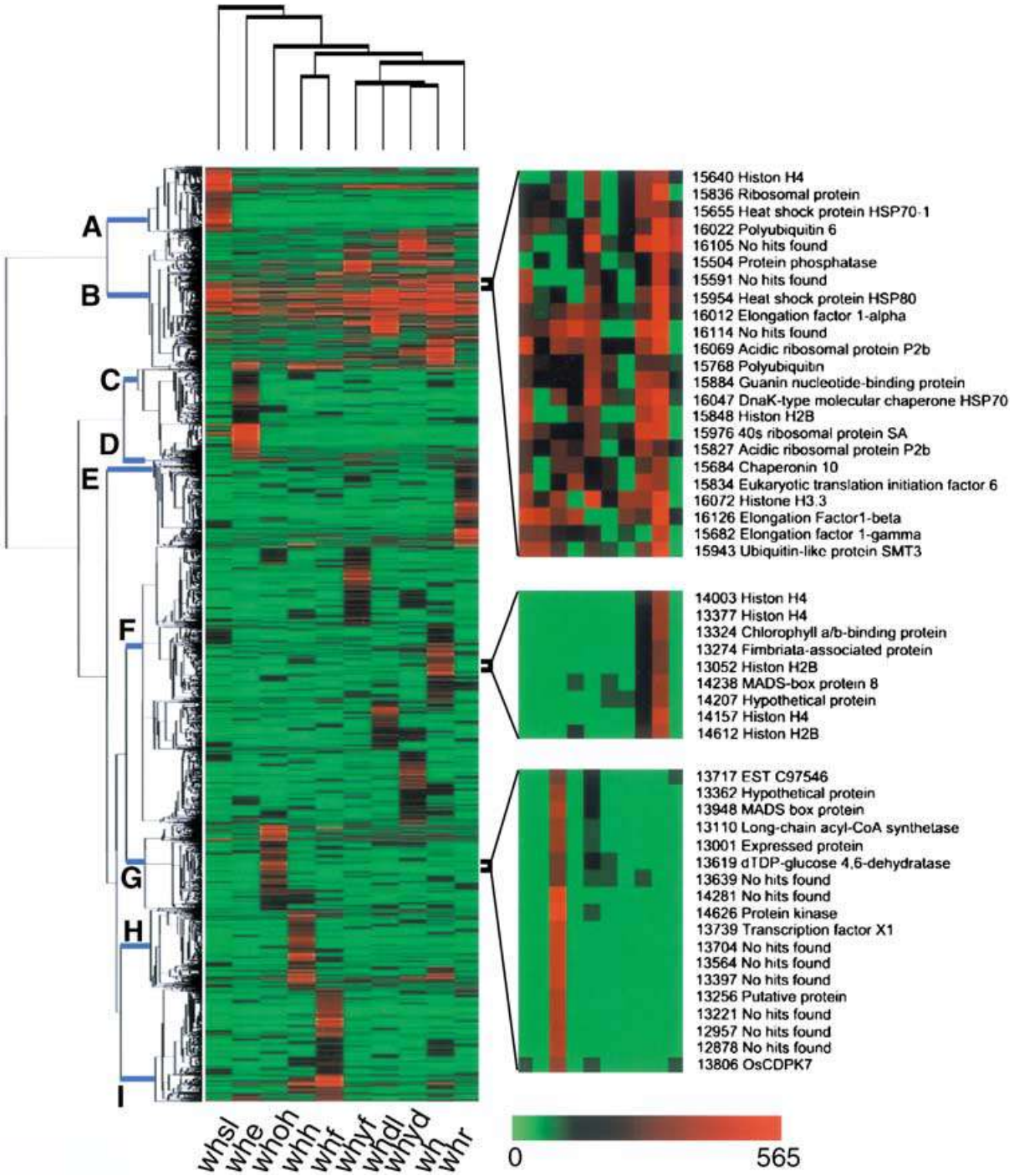

Figure 1. Clustered correlation display of wheat EST data.
A total of 5199 contigs with five or more members were selected to construct the clustered correlation map of cDNA libraries from 10 wheat tissues. Dendrograms and colored images were produced as described in the text. Color scale ranges from saturated green for 0 members to red for 565 members. Expression profile of each gene is represented by a single row of colored boxes and that of each library is represented by a single column. Nine major hierarchical clusters are indicated by unfilled bars. Some contig identities are shown in expanded regions: one shows members of major cluster B that were commonly expressed in almost all tissues; the other shows members belonging to cluster F that were specifically expressed in the spike at booting stage. A larger version of this display with gene annotation is available at http://shigen.lab.nig.ac.jp/wheat/komugi_private/est/.

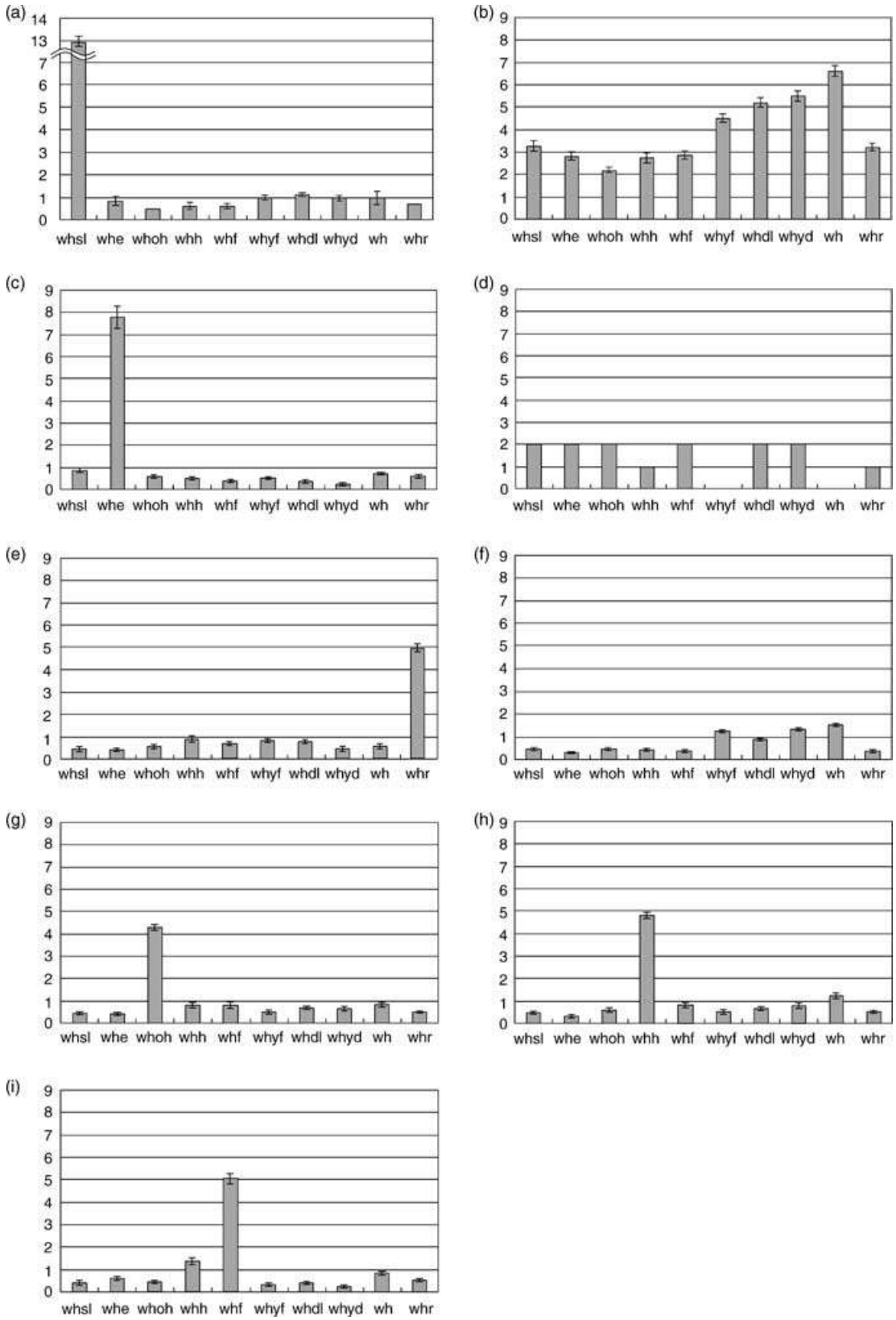

Figure 2. Gene expression patterns of nine major clusters.
(a–i) correspond with (A–I) in Figure 1. Mean number of members constituting a contig in each cDNA library is shown as a histogram with standard error.

known genes in the same clusters. For example, in group B of Figure 1, housekeeping genes like translation-related genes, including genes encoding for ribosomal proteins, elongation and initiation factors, and histone genes (Tabata *et al.*, 1983; Yang *et al.*, 1995), were frequently observed. However, chaperonin genes, such as heat shock protein (Newman *et al.*, 1994) and ubiquitin genes (Christensen *et al.*, 1992) were also found in group B, suggesting constituent roles for these genes in most wheat tissues. In the second magnification of Figure 1, genes preferentially

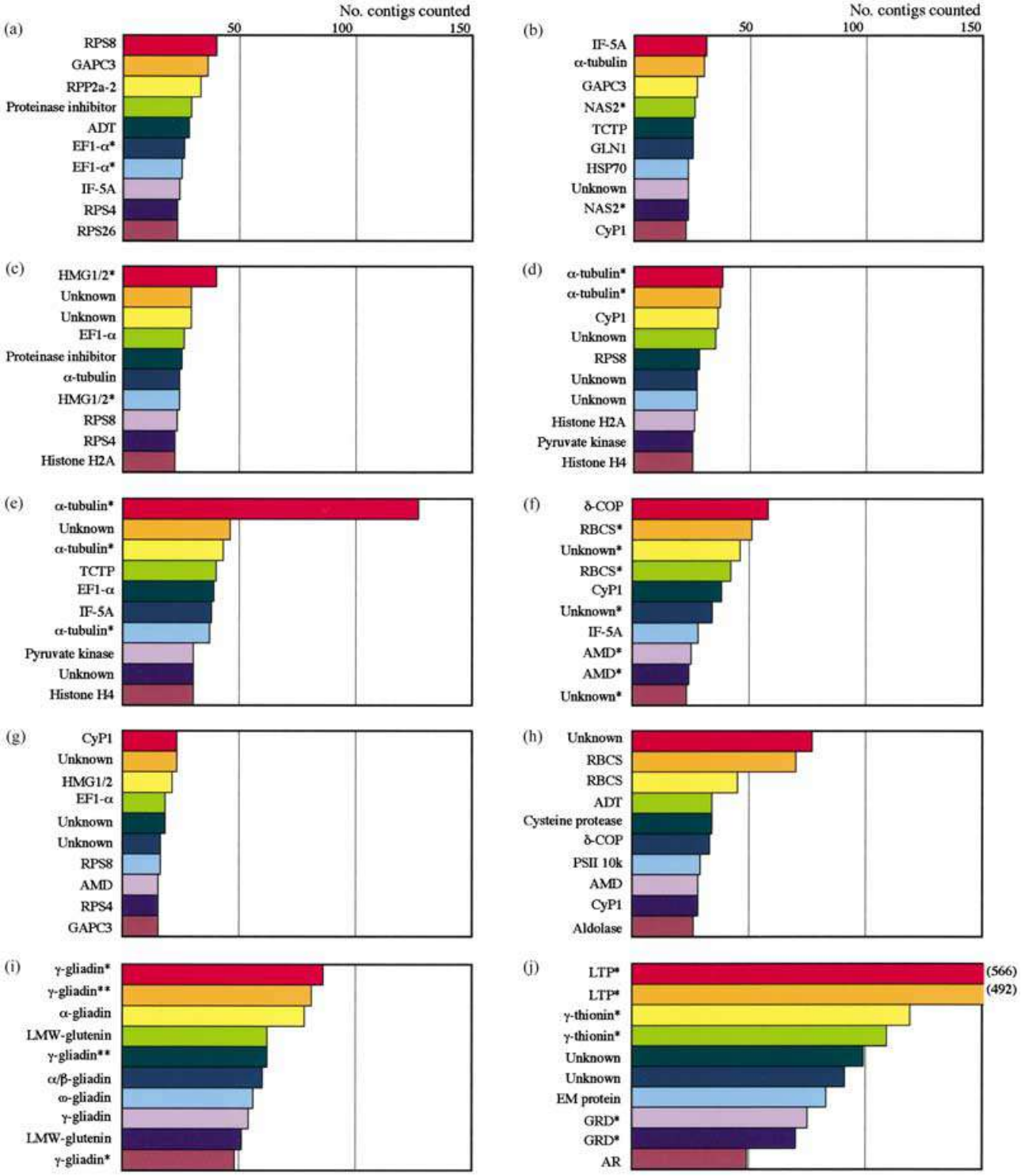

Table 3 Number of contigs specifically expressed in each of 10 tissues

Source of library (abbreviation)	Number of contigs specifically expressed (%)	Total number of contigs
Crown of seedling (Wh_dL)	3 (0.2)	1976 (38.0)
Root (Wh_r)	57 (2.8)	2004 (38.6)
Spikelet at early flowering (Wh_yf)	22 (1.0)	2123 (40.8)
Spikelet at late flowering (Wh_yd)	18 (0.8)	2159 (41.5)
Spike at booting stage (Wh)	17 (0.7)	2593 (49.9)
Spike at heading date (Wh_h)	42 (2.0)	2133 (41.0)
Pistil at heading date (Wh_oh)	30 (1.5)	1966 (37.8)
Spike at flowering date (Wh_f)	62 (2.9)	2148 (41.3)
Seed DPA10 (Wh_e)	82 (4.5)	1809 (34.8)
Seed DPA30 (Wh_sl)	123 (7.3)	1676 (32.3)
Subtotal	456 (8.8)	5199 (100)
Contigs expressed in two to nine tissues	4640 (89.2)	5199
Contigs expressed in all 10 tissues	104 (2.0)	5199

Contigs containing more than five members were collected for the analysis presented in this table.

expressed in the spike at booting stage are shown. In this panel, genes homologous to *MADS*-box genes, histone genes and others are listed. Contig 14238 displayed highest homology to SQUAMOSA (Schmitz *et al.*, 2000), suggesting similar functions in wheat. We identified a number of histone genes (*H2B* and *H4*; Tabata *et al.*, 1983; Yang *et al.*, 1995) specifically expressed in the spike at booting stage, supporting the existence of specifically expressed histones in meiosis (Hoyer-Fender *et al.*, 2000). In the third magnification, the *MADS*-box and *CDPK7* genes were found in addition to a number of genes with unknown function. Contig 13948 displays homology to *AGL9 MADS*-box gene (Newman *et al.*, 1994), and contig 13806 is homologous to *CDPK7* of rice (Saijo *et al.*, 2000), suggesting similar functions. The functions of known genes provide clues to functional estimation of unknown ESTs expressed in individual tissues, such as pistil at heading date in this case.

The hierarchical clustering method (Eisen *et al.*, 1998) was also applied to estimate relationships among the 10 libraries (Figure 1). Nearest neighbors on the tree reveal the most related expression profiles of genes among tissues. The expression profile of ESTs in the spikelet at the late flowering stage was related to that in the spikelet at the early flowering and booting stages as expected. Interestingly, the body map of ESTs in the crown of the seedling was closely related to that in the meristem of reproductive organs. This supports the notion that leaves and certain floral organs are derived from a common ancestral organ (Bowman *et al.*, 1993; Hofer *et al.*, 1997). The library of root also containing meristem was clustered to the above group at a higher order. Libraries from spikes at heading date and flowering date constituting one group were connected to the following group. Tissues related to seed development revealed specific expression profiles of ESTs along with seed maturation (Figure 1). This body map of wheat is related, to some extent, to that of rice in which the number of ESTs adopted was limited (707 contigs) and the numbers of ESTs differed from library to library (Ewing *et al.*, 1999).

Figure 3. List of top 10 contigs most abundantly expressed in each of the 10 cDNA libraries.
(a) Crown of seedling.
(b) Root.
(c) Spikelet at early flowering.
(d) Spikelet at late flowering.
(e) Spike at booting stage.
(f) Spike at heading date.
(g) Pistil at heading date.
(h) Spike at flowering date.
((i) Seed 10 days post-anthesis.
(j) Seed 30 days post-anthesis.
Proteins deduced from BLAST search are represented. Distinct contigs, but showing homology to the same protein, are marked by asterisks. Abbreviations of proteins are as follows: ADT, ADP–ATP carrier protein; AMD, *S*-adenosylmethionine decarboxylase; AR, aldose reductase; BPW2, plasma membrane water channel; CyP1, cyclophilin A1; EF1-α, elongation factor 1-α GAPC3, glyceraldehyde 3-phosphate dehydrogenase; GLN1, glutamine synthase root isozyme; GRD, glucose and ribitol dehydrogenase; HMG1/2, high mobility group protein; HSP70, DnaK-type molecular chaperone hsp70; IF-5A, translation initiation factor-5A; LEA protein, late embryogenesis abundant protein; LTP, lipid transfer protein; MDH, malate dehydrogenase; NAS2, nicochianamine synthase 2; RBCS, small subunit of RuBP caroboxylase/oxygenase; RPP2a-2, acidic ribosomal protein P2a-2; RPS, ribosomal protein small subunit; TCTP, translationally controlled tumor protein.

Genes highly expressed in each of the 10 various tissues during the wheat life cycle

The top 10 contigs of most abundantly expressed ESTs are listed in Figure 3. These contigs have dozens to hundreds of members. Expression patterns of these highly transcribed genes also characterize individual tissues. In fact, from the 46 contigs represented in Figure 3, a total of 26 appear in a tissue-specific manner. Genes encoding storage proteins, such as glutenins (Harberd *et al.*, 1986; Payne *et al.*, 1981) and gliadins (Harberd *et al.*, 1985) were specifically expressed in the developing seed (DPA10). In addition, genes typically expressed in sink tissues, such as lipid transfer protein (Desormeaux *et al.*, 1992) and thionin (Van Campenhout *et al.*, 1998) were found in seeds preparing for dormancy (DPA30). Proteins related to cell division (α-tubulin, Jeong *et al.*, 2000) and chromatin (histones, Huh *et al.* 1997; and high molecular weight group protein, Martinez-Garcia and Quail, 1999) were abundantly expressed in tissues containing root meristem (Wh_r), inflorescence meristem (Wh_yf, Wh_yd), and tissues undergoing meiosis (Wh). Genes encoding translation-related proteins, such as elongation factor (EF1-α; Dunn *et al.*, 1993), initiation factor (IF-5A; Lee *et al.*, 1998), and ribosomal proteins were abundantly expressed among all tissues, although members changed from tissue to tissue. Genes related to photosynthesis and photoreaction (Galili *et al.*, 1992; Ogihara *et al.*, 1994) were abundantly found in flower tissues, such as spikes at heading date and flowering date, suggesting active photoreactions in those tissues (Deng, 1998).

Some distinct contigs showed homologies to the same gene, as marked by asterisks in Figure 3. It is likely that these contigs encode the same proteins derived from one of the three homoeologous genomes. Furthermore, contig groupings were able to distinguish gene transcripts from multigene family-like genes encoding a small subunit of ribulose 1,5-bisphosphate carboxylase/oxygenase (Sasanuma, 2001) and storage proteins, such as glutenin (Allaby *et al.*, 1999) and gliadin (Rafalski, 1986). Thus, contig grouping using the PHRAP method appears to allow ESTs to be assigned to each member from multigenes not only within a genome, but also among three different genomes.

In addition, it should be noted that a number of functionally unknown proteins exist even among abundantly expressed genes (Figure 3).

Database search of contigs

Using the PHRAP method, 116 232 sequences were grouped into 25 971 contigs. The published database was searched for sequences homologous to these contigs. First, homology of contigs was searched against the genome database of indica rice (http://btn.genomics.org.cn/rice/). Out of 25 971 contigs, 7840 contigs (30.2%) revealed no hits in the database. In 7840 contigs, storage proteins, such as glutenins (Allaby *et al.*, 1999), gliadins (Von Bueren *et al.*, 2000), and allergen (Adams *et al.*, 1993) genes were found. In addition to those wheat-specific genes, genes encoding for some metabolites, cytochrome P450 (Nomura *et al.*, 2002), stress responses (Snowden and Gardner, 1993), protein kinase (Lange *et al.*, 1999), and transcription factors (Murai *et al.*, 1998) were included. Secondly, homology was searched against 1 108 179 DNA sequences in the EST database of model plants such as *Arabidopsis*, rice, barley, maize, and soybean (http://www.ncbi.nlm.nih.gov/dbEST/index.html). A total of 4580 contigs displayed no homologous counterparts in the database. Finally, the resulting 4580 contigs were examined for homology against other plant species including wheat (except our ESTs), goat grass, rye, oat, sorghum, tomato, potato, pepper, tobacco, and *Brassica* (http://www.ncbi.nlm.nih.gov/dbEST/index.html). Consequently, no hits were found for 2071 contigs (8.0%). These homology searches indicate that genome coverage of bacterial artificial chromosome (BAC) contigs of indica rice and EST collections of various plants were not completed. Many, if not all, of the 2071 contigs of wheat ESTs should represent novel plant genes.

Redundancy analysis of contigs

The 25 971 contigs classified by the PHRAP were then grouped using the BLAST method. Finally, 14 096 unique genes were classified. Because the total number of genes in angiosperms is estimated at around 27 000 from the complete sequence of the *Arabidopsis thaliana* genome (The Arabidopsis Genome Initiative, 2000), about half of the genes present in the entire genome can be captured, even in wheat. From 14 096 unique genes, 7911 genes (56.1%) were attributed to known genes according to the NCBI database, showing that functional annotation of wheat and/or higher plant gene sequences is still poor. These ESTs can be applied to search for novel genes in wheat and construct cDNA micro-arrays to monitor expression profiles in various stress-induced tissues (Aharoni and Vorst, 2001).

Experimental procedures

Plant material

A common wheat species, *Triticum aestivum* cv. Chinese Spring, was grown in a greenhouse for RNA sampling from crown tissue of 14-day-old seedlings (Wh_dL) and roots at the same stage (Wh_r), or were grown in the field for sampling of tissues from later stages: spikelets at early flowering (Wh_yf, Feekes' scale = 5–6; Feekes, 1941), spikelets at flower differentiation stage (Wh_yd, Feekes' scale = 6–7), spikes at booting stage (Wh, Feekes' scale = 10), spikes at heading date (Wh_h, Feekes' scale = 10.1), pistils at

heading date (Wh_oh, Feekes' scale = 10. 1), spikes at flowering date (Wh_f, Feekes' scale = 10.5.1), seeds 10 days post-anthesis (Wh_e, 10 DPA), and seeds 30 days post-anthesis (Wh_SL, 30 DPA). Sampled wheat tissue was collected, immediately frozen in liquid nitrogen, and stored at –80°C until use.

Construction of cDNA library

Total RNAs from these tissues were extracted as previously described (Ogihara *et al.*, 1998). Poly(A)+ RNA was prepared using Oligotex-dT30 as recommended by the supplier (Takara Shuzo, Tokyo, Japan). Double-stranded cDNA was synthesized using a cDNA synthesis kit (Stratagene, La Jolla, CA, USA) with an anchored oligo(dT) primer (5′-$(GA)_{10}$ACTAGTCTCGAG $(T)_{18}$-3′). Synthesized cDNA was ligated using an *Eco*RI adaptor. The cDNA was ligated with pBluescript SK(+) digested with a combination of *Eco*RI and *Xho*I. Ligated DNA was electroporated (BioRad, Hercules, CA, USA) into *Escherichia coli* XL1 Blue MRF′ (Stratagene, La Jolla, CA, USA) cells. Transformed cells were initially cultured in SOC medium for 1 h before further culture at 37°C for 2 h in 2× LB medium containing 100 μg ml^{-1} of ampicillin. Then, 4× LB medium with 40% glycerol was added and stored at –80°C until use.

DNA sequencing of cDNA clones

Transformed bacteria were randomly selected and plasmid DNAs were extracted using a Kurabo DNA extraction instrument (Toyobo, Tokyo, Japan). Inserted cDNA sequences were determined from both ends using the dye terminator cycle sequencing method (Applied Biosystems, Foster City, CA, USA).

Grouping ESTs into contigs

Related cDNA sequences from both ends were grouped as contigs using the PHRAP method (University of Washington Genome Center; http://www.genome.washingtonedu/UWGC) under the conditions of new_ace -penalty -5 -minmatch 50 -minscore 100. Subsequently, contigs were annotated according to DNA sequence homologies against the DDBJ/EMBL/NCBI database using the BLAST program (Karlin and Altschul, 1993). Contigs were then classified into related gene groups using the BLAST method (*E* value = 1e-30).

Contig and library correlation analysis

As statistical analysis of gene expression profiles was performed using EST data, contigs with five or more constituents were selected from 25 971 contigs (Table 1). Similarities between contigs or libraries were estimated using Pearson's correlation coefficient, as described by Eisen *et al.* (1998).

Homology search of wheat contigs against public database

Homology of 25 971 contigs was searched against Rice GD (http://btn.genomics.org.cn/rice/), and plant EST databases including *Arabidopsis*, rice, barley, maize, soybean, wheat (except our ESTs), goatgrass, rye, oat, sorghum, tomato, potato, pepper, tobacco, and *Brassica* were searched using the BLAST method (*E* value = 1e-5).

Hierarchical clustering

The hierarchical clustering method (Eisen *et al.*, 1998; http://rana.stanford.edu/clustering) was applied to compare EST expression profiles among the 10 wheat tissues and library gene expression profiles among contigs. The expression profile is displayed based on the number of constituents in a contig from 0 (green) to 565 (red), along with the increasing number of constituents.

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DNA sequence data were deposited to the DNA Data Bank of Japan (DDBJ), accession numbers BJ207074 to BJ323305. EST resources are available at http://shigen.lab.nig.ac.jp/wheat/est2002/

been a past history of selection on this trait. Yet, low levels of genetic variation for desiccation resistance appear to be preventing any further increases in resistance in this rainforest species despite ample genetic variation in other traits and at neutral markers as evident from the microsatellite results. Our results show that genetic variation in neutral markers can provide an incomplete picture of the evolutionary potential of populations, consistent with the weak association between genetic diversity as measured by quantitative methods and that measured by molecular methods (*25*). The absence of a selection response for traits linked to climatic stress in this study and in a few other cases (*26*) suggests that levels of variation must be evaluated for ecologically relevant traits in those species that are threatened by climate change and fragmentation, including endangered species (*27*).

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Supporting Online Material

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Materials and Methods

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Inferring Genetic Networks and Identifying Compound Mode of Action via Expression Profiling

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The complexity of cellular gene, protein, and metabolite networks can hinder attempts to elucidate their structure and function. To address this problem, we used systematic transcriptional perturbations to construct a first-order model of regulatory interactions in a nine-gene subnetwork of the SOS pathway in *Escherichia coli*. The model correctly identified the major regulatory genes and the transcriptional targets of mitomycin C activity in the subnetwork. This approach, which is experimentally and computationally scalable, provides a framework for elucidating the functional properties of genetic networks and identifying molecular targets of pharmacological compounds.

Efforts to systematically define the organization and function of gene, protein, and metabolite networks include experimental and computational methods for identifying molecular interactions (*1–3*), global structural properties (*4*, *5*), metabolic limits (*6*), and regulatory modules and characteristics (*7–9*). These methods have provided valuable insights in many applications, but they often provide only structural information or require extensive quantitative information, which is not generally available, particularly for larger regulatory networks. In previous computational studies (*10–12*), alternative methods have been proposed that would enable rapid deduction of network connectivity and functional properties solely from temporal gene-expression data. However, the acquisition of adequate temporal expression data remains difficult, and the practical utility of such approaches has not been determined.

Here, we present a rapid and scalable method that enables construction of a first-order predictive model of a gene and protein regulatory network using only steady-state expression measurements and no previous information on the network structure or function. We use multiple linear regression to determine the model from RNA expression changes resulting from a set of steady-state transcriptional perturbations. The model can be used to identify the regulatory role of individual genes in the network, useful control points in the network, and genes that directly mediate a pharmaceutical compound's bioactivity in the cell. The method, called network identification by multiple regression (NIR), is derived from a branch of engineering called system identification (*13*), in which a model of the connections and functional relations between elements in a network is inferred from measurements of system dynamics (e.g., the response of genes and proteins to external perturbations).

To apply a system-identification method, we assume that the behavior of a gene, protein, and metabolite regulatory network can be modeled by a system of nonlinear differential equations (*14*, *15*). Near a steady-state point (e.g., when gene expression does not change substantially over time), such a nonlinear system may be approximated to the first order by a linear system of equations describing the rate of accumulation of each network species resulting from a transcriptional perturbation:

$$d\mathbf{x}/dt = \mathbf{A}\mathbf{x} + \mathbf{u} \qquad (1)$$

where $\mathbf{x}$ is a vector representing the concentrations of N RNAs, proteins, and metabolites in the network; $d\mathbf{x}/dt$ represents the rate of accumulation of the species in $\mathbf{x}$; $\mathbf{u}$ is a vector representing an external perturbation to the rate of accumulation of the species in $\mathbf{x}$; and $\mathbf{A}$, the network model, is an $N \times N$ matrix of coefficients describing the regulatory interactions between the species in $\mathbf{x}$. Next, we identify the coefficients of $\mathbf{A}$ using only RNA expression changes that result from steady-state transcriptional perturbations. Because we measure RNA but not protein or metabolite species in this study, variables representing proteins and metabolites are not explicitly represented in the network model. Thus, regulatory connections in the model are not, in general, physical connections; rather, they represent effective functional relations between transcripts.

Under the steady-state assumption ($d\mathbf{x}/dt = 0$), Eq. 1 reduces to $\mathbf{A}\mathbf{x} = -\mathbf{u}$. To identify the network model, we could, in principle, make N distinct perturbations, $\mathbf{u}$, to the RNAs in a particular network, recover N sets of RNA concentrations, $\mathbf{x}$, and solve directly for $\mathbf{A}$ (*16*). How-

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ever, in larger networks it may be impractical to perform a full set of N perturbation experiments, and thus our problem would remain underdetermined. Even with a full set of perturbation experiments, RNA expression data are prone to high levels of measurement noise, making the direct solution unreliable. To overcome this problem, we assume that most biochemical networks are not fully connected (*17*, *18*, *19*), that is, some of the coefficients of **A** are zero. Thus, by assuming a maximum of k nonzero regulatory inputs to each gene (where $k < N$), we can transform our underdetermined problem into an overdetermined problem, making it robust both to measurement noise and incomplete data sets.

We next apply multiple linear regression (*20*) to calculate the model coefficients for each possible combination of k regulatory inputs (k coefficients) per gene. The k coefficients for each gene that fit the expression data with the smallest error are chosen as the best approximation of **A**. Using the standard errors on the RNA measurement data, the algorithm also computes the statistical significance of each recovered coefficient of **A** and the overall fit of **A**. A complete description of the algorithm is provided in the supporting online text.

We applied the NIR method to a nine-transcript subnetwork of the SOS pathway in *E. coli* (the "test network"). The SOS pathway, which regulates cell survival and repair after DNA damage, involves the *lexA* and *recA* genes, more than 30 genes directly regulated by *lexA* and *recA*, and tens or possibly hundreds of indirectly regulated genes (*21*–*25*). We chose the nine transcripts in our test network (Fig. 1) to include the principal mediators of the SOS response (*lexA* and *recA*), four other regulatory genes with known involvement in the SOS response (*ssb*, *recF*, *dinI*, and *umuDC*), and three sigma factor genes (*rpoD*, *rpoH*, and *rpoS*) whose regulatory role in the SOS response is not fully understood. Because much of the regulatory structure of our test network has been previously mapped, it serves as an excellent subject for the validation of our method. In addition, it serves as an entry point for further study of the SOS pathway, which regulates genes associated with important protective pathways relevant to antibiotic resistance (*23*, *26*).

We applied a set of nine transcriptional perturbations to the test network in *E. coli* cells (*27*). In each perturbation, we overexpressed a different one of the nine genes in the test network with an arabinose-controlled episomal expression plasmid (fig. S1). We grew the cells in batch cultures under constant physiological conditions to their steady state (~5.5 hours after the addition of arabinose). Cells were maintained in the exponential growth phase throughout all experiments. For all nine transcripts, we used quantitative real-time polymerase chain reaction (qPCR) to measure the change in expression relative to that in unperturbed cells. For each transcript, two qPCR reactions from each of eight replicate cultures were obtained, and qPCR data were filtered to eliminate aberrant or inefficient reactions (*27*). The mean expression changes for each transcript in each experiment (**x** in Eq. 1) were calculated (*27*), and only those changes that were greater than their standard error were accepted as significant and used for further analysis (that is, $x_i = 0$ if $|x_i| < S_{x_i}$, where x_i is the mean expression change and S_{x_i} is the standard error for transcript i).

Using the nine-perturbation expression data set (the training set, tables S6 to S8) and the NIR algorithm described above, we solved Eq. 1 for **A**, the model of the regulatory interactions in the test network (table S1). The number of input connections per gene (k) was chosen such that the solved model provided a statistically significant fit (as determined by an F test), was dynamically stable, and provided the best balance between coverage and false-positives (*27*). To evaluate the performance of the algorithm, we determined the number of connections in the test network that were correctly resolved in the model, **A**. A resolved connection was considered correct if there exists a known RNA, protein, or metabolite pathway between the two transcripts and if the sign of the net effect of regulatory interaction (that is, activating or inhibiting) is correct, as determined by the currently known network in Fig. 1.

The algorithm correctly identified the key regulatory connections in the network. For example, the model correctly shows that *recA* positively regulates *lexA* and its own transcription, whereas *lexA* negatively regulates *recA* and its own transcription. In addition, the model correctly identified *recA* and *lexA* as having the greatest regulatory influence on the other genes in the test network (table S5). Overall, the performance (coverage and false-positives) of the NIR algorithm was equivalent to that expected on the basis of simulations of 50 random nine-gene networks (Fig. 2). Moreover, for the subnetwork of six genes typically considered part of the SOS network (*recA*, *lexA*, *ssb*, *recF*, *dinI*, and *umuDC*), the performance of the algorithm improved substantially. This suggests that some of the false-positives identified for the three sigma factors in our model (*rpoD*, *rpoH*, and *rpoS*) may be true connections mediated by genes not included in our test network. Furthermore, our simulation results suggest that even small reductions in the measurement noise observed in our experiments [mean noise level = mean(S_{x_i})/mean(x_i) = 68%] could lead to substantial improvements in coverage and errors in the network model (Fig. 2). Reductions in experimental noise could be achieved with improved RNA measurement technologies such as competitive PCR coupled with matrix-assisted laser desorption/ionization–time-of-flight (MALDI-TOF) mass spectrometry (*28*).

We also tested the performance of the NIR algorithm with an incomplete training set consisting of perturbations to only seven of the nine genes. We solved for network models using all 36 combinations of seven perturbations and found that the algorithm

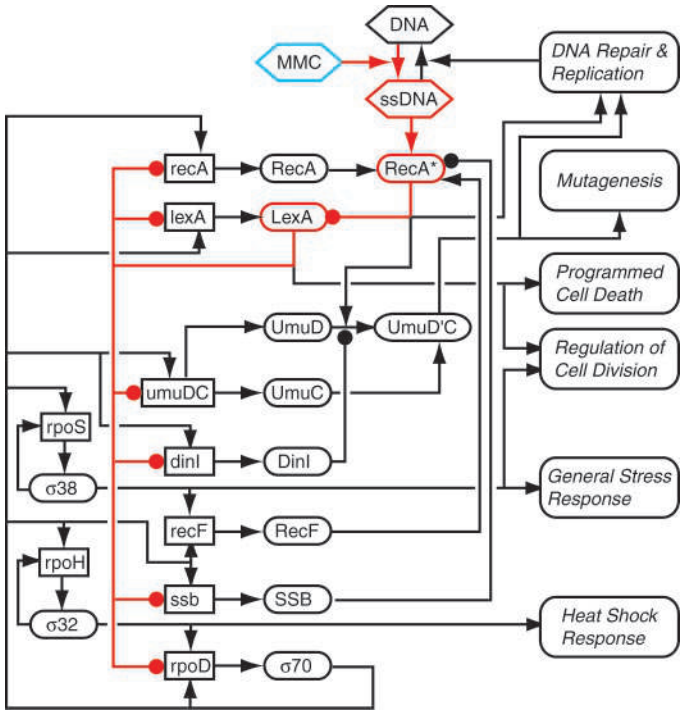

Fig. 1. Diagram of interactions in the SOS network. DNA lesions caused by mitomycin C (MMC) (blue hexagon) are converted to single-stranded DNA during chromosomal replication. Upon binding to ssDNA, the RecA protein is activated (RecA*) and serves as a coprotease for the LexA protein. The LexA protein is cleaved, thereby diminishing the repression of genes that mediate multiple protective responses. Boxes denote genes, ellipses denote proteins, hexagons indicate metabolites, arrows denote positive regulation, filled circles denote negative regulation. Red emphasis denotes the primary pathway by which the network is activated after DNA damage.

also performed comparably to simulations, albeit with slightly reduced performance in comparison with the full nine-perturbation training set (Fig. 2).

Much of the value of the network model lies in its predictive power, that is, its ability to predict expression changes and network behaviors that fall outside the training data set used to solve the model. Here, we demonstrate its predictive power by using it to distinguish the transcripts that are directly targeted by a pharmacological compound (the compound's mode of action) from transcripts that exhibit secondary responses to the expression changes of the direct targets. Thus, the direct targets represent the minimal subset of transcripts in the model that will produce the observed expression pattern if externally perturbed. Because proteins and metabolites are not measured in this study, the compound may not physically interact with transcripts identified as direct targets but instead may interact with protein or metabolite intermediates that are not explicitly represented in the network model.

To identify direct transcriptional targets of a compound, we first measure RNA expression changes ($\mathbf{x}_p$) resulting from treatment with the compound. The activity of the compound is treated as a set of unknown transcriptional perturbations ($\mathbf{u}_p$) that produce the measured expression changes. From Eq. 1, we calculate the unknown perturbations as $\mathbf{u}_p = -\mathbf{A}\mathbf{x}_p$ (*27*). The direct transcriptional targets of a compound are those that exhibit statistically significant values in $\mathbf{u}_p$. Calculation of the statistical significance of $\mathbf{u}_p$ is described in the supporting online text.

We first applied our scheme to RNA expression changes that result from the simultaneous controlled perturbation of the *lexA* and *recA* genes. This perturbation might represent the effects of a hypothetical compound and serves as a well-defined input for validating the predictive power of our model. Although five of the nine test-network genes responded with statistically significant transcriptional changes (Fig. 3A), application of our network model correctly identified only *lexA* and *recA* as the perturbed genes (2/2 = 100% coverage, 7/7 = 100% specificity) (Fig. 3B).

We next applied a mitomycin C (MMC) perturbation to determine whether our scheme could identify the transcriptional targets of MMC bioactivity in the SOS network. Perturbed cells were grown in 0.75 μg/ml MMC, and transcriptional changes were measured relative to those in control cells grown in the normal baseline condition (0.5 μg/ml MMC). All genes in the test network showed statistically significant transcriptional increases (Fig. 3C). When we applied the network model to the expression data, we correctly identified *recA* as the transcriptional target of MMC bioactivity, with only one false-positive, *umuDC* (1/1 = 100% coverage, 7/8 = 88% specificity) (Fig. 3D). Moreover, *recA* was identified at a higher significance level ($P \leq 0.09$) than was *umuDC* ($P \leq 0.22$), suggesting that it is the more likely, if not the only, true target. It is also possible, however, that *umuDC* interacts with gene, protein, or metabolite targets of the compound that are not represented in our model. Therefore, *umuDC* may have been correctly identified as a target in our model. We also found that a model recovered with a seven-perturbation training set that excludes the *lexA* and *recA* training perturbations performs nearly as well as the model recovered with a full training set (see supporting online text and fig. S3).

The NIR method, a form of system identification based on multiple linear regression analysis of steady-state transcription profiles, provides a framework for rapidly elucidating the structure and function of genetic networks with no prior information. The method is robust to high levels of measurement noise, scalable for larger biochemical networks (*27*), and equally applicable to transcript, protein, and metabolite activity data. With advances in high-throughput measurement methods, it may soon be feasible to include protein and metabolite measurements on a large scale. The model recovered with this method enables the identification of key properties of the network, such as the major regulatory genes, and it provides a mechanism for efficiently identifying the mode of action of uncharacterized pharmacological compounds. These capabilities may facilitate optimization of cellular processes for biotechnology applications and the development of novel classes of therapeutic drugs that account for and utilize the complex regulatory properties of genetic networks.

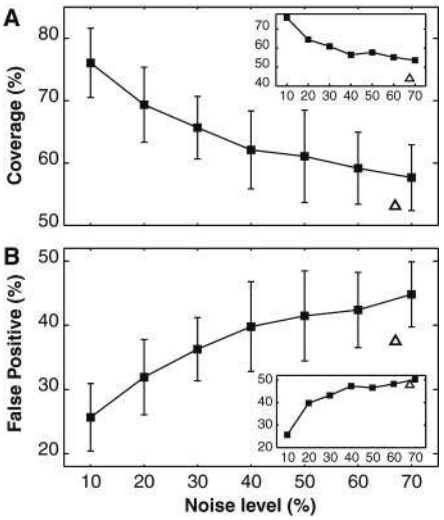

Fig. 2. NIR algorithm performance. (**A**) Coverage (correctly identified connections/total true connections) and (**B**) false-positives (incorrectly identified connections/total identified connections) were calculated for SOS models solved with a nine-perturbation training set (main panels) and a seven-perturbation training set (insets). Error bars are not included in the insets for clarity. Experiment (open triangles): Coverage and false-positives were calculated by comparing the solved model (table S1) to connections described in the literature (table S4 and Fig. 1). Because a nonsignificant fit was obtained for *recF*, the weights for inputs to *recF* were set to zero in the model. The mean noise observed on the mRNA measurements in our experiments was 68% (noise = S_x/μ_x, where S_x is the standard deviation of the mean of x, μ_x). Simulations (filled squares): Simulated perturbations were applied to 50 randomly connected networks of nine genes with an average of five regulatory inputs per gene. For each perturbation to each random network, the mRNA expression changes at steady state were calculated. The noise on the perturbations was set to 20%, equivalent to that observed on perturbations in our experiments. The noise on the mRNA concentrations was varied from 10 to 70%.

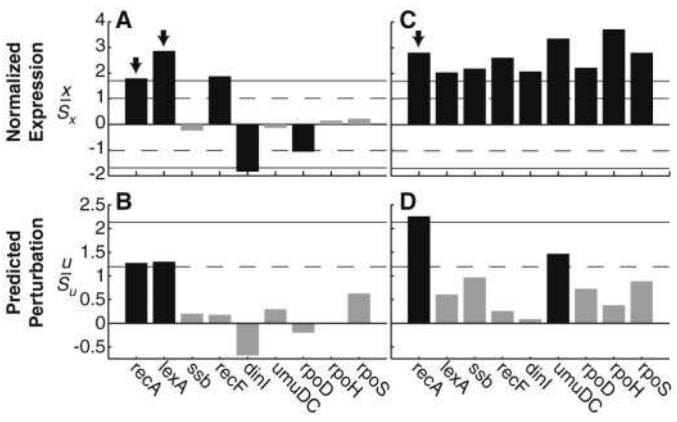

Fig. 3. Cells were perturbed either with a *lexA-recA* double perturbation or with MMC. The mean relative expression changes (x), normalized by their standard deviations (S_x), are illustrated for the *lexA-recA* double perturbation (**A**) and the MMC perturbation (**C**). Arrows indicate the genes known to be targeted by the perturbation. Predicted perturbations in the *lexA-recA* experiment (**B**) and the MMC experiment (**D**) were calculated from the expression data in (A) and (C) using the SOS model solved with the nine-perturbation training set (*27*). The predicted perturbations to each gene (u) were normalized by their standard deviations (S_u) to determine statistical significance. In all panels, black bars indicate statistically significant and gray bars indicate statistically nonsignificant. Horizontal lines denote significance levels: P = 0.3 (dashed), P = 0.1 (solid).

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Supporting Online Material

www.sciencemag.org/cgi/content/full/301/5629/102/DC1
Materials and Methods
SOM Text
Figs. S1 to S5
Tables S1 to S8
References

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Intracellular Bacterial Biofilm-Like Pods in Urinary Tract Infections

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Escherichia coli **entry into the bladder is met with potent innate defenses, including neutrophil influx and epithelial exfoliation. Bacterial subversion of innate responses involves invasion into bladder superficial cells. We discovered that the intracellular bacteria matured into biofilms, creating pod-like bulges on the bladder surface. Pods contained bacteria encased in a polysaccharide-rich matrix surrounded by a protective shell of uroplakin. Within the biofilm, bacterial structures interacted extensively with the surrounding matrix, and biofilm associated factors had regional variation in expression. The discovery of intracellular biofilm-like pods explains how bladder infections can persist in the face of robust host defenses.**

Urinary tract infections (UTIs) result in $1.6 billion in medical expenditures in the United States each year (*1*), with uropathogenic strains of *Escherichia coli* (UPEC) accounting for 70 to 95% of all UTIs (*2*). With the advance of multi–drug-resistant UPEC (*3*), it is important to determine the pathogenic mechanisms of UPEC. In animal models, UPEC pathogenesis initiates with bacterial binding of superficial bladder epithelial cells via the adhesin FimH at the tips of bacterially expressed type 1 pili (*4*). Initial colonization events activate inflammatory and apoptotic cascades in the epithelium, which is normally inert and only turns over every 6 to 12 months (*5*). Bladder epithelial cells respond to invading bacteria in part by recognizing bacterial lipopolysaccharide (LPS) via the Toll-like receptor 4 (TLR-4)–CD14 pathway, which results in strong neutrophil influx into the bladder (*6*). In addition, FimH-mediated interactions with the bladder epithelium stimulate exfoliation of superficial epithelial cells, causing many of the pathogens to be shed into the urine. Genetic programs are activated that lead to differentiation and proliferation of the underlying transitional cells in an effort to renew the exfoliated superficial epithelium (*7*). Despite the robust inflammatory response and epithelial exfoliation, UPEC are able to maintain high titers in the bladder for several days (*8–13*).

A bacterial mechanism of FimH-mediated invasion into the superficial cells apparently allows evasion of these innate defenses (*9*); subsequent replication as disorganized bacterial clusters inside superficial cells leads to high bacterial titers in the bladder. Bacteria in these intracellular niches [which we termed "bacterial factories" (*9*)] create a chronic quiescent reservoir in the bladder, which can persist undetected for several months without bacteria shedding in the urine. These bacteria are completely resistant to 3- and 10-day courses of antibiotics (*9, 14*). Thus, in addition to the intestine and vagina as reservoirs for UPEC, the bladder itself may serve as the source for recurrent cystitis and asymptomatic bacteriuria seen in a large proportion of women with UTIs (*9, 14, 15*).

To define bacterial-specific effects on UTI progression, we studied acute UTIs initiated by clinically isolated UPEC or laboratory (K-12) strains in TLR-4 mutant C3H/HeJ mice, which lack an intact innate immune response (*16, 17*). C3H/HeJ mice were inoculated with UPEC strain UTI89 (*9*) or type 1–piliated K-12 strain MG1655 (*18*), and numbers of colony-forming units (CFU) were determined in bladders at early time points after inoculation (fig. S1) (*10, 19*). While UTI89 levels increased nearly two orders of magnitude over 24 hours to about 6×10^6 CFU per bladder, MG1655 levels decreased over this time period to 10^3 CFU per bladder.

To investigate the increase in UPEC bacterial load at 24 hours, we performed scanning electron microscopy (SEM) (*8, 10*) of infected C3H/HeJ mouse bladders, which revealed numerous, large protrusions, or pods, on the surface of bladders infected with UPEC strain UTI89 (Fig. 1, A to C) (fig. S2). This was a rare event with the K-12 strain of *E. coli*, MG1655, because pods were not detected at this time point (Fig. 1D). In contrast, other clinical isolates such as UPEC strain NU14 (*9, 10*) also elicited abundant pod formation. SEM and hematoxylin and eosin (H&E) staining of the pods revealed that bacterial replication resulted in large bacterial colonies that extended above the lumenal surface (Fig. 1E). Video microscopy revealed that the previously described bacterial factories undergo a maturation process (*20*), whereby the loose collections of UPEC rods converted into a uniform coccoid morphology. This process was coupled with the organization of the bacteria into tightly packed biofilm-like pod structures (Fig. 1E) (*20*), Mutations in *fimH* completely abolish this pathogenic cascade (*10*).

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Selected Publications:

1. **Jelesko, J. G.**, K. Carter, W. Thompson, Y. Kinoshita, W. Gruissem. Meiotic recombination between paralogous RBCSB genes on sister chromatids of Arabidopsis thaliana. Genetics 166:947-957.
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State of VA/CTRF
The Virginia Consortium for Mucosal Therapy of Infectious and Autoimmune Diseases
This is a multi-institutional research program including University of Virginia, Virginia Tech and Virginia Commonwealth University. The objective of this program is to develop mucosal therapeutics through biotechnology including: application of bioinformatics technology to discover potential targets for immunotherapeutic or chemical intervention, mechanisms of regulation of mucosal immune responses and develop plant-based vaccines and mucosal delivery systems.
Role: Research Director (Virginia Tech component)

BioDefense Technologies
Nasally delivered subunit vaccine for plague
Subcontract to Virginia Tech from NIAID/NIH STTR Phase I grant R41 AI 52958-01 awarded to BioDefense Technologies, Inc. (PI, C. Cramer)
Feasibility study to determine if tobacco can produce immunogenic plague antigens (F1-V fusion fused to the RTB adjuvant) for development of intranasally delivered vaccines.
Role: PI for Virginia Tech subcontract.

NIH BioDefense Regional Centers (Center PI: M. Levine, Univ. Maryland, Baltimore)
Crystoporidium genomics, pathogenesis and vaccinology -- Project 1 of "Enterics Research Project for MidAtlantic Regional Center of Excellence: Low infectious dose enteropathogens: detection, pathogenesis and vaccinology."
The goal of this project is to develop a vaccine for *Crystoporidium parvum* through the identification of *C. parvum* genes involved in pathogenicity and immunity and the use of novel plant-based mucosal adjuvants.
Co-Investigators: Guerrant, Kapers,Bushen, Xu, Ozaki, Cramer, Medina-Bolivar, Kirkpatrick, Beaty, Petri

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Department of Plant Pathology, Physiology, and Weed Science
Last Updated November 14, 2003

Craig L. Nessler

Professor and Head
Department of Plant Pathology,
Physiology, and Weed Science
413 Price Hall
Virginia Tech University
Blacksburg, VA 24061-0331

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E-mail: cnessler@vt.edu

Education:

- Ph.D., Department of Plant Science, Indiana University, 1976
- M.A., Biology, College of William and Mary, 1972
- B.S., Biology, College of William and Mary, 1971

Professional Experience:

- Head, Department of Plant Pathology, Physiology and Weed Science, Virginia Tech, Blacksburg, VA 24061-0331, 2000-present
- Professor of Plant Physiology, Virginia Tech, 2000-present
- Professor and Associate Head, Department of Biology, Texas A&M University, 1993-2000
- Associate Professor, Department of Biology, Texas A&M University, 1985-1992
- Visiting Research Scientist, Plant Biotechnology Institute (NRC Canada), 1989-1990
- Assistant Professor, Department of Biology, Texas A&M University, 1979-1985
- Post-doctoral Research Associate, Department of Crop Science, North Carolina State University, 1977-1979
- Post-doctoral Research Associate, Department of Plant Science , Indiana University, 1976-1977

Awards and Honors:

- 1992- Distinguished Teaching Award for, College of Science, Association of Former Students of Texas A&M University.
- 1982-1983-Award of Merit for Outstanding Undergraduate Teaching,. Gamma Sigma Delta, The Honor Society of Agriculture, Texas A&M University.

Teaching Interests:

- Biology of Plants
- Molecular Cell Biology
- Economic Botany

Research Interests:

My laboratory focuses on plant metabolic engineering. Projects in this area include:

- Manipulation of indole and opiate alkaloid biosynthetic pathways
- Increase of Vitamin C content in crops

- Introduction of novel biosynthetic pathways into plants for disease and insect resistance.

Selected Publications:

1. Pilatzke-Wunderlich, I. and C. L. Nessler, (2001). Expression and activity of cell wall degrading enzymes in the latex of opium poppy, Papaver somniferum L. Plant Mol. Biol. in press.
2. El-Ahmady, S. -H. and C.L. Nessler (2001) Cellular localization of tyrosine decarboxylase expression in transgenic opium poppy and tobacco. Plant Cell Reports, in press.
3. Jain, A.K., Vincent, R.M., and C. L. Nessler, (2000). Molecular characterization of a 3-hydroxy-3-methylglutaryl CoA reductase (HMGR) gene from mulberry (Morus alba L.) Plant Mol. Biol. 42: 559-569.
4. Jain, A.K., and Nessler, C.L. (2000) Metabolic engineering of an alternative pathway for ascorbic acid biosynthesis in plants. Mol. Breeding 6:73-78.
5. Nessler, C.L. (1998) In vitro culture technologies. Poppy: The Genus Papaver. Jeno Bernath ed. Harwood Academic Publishers, Amsterdam, The Netherlands, pp. 209-218.
6. Lopez-Meyer, M. and C.L. Nessler. (1997) Tryptophan decarboxylase is encoded by two autonomously regulated genes in *Camptotheca acuminata* which are differentially expressed during development and stress. Plant J. 11: 1167-1175.
7. Maldonado-Mendoza, I.E., R.M. Vincent, and C.L. Nessler. (1997) Molecular characterization of three differentially expressed members of the *Camptotheca acuminata* 3-hydroxy-3-methylglutaryl-CoenzymeA reductase gene family. Plant Mol. Biol., 34: 781-790.

Current research sponsors:

GlaxoWellcome Australia Ltd., National Institutes of Health-National Cancer Institute

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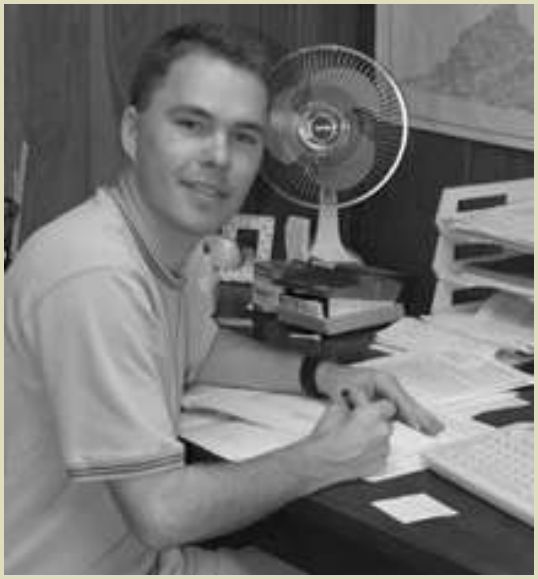
Department of Plant Pathology, Physiology, and Weed Science

Last Updated April 25, 2001



Shawn Askew

Assistant Professor of Turfgrass Weed Science
Extension Turfgrass Weed Specialist
Department of Plant Pathology,
Physiology, and Weed Science
Glade Road Research Facility
Blacksburg, Virginia 24061-0330
Phone: 540-231-5807
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E-Mail: saskew@vt.edu

Education:

- Ph.D., Crop Science Department, North Carolina State University, 2001.
- M.S., Department of Plant and Soil Sciences, Mississippi State University, 1997.
- B.S., Agricultural Pest Management, Mississippi State University, 1995.

Professional Experience:

- Assistant Professor of Turfgrass Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA, 2001-present.
- Research Associate, Crop Science Department, North Carolina State University, (Under direction of Dr. John Wilcut), 1997-2001.
- Graduate Research Assistant, Department of Plant and Soil Sciences, Mississippi State University, (Under direction of Dr. David Shaw), 1994-1997.

Recent Awards and Honors:

- Outstanding Ph.D. Student, Weed Science Society of America, 2002.
- Outstanding Ph.D. Student, Crop Science Department, NCSU, 2001.
- Outstanding Ph.D. Student, Weed Science Society of North Carolina, 2001.
- Outstanding Masters Student, Southern Weed Science Society, 1998.

Extension Interests: Dr. Askew's primary responsibility is to provide statewide leadership in the development of weed control programs for turfgrass. Emphasis is placed on development of recommendations and other weed control information pertinent to current problems in home lawns, professional turf (golf courses, football fields, etc.) and commercial sod and seed production. Dr. Askew maintains a close working relationship with Virginia Cooperative Extension agents and provides training aids and research to address turfgrass weed problems. A significant amount of his time is spent developing extension publications, troubleshooting, and conversing with agents, professional turfgrass personnel, and sod/seed farmers.

Research Interests: The research endeavors of Dr. Askew's position are closely tied to his extension activities. Research efforts of his program include: development and evaluation of new herbicides on site and in the lab/glasshouse, evaluation of organic and cultural weed control, new diagnostic and application technology such as sensors and photo-optics, and environmental effects of weed management in turfgrass. Dr. Askew is currently seeking qualified graduate students to participate in research and

educational activities.

Selected Publications:

2002:

Askew, S. D. and J. W. Wilcut. 2002. Ladysthumb interference and achene production in cotton. Weed Sci. 50:326-332.

Askew, S. D. and J. W. Wilcut. 2002. Absorption, translocation, and metabolism of foliar applied CGA 362622 in cotton, peanut, and selected weeds. Weed Sci. 50:293-298.

Askew, S. D. and J. W. Wilcut. 2002. Pennsylvania smartweed interference and achene production in cotton. Weed Sci. 50:350-356.

Askew, S. D. and J. W. Wilcut. 2002. Pale smartweed interference and achene production in cotton. Weed Sci. 50:357-363.

Askew, S. D., J. W. Wilcut, and J. R. Cranmer. 2002. Cotton (*Gossypium hirsutum*) and weed response to flumioxazin preplant and postemergence directed. Weed Technol. 16:184-190.

Clewis, S. B., S. D. Askew, and J. W. Wilcut. 2002. Economic assessment of diclosulam and flumioxazin in strip- and conventional-tillage peanut (*Arachis hypogea*). Weed Sci. 50:378-385.

Scott, G. H., S. D. Askew, and J. W. Wilcut. 2002. Glyphosate systems for weed control in glyphosate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 16:191-198.

Scott, G. H., S. D. Askew, J. W. Wilcut, and A. C. Bennett. 2002. Economic evaluation of HADSS computer program in North Carolina peanut. Weed Sci. 50:91-100.

2001:

Askew, S. D. and J. W. Wilcut. 2001. Tropic croton (*Croton glandulosus*) interference in cotton (Gossypium hirsutum). Weed Sci. 49:184-189.

Clewis, S. B., S. D. Askew, and J. W. Wilcut. 2001. Common ragweed interference in Peanut. Weed Sci. 49:768-772.

Scott, G. H., S. D. Askew, and J. W. Wilcut. 2001. Economic evaluation of diclosulam and flumioxazin systems in peanut (*Arachis hypogaea*). Weed Technol. 15:360-364.

Scott, G. H., S. D. Askew, A. C. Bennett, and J. W. Wilcut. 2001. Economic evaluation of HADSS computer program for weed management in non-transgenic and transgenic cotton. Weed Sci. 49:549-557.

Wilcut, J. W., S. D. Askew, W. A. Bailey, J. F. Spears, and T. G. Isleib. 2001. Virginia market-type peanut (*Arachis hypogaea*) cultivar tolerance and yield response to flumioxazin preemergence . Weed Technol. 15:137-140.

2000:

Askew, S. D., D. R. Shaw, and J. E. Street. 2000. Graminicide application timing influences red rice (Oryza sativa) control and seedhead reduction in soybean (*Glycine max*). Weed Technol 14:176-181.

Scott, G. H., S. D. Askew, J. W. Wilcut, and C. Brownie. 2000. *Datura stramonium* interference and seed rain in *Gossypium hirsutum*. Weed Sci. 48:613-617.

Smith, D. B., S. D. Askew, W. H. Morris, D. R. Shaw, and M. Boyette. 2000. Droplet size and leaf morphology effects on pesticide spray deposition. Transactions of the ASAE 43:255-259.

1999:

Askew, S. D. and J. W. Wilcut. 1999. Cost and weed management with herbicide programs in glyphosate-tolerant cotton (*Gossypium hirsutum*). Weed Technol. 13:308-313.

Askew, S. D., J. W. Wilcut, and V. B. Langston. 1999. Weed management in soybean (*Glycine max*) with preplant-incorporated herbicides and cloransulam-methyl. Weed Technol.13:276-282.

Askew, S. D., J. W. Wilcut, and J. R. Cranmer. 1999. Weed management in peanut (Arachis hypogaea) with flumioxazin and postemergence herbicides. Weed Technol. 13:594-598.

Wilcut, J. W. and S. D. Askew. 1999. Chemical weed control. Pages 627-661 in J. R. Ruberson, ed. Handbook of Pest Management. Marcel Dekker, New York, NY.

1998:

Askew, S. D., J. E. Street, and D. R. Shaw. 1998. Herbicide combinations for red rice (Oryza sativa) control in soybean (Glycine max). Weed Technol. 12:103-107.

Askew, S. D. and D. R. Shaw. 1998. Red Rice (Oryza sativa) control and seedhead reduction with glyphosate. Weed Technol. 12:504-506.

Department of Plant Pathology, Physiology, and Weed Science

Last Updated June 28, 2002

JEFFREY F. DERR

Extension Weed Scientist, Horticultural Crops
Hampton Roads Ag. Res. and Ext. Center
1444 Diamond Springs Road
Virginia Beach, VA 23455

Phone: (757) 363-3912
Fax: (757) 363-3950
E-Mail: jderr@vt.edu

Education:

- Ph.D. Weed Science , North Carolina State University
- M.S. Weed Science, North Carolina State University
- B. S. Horticulture, Pennsylvania State University

Professional Experience:

- Professor and Extension Weed Scientist for Horticultural Crops, 1999 to present.
- Assoc. Professor and Extension Weed Scientist for Horticultural Crops, Dept. Plant Path., Physiol. and Weed Science/HRAREC, 1990 to 1999.
- Asst. Professor and Extension Weed Scientist for Horticultural Crops , Virginia Tech, 1984-1990.

Position responsibilities: conduct a statewide extension and research program in weed management for horticultural crops. Commodity responsibilities include tree fruit, small fruit, nursery and landscape ornamentals, and turf.

Recent Awards and Honors:

- 1997 Outstanding Applied Research Award for Turf, Ornamentals, and Vegetation Management. Northeastern Weed Science Society.

Teaching Interests:

- Teach PPWS 4754 - Weed Science Principles and Practices/HRAREC
- Advisor for MS and Ph.D. students
- Provide guest lectures on weed management in Weed Science, Ag. Technology, and Horticulture classes taught in Blacksburg

Research Interests:

- Develop improved control of annual and perennial broadleaf weeds in tree and small fruit production
- Develop Integrated Pest Management (**IPM**) strategies for weeds in nursery crops.
- Evaluate strategies for yellow nutsedge management in horticultural crops
- Improve ways for grass weed control in turf situations.
- Alternatives to chemicals for weed management through evaluation of mulches, landscape fabrics, and other nonchemical strategies for weed control
- Evaluate herbicides with reduced risk to the environment for cost-effective weed management in horticultural crops

Extension programs:

- Weed Identification: Provide information on weed identification and identification of herbicide injury at extension programs and growers meetings in western, central, northern, and eastern Virginia.
- Integrated Pest Management (IPM): Develop control recommendations for weed management in horticultural crops using an integrated pest management approach. Research results are incorporated yearly into the Pest Management Guides, other extension publications, and through the preparation of popular articles. Weed management options are provided to growers at extension programs, field days, and special seminars.

Selected Publications:

1. Derr, J. F. 2002. Detection of fenoxaprop-resistant smooth crabgrass (*Digitaria ischaemum*) in turf. Weed Technology 16:396-400.
2. Derr, J. F. 2001. Biological assessment of herbicide use in apple production. I. Background and current use estimates. HortTechnology 11:11-19.
3. Derr, J. F. 2001. Biological assessment of herbicide use in apple production. II. Estimated impacts following loss of specific herbicides. HortTechnology 11:20-25.
4. Chandran , R. S. and J. F. Derr. 1999. Isoxaben dissipation in field soil as affected by application timing. J. Environ. Qual. 28:1760-1764.
5. Chandran, R. S. and J. F. Derr. 1998. Duration of broadleaf weed control with isoxaben using soil bioassays. Weed Technol. 12:542-547.
6. Chandran, R. S., J. F. Derr, and S. W. Bingham. 1998. Effect of isoxaben application rate and timing on residual broadleaf weed control in turf. Weed Technol. 12:569-574.
7. Salihu, S., J. F. Derr, and K. K. Hatzios. 1998. Effect of Gallery applied at different growth stages to dwarf burning bush (*Euonymus alatus* 'Compacta'). J. Environ. Hort. 16:155-158.
8. Salihu, S., K. K. Hatzios, and J. F. Derr. 1998. Comparative uptake, translocation, and metabolism of root-applied isoxaben in ajuga (*Ajuga reptans*), and two ornamental euonymus species). Pest. Biochem. 60:119-131.
9. Y. Kuk, J. Wu, J. F. Derr, and K. K. Hatzios. 1999. Mechanism of fenoxaprop resistance in an accession of smooth crabgrass (*Digitaria ischaemum*). Pest. Biochem Physiol. 64:112-123.

Current or Recent Research Sponsors:

- USDA/NAPIAP Program
- USDA Southern Region IPM Program
- Virginia Nursery and Landscape Association
- Virginia State IPM Program
- Virginia Dept. of Transportation
- Agribusiness

Department of Plant Pathology, Physiology, and Weed Science

Last Updated June 28, 2002

E. Scott Hagood

Professor
418 Price Hall
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Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0331

Phone: (540)231-6762
Fax: (540)231-7477
E-Mail: shagood@vt.edu

General Introduction

- Professor.
- PhD, Purdue University, 1980.
- Research 25%, extension 75%.

Dr. Hagood's primary responsibility is to provide state wide leadership in the development of weed control programs for agronomic crops, train graduate students, and serve as the department's Extension Project Leader. With a majority extension appointment, emphasis is placed on development of recommendations and other weed control information pertinent to current problems of Virginia farmers, and the efficient dissemination of this information. The research component of his position is closely tied to his extensive activities, and involves development and evaluation of new herbicides and weed control techniques that show promise for use in Virginia agriculture. One of his most important activities has been the development and
evaluation of new herbicides and weed control techniques that show promise for use in Virginia agriculture. One of his most important activities has been the development of a close working relationship with the state's extension agents, agroservice personne,farmers, and with faculty in other departments. Dr. Hagood's efforts in this area have been successful due in large part to a commitment to county level and regional educational programs, as well as test demonstration work and field days. The result has been excellent recognition of extension weed science programs in all areas of the state. A significant amount of his time has been spent in developing this relationship through the preparation of extension publications, troubleshooting, and in phone conversations with agents, agroservice personnel, and farmers. He directs graduate students.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

P. L. Hipkins
Research Associate
Department of Plant Pathology,
Physiology and Weed Science
Blacksburg, VA 24061-0330

Ph. (540)231-9842
Fax (540)231-7477
E-mail: lhipkins@vt.edu

(M.S., Virginia Polytechnic Institute and State University, Blacksburg, VA)

Mr. Hipkins' research is concentrated on vegetation management on rights-of-way. This work investigates the various methods that can be employed, including cultural and chemical techniques, to assist the Virginia Department of Transportation in its mission of providing safe, aesthetically pleasing highways. Other duties, through the Department of Horticulture, include the investigation of wildflower establishment and propagation. This work, along with that described above is funded by the Virginia Department of Transportation. Research funded by industry includes the evaluation of new products to determine their potential rights-of-way application as well as new application techniques. Much of this work has been concentrated on vegetation control during the dormant season.

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

James H. Westwood

Assistant Professor
406 Price Hall
Department of Plant Pathology, Physiology, and Weed Science
Virginia Polytechnic Institute and State University

Phone: (540)231-7519
Fax: (540)231-7477
E-Mail: westwood@vt.edu

Education:

- Ph.D. Purdue University, West Lafayette, IN.
- M.S. University of Minnesota, St. Paul, MN.
- B.A. Concordia College, Moorhead, MN.

Professional Experience:

1/99 to present	**Assistant Professor**, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA.
1/97 to 12/98	**Research Scientist**, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA.
5/94 to 12/96	**Research Associate**, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA.
8/89 to 4/94	**Graduate Research Assistant**, Department of Horticulture, Purdue University, West Lafayette, IN.
5/89 to 8/89	**Research Technician**, University of Missouri, Columbia, MO.
5/86 to 9/88	**Agricultural Extension Agent,** (US Peace Corps) Mauritanian National Rural Development Society, Dar Es Salaam, Mauritania.
9/82 to 12/85	**Graduate Teaching Assistant**, University of Minnesota, St. Paul, MN.
5/81 to 8/82	**Laboratory Technician**, A.R.S./U.S.D.A. Metabolism and Radiation Research Laboratory, Fargo, ND.

Research Interests:

I am interested in the biology and control of weeds, with a specific interest in the area of parasitic weeds. My research focuses on broomrape (*Orobanche* sp.), a plant that lives as an obligate parasite on the roots of many important vegetable and legume crops, thereby posing a serious threat to agriculture. The life cycle of this weed incorporates several intriguing adaptations for parasitism, including a complex system of communication between parasite and host. Research projects include molecular-level characterization of host response to parasitization, development of model systems for parasitic weed biology, and strategies to enhance host resistance to broomrape. I have additional interests in exotic, invasive weeds and in the implications of genetic engineering on agriculture.

Selected Publications:

Nandula V. K., Westwood, J. H., Foster, J. G., and Foy, C. L. 2001. Influence of Glyphosate on Amino Acid Composition of Egyptian Broomrape (*Orobanche aegyptiaca* (Pers.)) and Selected

Hosts. Journal of Agricultural and Food Chemistry 49:1524-1528.

Westwood, J. H. 2000. Characterization of the *Orobanche-Arabidopsis* system for studying parasite-host interactions. Weed Science 48:742-748.

Morozov, I. V., C. L. Foy, and J. H. Westwood. 2000. Small Broomrape (*Orobanche minor*) and Egyptian Broomrape (*Orobanche aegyptiaca*) parasitization of red clover (*Trifolium pratense*). Weed Technology 14:312-320.

Traynor, P. L. and J. H. Westwood, eds., A Workshop on: The Ecological Effects of Pest Resistance Genes in Managed Ecosystems. 1999. Informations Systems for Biotechnology, Blacksburg. 129 pp. (Accessable online at: http://www.nbiap.vt.edu/)

Westwood, J. H. and C. L. Foy. 1999. Influence of nitrogen on germination and early development of broomrape (*Orobanche* spp.). Weed Sci. 47:2-7.

Westwood, J. H., X. Yu, C. L. Foy and C. L. Cramer. 1998. Expression of defense-related 3-hydroxy-3-methylglutaryl CoA reductase in response to parasitization by *Orobanche*. Mol. Plant-Microbe Interact. 11:530-536.

Hershenhorn, J., D. Plakhine, Y. Goldwasser, J. H. Westwood, C. L. Foy, and Y. Kleifeld. 1998. Effect of sulfonylurea herbicides on early development of Egyptian broomrape (*Orobanche aegyptiaca*) in tomato (*Lycopersicon esculentum*). Weed Technol. 12:108-114.

Teaching Interests:

I teach Weed Science: Principles and Practices. This course provides an overview of weed science: The importance of weeds, aspects of their biology and ecology, and methods of effective weed control.

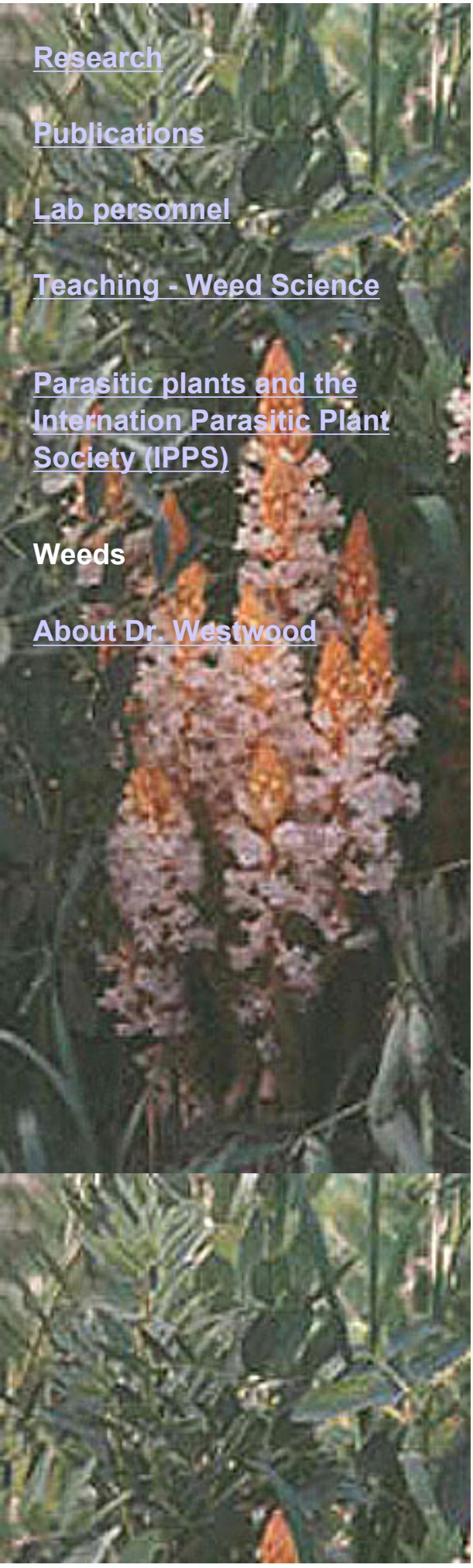
Current or Recent Research Sponsors:

- USDA - 1997 to present
- BARD (US-Israel Binational Fund) - 2000 to present
  BSF (US-Israel Binational Science Foundation) - 2000 to present
  USAID Integrated Pest Management CRSP - 1998 to present

Further Information:

- Westwood lab homepage

Department of Plant Pathology, Physiology, and Weed Science
Last Updated August 06, 2002



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[Parasitic plants and the Internation Parasitic Plant Society (IPPS)](#)

Weeds

[About Dr. Westwood](#)

Welcome to the

Westwood Laboratory Web Page

Department of Plant Pathology, Physiology, and Weed Science

Virginia Tech

Weed Biology and Ecology

Current Research

Molecular Analyses and Manipulation of Host Defense Responses to *Orobanche*

Orobanche species (common name: broomrapes) are parasitic plants that attach themselves to the roots of other plants, from which they then draw all of their water and nutritional needs. This can have an enormous detrimental impact on the 'host' plant, resulting in dramatic crop losses in affected regions, and making *Orobanche* among the world's most destructive weeds. The goals of this research are to increase our understanding of the fundamental interactions between *Orobanche* and their hosts, and then use this knowledge to design new strategies to prevent crop destruction by these weeds. Our research approach is to use tobacco as a model plant for characterizing defense responses against *Orobanche*. To accomplish this we are examining the way *Orobanche* parasitization changes the expression of a variety of genes in the host plant that are known to play specific roles in plant defense against other organisms. Because very little is currently known about host plant defense reactions to *Orobanche*, this is increasing our understanding of how the parasite integrates itself into the host tissues, and provides us with new tools for deterring this invasion. In subsequent experiments the identified *Orobanche*-responsive promoter(s) will be fused to genes which regulate host resistance to other pathogens, and used to generate transgenic plants. These plants will be tested for their ability to resist parasitization by *Orobanche*. Successful demonstration of this novel *Orobanche*-resistance mechanism will have significant implications for parasitic weed control.

Collaborator: Dr. Carole Cramer, Virginia Tech.

[This research is supported by USDA-NRICGP grant No. 97-35315-4206]

Engineering plants for resistance to parasitic weeds based on expression of a protein toxin

This project seeks to create *Orobanche*-resistant crops through genetic engineering. We have identified a protein molecule that exhibits selectivity against *Orobanche* when expressed in a host plant. We are currently in the process of optimizing this system through the use of parasite-inducible promoters, and aided by modeling the movement of proteins from host to parasite using the green fluourescent protein reporter gene.

Collaborators: Dr. Radi Ali, Newe Ya'ar Research Center, Israel. Dr. Carole Cramer, Virginia Tech.

[This research is supported by BARD project IS-3048-98]

Events in seed preconditioning of *Orobanche aegyptiaca*

This project is examining molecular and physiological events in *Orobanche* seed preconditioning. Seed preconditioning is a critical stage in the transtition out of dormancy for these parasites in which the seed prepares itself to respond to a germination signal exuded by the roots of a host plant. We are studying the expression of genes during this period in association with collaborators who are characterizing morphological and physiological changes associated with this process.

Collaborators: Dr. Daniel Joel, Newe Ya'ar Research Center, Israel. Dr. Alfred Mayer, Hebrew University of Jerusalem, Israel, Dr. Greg Welbaum, Virginia Tech.

[This research is supported by BSF project 1999372]

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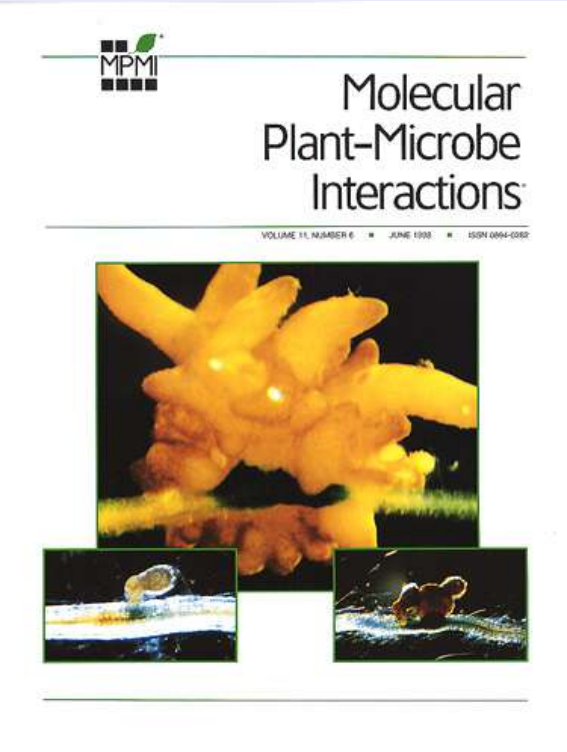
Publications

Some recent publications are listed below:



Nandula V. K., Westwood, J. H., Foster, J. G., and Foy, C. L. 2001. Influence of Glyphosate on Amino Acid Composition of Egyptian Broomrape (*Orobanche aegyptiaca* (Pers.)) and Selected Hosts. Journal of Agricultural and Food Chemistry (in press)

Westwood, J. H. 2000. Characterization of the *Orobanche-Arabidopsis* system for studying parasite-host interactions. Weed Science 48:742-748.

Morozov, I. V., C. L. Foy, and J. H. Westwood. 2000. Small broomrape (*Orobanche minor*) and Egyptian broomrape (*Orobanche aegyptiaca*) parasitization of red clover (*Trifolium pratense*). Weed Technology 14:312-320.

Westwood, J. H. and C. L. Foy. 1999. Influence of nitrogen on germination and early development of broomrape (*Orobanche* spp.). Weed Science 47:2-7.

Westwood, J. H., X. Yu, C. L. Foy and C. L. Cramer. 1998. Expression of a defense-related 3-hydroxy-3-methylglutaryl CoA reductase gene in response to parasitization by *Orobanche* spp. Mol. Plant-Microbe Interact. 11:530-536.

Hershenhorn, J., D. Plakhine, Y. Goldwasser, J. H. Westwood, C. L. Foy, and Y. Kleifeld. 1998. Effect of sulfonylurea herbicides on early development of Egyptian broomrape (*Orobanche aegyptiaca*) in tomato (*Lycopersicon esculentum*). Weed Technol. 12:108-114.

Westwood, J. H. and C. L. Foy. 1998. Arabidopsis thaliana can be a model host for *Orobanche* research. Pp. 155-160 in K. Wegmann, L. J. Musselman and D. M. Joel, eds. Current Problems of *Orobanche* Researches, Proceedings of the Fourth International Workshop on *Orobanche*. Institute for Wheat and Sunflower, "Dobroudja", Bulgaria.

Nandula, V. K., J. H. Westwood, J. G. Foster, and C. L. Foy. 1998. Effects of glyphosate on amino acid composition of *Orobanche aegyptiaca* and two of its hosts. Pp. 367-372 in K. Wegmann, L. J. Musselman and D. M. Joel, eds. Current Problems of *Orobanche* Researches, Proceedings of the Fourth International Workshop on *Orobanche*. Institute for Wheat and Sunflower, "Dobroudja", Bulgaria.

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Members of the Westwood Lab

Summer 2002

Left to right, front to back:

Nourredine Hamamouch, Ph.D. student

Jim Westwood

Peter Hurtado, M.S. student

Sara Opseth, Undergraduate student

Veronique Verdoucq, Lab Technician

Sue Meredith, Lab Technician

Kerri Huffman, Undergraduate student

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WEED SCIENCE: PRINCIPLES AND PRACTICES

PPWS4754 - Fall, 2002

CRN 94229

Dr. Jim Westwood

Department of Plant Pathology, Physiology, and Weed Science

Lecture: Monday and Wednesday, 12:20 - 1:10 pm, Price Hall room 400

Laboratory: Tuesday, 2:00 - 4:50 pm, Price Hall room 400

Course Objectives:

- To provide an understanding of the concepts and principles underlying weed biology and modern control practices for managing weeds.
- To teach the identification, growth characteristics, and appropriate control methods for selected weed species common to the region.
- To expose students to some experimental and practical aspects of modern weed control.
- To acquaint the students with sources of information for further inquiry.
- To create an awareness of and an appreciation of the impact of weed science as a dynamic discipline and career field in modern agriculture.

Textbooks:

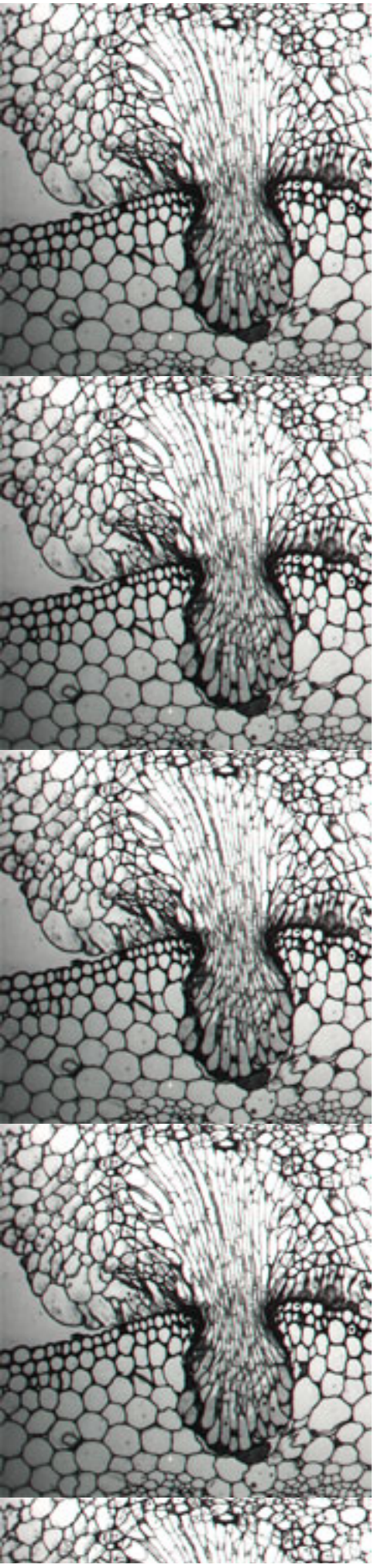
1. WEED SCIENCE: PRINCIPLES AND PRACTICES, 4th edition, by T. J. Monaco, S. C. Weller, and F. M. Ashton, Wiley, New York,. 2002.
2. WEEDS OF THE NORTHEAST, by R. H. Uva, J. C. Neal, and J. M. DiTomaso, Comstock Publishing (Cornell Univ. Press), Ithaca, NY. 1997.

Parasitic Plants

Some web sites of interest

- I[International Parasitic Plant Society](#) Home page of IPPS
- [The Parasitic Plant Connection](#)
- [Haustorium](#) (Parasitic Plants Newsletter; see also the IPPS page)
- [Parasitic Plants Database](#)
- [Ecology and Management of Parasitic Weeds](#)

[Back to main page](#)



IPPS

The International Parasitic Plant Society

A non-profit scientific and educational organization

James H. Westwood

Assistant Professor

Virginia Tech Department of Plant Pathology, Physiology, and Weed Science

Education:

- **Ph.D. Horticulture/Weed Science -Purdue University, West Lafayette, IN**
- **M.S. Plant Physiology -University of Minnesota, St. Paul, MN**
- **B.A. Biology -Concordia College, Moorhead, MN**

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Samuel A. Alexander

Associate Professor of Plant Pathology
33446 Research Drive,
Eastern Shore AREC, Painter, VA 23350

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E-Mail: salex@vt.edu

Education:

- Postdoctoral Fellow--Department of Plant Pathology, Pennsylvania State University, 1974-76.
- Ph.D. Plant Pathology--Department of Plant Pathology & Physiology, Virginia Polytechnic Institute & State University, 1970-73.
- M.S. Botany--Department of Botany and Bacteriology, Louisiana Tech University, 1968-70.
- B.S. Botany--Department of Botany & Bacteriology, Louisiana Polytechnic Institute, 1959-64.

Professional Experience:

- Associate Professor of Plant Pathology, 1982-present Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University
- Assistant Professor of Plant Pathology, 1976-82 Department of Plant Pathology and Physiology, Virginia Polytechnic Institute and State University
- Research Associate, 1974-76 - Department of Plant Pathology, Pennsylvania State University

Recent Awards and Honors:

- Scientific Leadership Award. 1995. Award by the U.S.Environmental Protection Agency, Office of Research and Development, for scientific leadership in the Environmental Monitoring and Assessment Program.
- Tribute of Appreciation. 1995. Awarded by the Office of Monitoring, Modeling and Quality Assurance, U. S. Environmental Protection Agency for contributions and support to the Environmental Monitoring and Assessment Program.
- Certificate of Appreciation. 1992. Awarded by the Chief, U.S.D.A. - Forest Service for making a significant contribution to the preparation of the North American Background Paper for Future UNEP/FAO Global Forest Assessments.

Research Interests:

The goal of my research program is to develop integrated pest management strategies for minimizing the effects of diseases on vegetable production in Virginia.

- Vegetable Disease Forecast Systems

  The purpose was to optimize the efficiency of fungicide applications by utilizing the weather based disease-forecasting models such as, TOMCAST for the management of early blight foliar and fruit infection *(Alternaria solani)* in tomatoes and potatoes, Wisdom for the management of early blight and late blight infection *(Phytophthora infestans)* in potatoes. Fungicides, nematicides and bactericides are important tools in the management of vegetable diseases. The objective of this project is the development of the most effective and environmentally compatible use of these compounds in an integrated pest management strategy for vegetable diseases.
- Biological Management of Vegetable Diseases

  Lesion nematode management with Marigold rotations examines the ability of marigolds to reduce lesion nematode numbers, and therefore, increase yields when double-cropped with tomato or potato. Marigolds represent an alternative management tool for nematode diseases in vegetable crops.

Selected Publications:

1. Alexander, S. A. and C. M. Waldenmaier. 1998. Reduction of lesion nematode populations in potato using marigolds in rotation. American Phytopathological Society, Potomac Div. Meeting, Morgantown, WV.
2. Alexander, S. A. and C. J. Palmer. 1998. Forest health monitoring in the United States: first four years. Environ. Monitoring and Assessment J. (In press).
3. Alexander, S. A. and C. M. Waldenmaier. 1997. Evaluation of the disease forecaster TOMCAST for control of diseases in staked tomatoes. Amer. Phytopath. Soc. Fungicide and Nematicide Tests, Vol. 53: 244.
4. Alexander, S. A. and C. M. Waldenmaier. 1997. Field studies to evaluate marigold as a sequential crop in rotation with tomato. Biological and Cultural Tests for Control of Plant Diseases, Vol. 12: 104.
5. Alexander, S. A. and C. M. Waldenmaier. 1997. Field studies to evaluate marigold as a sequential crop in rotation with white potato. Biological and Cultural Tests for Control of Plant Diseases, Vol. 12: 95.
6. Alexander. S. A., C. I. Liff and C. J. Palmer. 1995. Monitoring the health of forest ecosystems in the United States: Role of Information Management. J. Toxicological and Environmental Chemistry 49: 85-91.
7. Alexander, S. A., J. A. Carlson and J. E. Barnard. 1992. The visual damage survey: a study to evaluate the eastern forest condition. In: Ecological Indicators, Vol. I. Edited by: D. H. McKenzie, J. E. Hyatt and V. J. McDonald. Elsevier Applied Science, New York. pp. 810.
8. Nevill, R. J. and S. A. Alexander. 1992. Transmission of *Leptographium procerum* to eastern white pine by *Hylobius pales* and *Pissodes nemorensis*. Plant Disease 76:307-309.
9. Alexander, S. A. 1989. Annosus root disease hazard rating, detection, and management strategies in the Southeastern United States. pp. 111-116. In Symposium on Research and Management of Annosus Root Disease in Western North America. Gen. Tech. Rept. PSW-116. 177 p.
10. Alexander, S. A., W. E. Horner and K. J. Lewis. 1988. *Leptographium procerum* as a pathogen of pines. pp. 97-112. In Leptographium Root Diseases on Conifers. Edited by: T. C. Harrington and F. W. Cobb, Jr. APS Press. pp.149.
11. Horner, W. E., S. A. Alexander and K. J. Lewis. 1987. Colonization patterns of *Verticicladiella procera* in Scots and eastern white pine and associated resin-soaking, reduced sapwood moisture

content and reduced needle water potentials. Phytopathology 77:557-560.

12. Lewis. K. J., S. A. Alexander and W. E. Horner. 1987. Distribution and efficacy of propagules of *Verticicladiella procera* in soil. Phytopathology 77:552-556.

Additional Information:

- Eastern Shore AREC Home Page

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

Houston B. Couch

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Education:

- B.S., Tennessee Technological University – Cookeville, 1950
- Ph.D., University of California – Davis, 1954

Professional Experience:

- **Professor** of Plant Pathology (Turfgrass Diseases), Virginia Polytechnic Institute and State University – Blacksburg, 1974 to present.
- **Professor and Head**, Department of Plant Pathology and Physiology, Virginia Polytechnic Institute and State University – Blacksburg, 1965-1974.
- **Associate Professor** of Plant Pathology (Turfgrass Diseases), Department of Plant Pathology, The Pennsylvania State University – University Park, 1960-1965.
- **Assistant Professor** of Plant Pathology (Turfgrass Diseases), Department of Botany and Plant Pathology, The Pennsylvania State University – University Park, 1954-1960.
- **Graduate Research Assistant**, Department of Plant Pathology, University of California – Davis, 1950-1954.

Recent Awards and Honors:

2003 - Received the United States Golf Association Green Section Award for "Distinguished service to golf through work with turfgrass."

2002 - Received National Distinguished Service Award from the Golf Course Superintendents Association of America for "Outstanding contributions to the advancement of the golf course superintendents profession."

2000 – Member of turf IPM research and advisory team that received the Epsilon Sigma Phi Team Award for the development of a turfgrass disease and insect forecasting program and setting up a website that provides risk and spray advisory information on disease, insect and weed control to turfgrass management specialists in southeastern Virginia 24 hours a day during the spring, summer and fall seasons.

1994 – 63rd Massachusetts Turfgrass Conference was dedicated to Dr. Couch in recognition of his achievements in research on the nature and control of turfgrass diseases.

1990 – Presented the R. D. Cake award of the Virginia Turfgrass Council for research contributions to turfgrass disease control.

Teaching Interests:

Teaches a semester–length course in the Virginia Tech baccalaureate program on the nature and control of turfgrass diseases.

Also teaches a short course, Maximizing Turfgrass Disease Control, three to four times annually in the education program of the Golf Course Superintendents Association of America.

Research Interests:

- **Influence of environmental factors and cultural practices on the incidence and severity of turfgrass diseases.** These studies are designed to assess the impact of cutting height, thatch accumulation, plant nutrition, soil pH, soil moisture stress, and leaf wetness duration/air temperature combinations on the infection and colonization of leaves and crowns of turfgrasses by pathogenic fungi. Diseases studied in this series to date are Rhizoctonia blight, Fusarium blight, Pythium blight, Helminthosporium leaf spot, rust, melting-out, and Corticium red thread. Information from this research is being used in the development of IPM programs for turfgrass management.
- **Impact of plant stress on the development of foliar and crown diseases of turfgrasses.** The purpose of this research is to determine (a) the extent of stress-induced alterations of the chemical coating and physical makeup of the cuticle, and (b) the level of senescence of the underlying tissue required for successful infection and colonization of turfgrass leaf blades and crowns by primary saprophytic phylloplane inhabiting fungi. To date, these studies have shown that anthracnose of annual bluegrass and Curvularia blight of creeping bentgrass can only develop in tissue that has reached advanced levels of senescence, and that control of these diseases is best achieved by cultural practices that reduce management and environmentally-induced stress on the plants rather than the application of pesticides.
- **Control of Turfgrass Diseases through the Use of Chemical Pesticides.** The objective of this research is to maximize turfgrass disease control with chemical pesticides by (a) determining the relationship between nozzle types, pressure at the nozzle, and fungicide effectiveness, and (b) identifying the optimum dilution levels, in-tank stability, and resistance to post-application leaf washing for the more commonly used fungicides. In addition, fungicide combinations are being evaluated for possible synergistic and antagonistic interactions. To date, reduced rate synergistic fungicide mixtures have been worked out for use in the control of Pythium blight and Sclerotinia dollar spot. Each of these mixtures provides disease control levels greater than the most effective component at its full label rate.
- **Biological Control of Turfgrass Diseases.** This research includes (a) comparisons of natural organic and synthetic fertilizers and (b) tests of preparations containing selected species of fungi and bacteria for control of turfgrass diseases. It has been determined that when used at similar rates of available nitrogen, natural organic and synthetic fertilizers have the same impact on disease development. Certain preparations of microbial species have shown promise in reducing disease incidence and severity. Tests with these materials are ongoing.

Selected Publications:

Journal Articles:

1. Bloom, J. R. and H. B. Couch. 1960. Influence of environment on diseases of turfgrasses. I. Effect of nutrition, pH, and soil moisture on Rhizoctonia brown patch. Phytopathology 50:532-535.

2. Couch, H. B. and J. R. Bloom. 1960. Influence of environment on diseases of turfgrasses. II. Effect of nutrition, pH, and soil moisture on Sclerotinia dollar spot. Phytopathology 50:761-763.

3. Couch, H. B. 1966. Relationship between soil moisture, nutrition and severity of turfgrass diseases. Jour. Sports Turf Res. Inst. 11(42):54-64.

4. Couch, H. B. and E. R. Bedford. 1966. Fusarium blight of turfgrasses. Phytopathology 56:781-786.

5. Moore, L. D. and H. B. Couch. 1968. Influence of calcium nutrition on pectolytic and cellulolytic enzyme activity of extracts of Highland bentgrass foliage blighted by *Pythium ultimum*. Phytopathology 58: 833-838.

6. Daniel, J. W., W. E. Chappell and H. B. Couch. 1969. Effect of sublethal and lethal temperatures on plant cells. Plant Physiology 44:1684-1689.

7. Muse, R. R., H. B. Couch and B. D. Muse. 1972. Pectolytic and cellulolytic enzymes associated with Helminthosporium leaf spot on Kentucky bluegrass. Canad. Jour. Microbiol. 18:1091-1098.

8. Joyner, B. G. and H. B. Couch. 1976. Relation of dosage rates, nutrition, air temperature, and suscept genotype to side effects of systemic fungicides on turfgrass. Phytopathology 66:806-810.

9. Muchovej, J. J. and H. B. Couch. 1984. *Marasmus graminum*, a colonizer of senescent leaves of Kentucky bluegrass (*Poa pratensis*). Plant Pathology 33:589-590.

10. Muchovej, J. J. and H. B. Couch. 1987. Colonization of bentgrass turf by *Curvularia lunata* after leaf clipping and heat stress. Plant Disease 71:873-875.

11. Couch, H. B. and B. D. Smith. 1991. Increase in incidence and severity of target diseases by certain fungicides. Plant Disease 75: 1064-1067.

12. Couch, H. B. and B. D. Smith. 1991. Synergistic interactions of fungicides against *Pythium aphanidermatum* on perennial ryegrass. Crop Protection 10: 386-390.

Books:

1. Couch, H. B. 1995. Diseases of Turfgrasses. 3rd Edition. Krieger Publishing Co. Melbourne, Fla. 403 p.

2. Couch, H. B. 2000. The Turfgrass Disease Handbook. Krieger Publishing Co. Melbourne, Fla. 210 p.

Current or Recent Research Sponsors:

United States Golf Association Green Section; Golf Course Superintendents Association of America; Virginia Turfgrass Foundation; Agri-Chemicals Industry

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Chester L. Foy

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Education:

- B.S., University of Tennessee, Knoxville, TN, 1952
- M.S., University of Missouri, Columbia, MO, 1953
- Ph.D., University of California, Davis, CA, 1958

Professional Experience:

- **Professor** of Plant Physiology/Weed Science, Virginia Tech, Blacksburg, VA 24061-0331, 1980-present.
- **Professor and Head**, Plant Pathology and Physiology, Virginia Tech, 1974-1980.
- **Professor** of Plant Physiology/Weed Science, Virginia Tech, 1968-1974.
- **Associate Professor** of Plant Physiology/Weed Science, Virginia, 1966-1968.
- **Associate Professor** of Agricultural Botany, University of California, Davis, CA 95616, 1964-1966.
- **Assistant Professor** of Agricultural Botany, University of California-Davis, CA, 1958-1964.
- **Graduate Research Assistant**, Botany, University of California-Davis, 1956-1958.
- **Assistant Specialist (Research)**, University of California-Davis, 1953-1956.
- **Assistant Instructor**, University of Missouri, Columbia, MO 65201, 1952-1953.

Research Awards and Honors:

- 1999 – Phi Beta Delta **Faculty International Award** (Virginia Tech Chapter, first time awarded).
- 1998 – Gamma Sigma Delta **International Award for Distinguished Achievement in Agriculture** (first time awarded to one in my discipline and only the second awarded in any discipline in Virginia).
- 1996 – Inducted as a **Charter Member**, Gamma Omega Chapter of Phi Beta Delta – Honor Society for International Scholars.
- 1996 – International Weed Science Society **Outstanding Achievement Award – Developed Countries**.

Teaching Interests:

- Weed Science: Principles and Practices
- Pest Control: Insects, Diseases, and Weeds (weeds portion)

Research Interests:

- Crop Production and Protection.
- Vegetation Management in Agronomic and Fruit Crops, and Control of Specific Perennial Weeds.

- Routes and Mechanisms of Absorption, Translocation, Accumulation, and Exudation of Herbicides, Growth Regulators, and Surfactants and Other Adjuvants.
- Metabolism and Fate of Herbicides, Growth Regulators, and Surfactants and Other Adjuvants.
- Physiological, Biochemical, and Morphological Changes Induced by Exogenous Chemicals.
- Modes of Action and Selectivity of Herbicides and Growth Regulators.
- Minimizing Pesticide Residues in the Biosphere.
- Allelopathy.
- Parasitic Weeds.

Selected Publications:

1. Li, H-Y. and C. L. Foy. 1999. A biochemical study of BAS 517 using excised corn and soybean root systems. Weed Sci. 47:28-36.
2. Inderjit, K. M. M. Dakshini, and C. L. Foy, eds. 1999. Principles and Practices in Plant Ecology: Allelochemical Interactions. CRC Press, Inc., Boca Raton, FL. 363 p.
3. Inderjit and C. L. Foy. 1999. Nature of interference mechanisms of mugwort (*Artemisia vulgaris*). Weed Technol. 13:176-182.
4. Nandula, V. K., C. L. Foy, and D. M. Orcutt. 1999. Glyphosate for *Orobanche aegyptiaca* control in *Vicia sativa* and *Brassica napus*. Weed Sci. 47:486-491.
5. Westwood, J. H. and C. L. Foy. 1999. Influence of nitrogen on germination and early development of broomrape (*Orobanche* spp.). Weed Sci. 47:2-7.
6. Foy, C. L., D. W. Pritchard, and G. W. Beetsman, eds. 1998. Formulation Science, Vol. I. Association of Formulation Chemists, Wayne, NJ. 611 p.
7. Westwood, J. H., X. Yu, C. L. Foy, and C. L. Cramer. 1998. Expression of a defense-related 3-hydroxy-3-methylglutaryl CoA reductase gene in response to parasitization by *Orobanche* spp. Mol. Plant Microbe Interact. 11:530-536.
8. Hershenhorn, J., D. Plakhine, Y. Goldwasser, J. H. Westwood, C. L. Foy, and Y. Kleifeld. 1998. Effect of sulfonylurea herbicides on early development of Egyptian broomrape (*Orobanche aegyptiaca*) in tomato (*Lycopersicon esculentum*). Weed Technol. 12:108-114.
9. Foy, C. L. and D. W. Pritchard, eds. 1996. Pesticide Formulation and Adjuvant Technology. CRC Press, Inc., Boca Raton, FL. 363 p.
10. Sun, J. and C. L. Foy. 1996. Differences between Silwet L-77 and its blends in physical-chemical properties and herbicidal enhancement of two sulfonylureas in four weed species. p. 917-924 *in* H. Brown, G. W. Cussans, M. D. Devine, S. O. Duke, C. Fernandez-Quintanilla, A. Helweg, R. E. Labrada, M. Landes, P. Kudsk, and J. C. Strebig, eds. Proc. Second Int. Weed Control Congress, Copenhagen, Denmark.
11. Li, H-Y. and C. L. Foy. 1993. Bioassay and anatomical study of BAS 517 using etiolated crop seedlings. Weed Sci. 41:490-496.

Current or Recent Research Sponsors:

Agricultural Chemical Industry; US AID, USDA, IPM CRSP

Additional Information:

- Current Editor of WEED TECHNOLOGY
- Editorial Board of PESTICIDE BIOCHEMISTRY AND PHYSIOLOGY

Department of Plant Pathology, Physiology, and Weed Science

Last Updated May 16, 2000

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Education:

- B.S., M.S., Ph.D. Colorado State University

Professional Experience:

- **Professor** of Plant Pathology, Department of Plant Pathology, Physiology and Weed Science, Virginia Tech, Blacksburg, VA 24061-0331, 1967-present.

Teaching Interests:

- Plant pathogenic fungi
- Forest pathology

Research Interests:

- Ecology of plant pathogenic fungi
- Chestnut blight

Selected Publications:

1. Griffin, G.J. 2000. Blight control and restoration of the American chestnut. J. of Forestry 98:22-27.
2. Griffin, G.J. 1999. Frequencies and spatial patterns of white hypovirulent and pigmented strains of Cryphonectria parasitica within blight-controlled cankers on grafted American chestnut trees 15-16 years after inoculation. Eur. J. For. Path. 29:377-390.
3. Robbins, N. and Griffin, G.J. 1999. Spread of white hypovirulent strains of Cryphonectria parasitica on grafted American chestnut trees exhibiting a high level of blight control. Eur. J. For. Path. 29:51-64.
4. Kilic, O. and Griffin, G.J. 1998. Effect of dsRNA-containing and dsRNA-free hypovirulent isolates of *Fusarium oxysporum* on severity of Fusarium seedling disease of soybean in naturally infested soil. Plant and Soil 201: 125-135.
5. Dierauf, T., Artman, J., Elkins, J.R., Griffin, S.L. and Griffin, G.J. 1997. High level of chestnut blight control on grafted American chestnut trees inoculated with hypovirulent strains. Journal of Arboriculture 23:87-88.

Current or Recent Research Sponsors:

American Chestnut Cooperators' Foundation

Further Information:

- Chestnut Blight

Department of Plant Pathology, Physiology, and Weed Science
Last Updated July 19, 2002

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Education:

- Ph.D., Plant Pathology, University of California, Riverside, 1975
- M.S., Microbiology, California State University, Long Beach, 1971
- B.S., Microbiology, California State University, Long Beach , 1965

Professional Experience:

- Professor of Plant Pathology, Department of Plant Pathology, Physiology, and Weed Science (PPWS), Virginia Polytechnic Institute and State University (VPI&SU), Blacksburg, VA 24061-0331, 1988-present.
- Associate Professor of Plant Pathology, PPWS, VPI&SU, 1983-88.
- Assistant Professor of Plant Pathology, PPWS, VPI&SU, 1980-83.
- Assistant Plant Pathologist, Department of Plant Pathology and Botany, The Connecticut Agricultural Experiment Station, New Haven, 1977-80.
- Research Assistant, Department of Plant Pathology, University of California, Riverside, 1971-75.
- Scientist II, Bioscience Section, Jet Propulsion Laboratories, Pasadena California, 1969-71 (Field and laboratory research U.S. Antarctic Research Program).
- Peace Corps Volunteer, Biology Instructor, St. Francis Xavier College, Corozal Town, Belize (British Honduras), Central America, 1966-68.
- Technician, Quality Control Laboratory, American Chemicals and Plastics Co., subsidiary of Stauffer Chemicals and Richfield Oil Companies, Long Beach, California, 1963-65.

Teaching Interests:

- Phytopathogenic Prokaryotes (PPWS 5114)
- Plant Disease Physiology and Development (PPWS5454)
- Introductory Genetics (BIOL2004)
- Pathogenesis of *Agrobacterium*

Research Interests:

(for more details click here):

- Molecular basis for pathogenesis in phytopathogenic bacteria.
- Molecular relationships among plant pathogenic bacteria.
- Manipulation of the disease for biological control of disease.

- Genetic engineering of plants for resistance.
- Safe release for genetically engineered organisms.
- Phylogenetics of plant pathogenic fungi.

Selected Publications:

1. Lacy, G.H. and E.L. Stromberg. 2000. Descriptions of: Pathogen, Pathogenesis, Suscept, and Avirulence. *In*: Baudoin, A.B.A.M. Dictionary of Plant Pathology, Am. Phytopathol. Soc. Press, St. Paul, MN, **In Press**.

2. Stromberg, E.L. and G.H. Lacy. 2000. Descriptions of: Pathogen-Suscept Interaction, Pathogenicity, Susceptibility, and Virulence. . *In*: Baudoin, A.B.A.M. Dictionary of Plant Pathology, Am. Phytopathol. Soc. Press, St. Paul, MN, **In Press**.

3. Schaad, N.W., J.B. Jones, and **G.H. Lacy**. 2000. Xanthomonads. *In* N.W. Schaad, ed., Laboratory Guide for Identification of Plant Pathogenic Bacteria, 3rd Ed., American Phytopathological Society, St. Paul, MN. **In Press**.

4. Schaad, N.W., A.K. Vidaver, **G. H. Lacy**, K. Rudolph, and J.B. Jones. 2000. Evaluation of proposed amended names of several pseudomonads and xanthomonads and recommendations. Phytopathology 90: 208-213.

5. Stromberg, E.L., Roberts, D.P., **Lacy, G.H.**, and Buyer, J.S., 2000. Field evaluation of selected bacterial isolates and seed treatment fungicides for the control of take-all in Jackson soft red winter wheat, 1999, Biol. Cult. Tests Control Plant Dis. 15: **In Press**.

6. Roberts, D.P., E.L. Stromberg, **G.H. Lacy**, J.S. Buyer. 1999. Biological disease control: Considerations for seed treatment and stand establishment. Acta Horticulturae. May 1999.

7. Stromberg, E.L., Roberts, D.P., **Lacy, G.H.**, and Buyer, J.S., 1999. Field evaluation of selected bacterial isolates and seed treatment fungicides for the control of take-all in Jackson soft red winter wheat, 1998. Biol. Cult. Tests Control Plant Dis. 14:127-129.

8. Denbow, D.M., E.A. Grabau, **G.H. Lacy**, E.T. Kornegay, D.R. Russell, and P.F. Umbeck. 1998. Soybeans transformed with a fungal phytase gene improve phosphorous availability for broilers. Poul. Sci. 77: 878-881.

9. Denbow, D.M., E.A. Grabau, **G.H. Lacy**, E.T. Kornegay, D.R. Russell, and P.F. Umbeck. 1998. soybeans transformed with a fungal phytase gene improve phosphorous availability for broilers. Poul. Sci. 77: In Press.

10. Li, J., C.E. Hegeman, R.W. Hanlon, **G.H. Lacy**, D.M. Denbow, and E.A. Grabau. 1997. Secretion of active recombinant phytase from soybean cell suspension cultures. Plant Physiol. Galley proofs returned.

11. Palmer, S., V.S. Scanferlato, D.R. Orvos, **G.H. Lacy**, J. Cairns, Jr. 1997. Survival and ecological effects of genetically engineered *Erwinia carotovora* in soil and aquatic microcosms. Environ. Toxicol. & Chem. 16: 650-657.

Current or Recent Research Sponsors:

Jeffress Memorial Trust
Novartis
Virginia Small Grains Board

United States Department of Agriculture

Laboratory Personnel:

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Department of Plant Pathology, Physiology, and Weed Science
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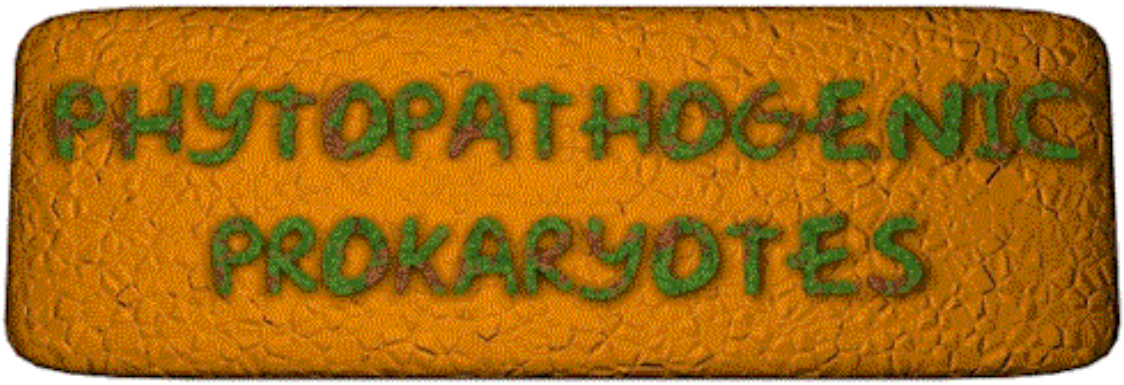

PPWS 5114: PHYTOPATHOGENIC PROKARYOTES

Fall 2001 Index #)

Lecture, 8-9 AM Mondays in room 420 Price Hall; Laboratory, TBA in room 202 PMB; Final, Monday December 13th 7:45-9:45 AM

Instructor:	Dr. George H. Lacy
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Catalog Description: PPWS 5114: PHYTOPATHOGENIC PROKARYOTES. Part of a series of courses on agents (fungi, nematodes, prokaryotes, and viruses) causing plant disease required for graduate students in plant pathology. Identification, taxonomy, classification, cytochemistry, anatomy, genetics, plant-pathogen interactions, disease physiology, and control of phytopathogenic prokaryotes. (1H, 1L, 2C). I. Odd years.

Prerequisites and Corequisites: Graduate standing or, for undergraduates, consent of the instructor. It is recommended that students have taken or are taking courses in plant pathology,

microbiology and/or biochemistry.

Learning Objectives: Using lectures, demonstrations, discussion, and hands-on experiences students successfully completing this course will be able to **a)** describe the importance of phytopathogenic prokaryotes; **b)** isolate, culture, and identify and characterize pathogens; **c)** define the ecology and epidemiology of pathogens; **d)** discuss molecular mechanisms for pathogenesis; **e)** assay biologically active macromolecules including DNA and proteins; **f)** apply physiological principles to understanding plant-microbe interactions; and **g)** design disease control strategies.

Teaching perspective. There are three traditional ways to teach a plant pathology course:

A. Learning how to diagnose and control specific diseases,

B. Specific pathogen identification and taxonomy, and

C. Understanding the biology, ecology, and genetics of the host-pathogen interaction.

For this course, I have selected the third method for presenting the information. I believe that overall understanding will be more useful than specific examples. My philosophy is that knowledge of specific diseases, pathogens, or controls (*e.g.*, Virginia diseases and pathogens) although useful for plant pathologists in Virginia does not assist the great majority of our graduate students who will follow their careers in other geographic regions

in this country or in other regions of the world where environmental conditions, economically important crops, diseases, and pathogens are vary from those encountered in Virginia.

Texts and references. Primary sources.

Required text: Lacy, G.H., 1999, *Lectures in Phytopathogenic Prokaryotes*. 220pp. See pdf files for individual lectures below.

Recommended texts: Currently texts are out of date. However, valuable resource material may be found in the following texts:

Molecular emphasis: Sigee, D.C., 1993. *Bacterial Plant Pathology: Cell and Molecular Aspects,* Cambridge University Press, 325pp.;

General emphasis: Goto, M. 1990. *Fundamentals of Bacterial Plant Pathology,* Academic Press, 342pp.; Identification guide: Schaad, N.W. (ed), 1988.

Laboratory methods: Schaad, N. 2000. *Laboratory Guide for Identification of Plant Pathogenic Bacteria*, 2nd edition, American Phytopathological Society, 164pp. (Currently, the 3rd edition of this valuable resource is in the final stages of preparation.

Assignments. *Research critiques:* Five journal research critiques (≤ 2 pages, printed) on articles pertaining to phytopathogenic prokaryotes are required from each student during the semester. The articles must have publication dates no earlier than 1999. The student must critique the methods, results, or conclusions. The critiques will be e-mailed (as an attachment) to each person in the

class as well as the instructor. This is an exercise with four goals: 1) To introduce the student to different journals; 2) To provide additional material to the course content; 3) To instill the habit of critical interpretation in students; and 4) Encourage the student to read in areas related to his/her interests in plant pathology.

Laboratory Reports: Three laboratory reports, (≤ 6 pages, printed) are due during the semester. The format will be title, author, abstract, introduction, materials and methods, results, discussion, and references. Use *Phytopathology* format. This report format allows the student to work independently and arrange their own time in the laboratory to accomplish the work. Your grade will correlate with the amount and quality of the laboratory work as well as its readability and your promptness.

Term paper: A term paper subject (≤ 10 pages, printed) will be suggested by the student and approved by the instructor. Subjects from two areas may be selected: **1)** Pathogen description including, disease symptoms, epidemiology, pathogen survival, disease mechanisms, bacteriology, phylogenetics, identification, isolation, and disease control. **2)** Topics of interest. Subject selection, major references, paper outline, and final paper will each be due at different times. Grades will correlate with the quality and readability of the report as well as punctuality.

VPI&SU Graduate Honor System. Examinations, laboratory reports, term papers, and research criticisms must be the work of a single student. Students may collaborate in the laboratory to help each other complete laboratory work. Sharing electron files, except for the initial data files (e.g., electrophoresis results of Rep-PCR and sequencing) is not permitted.

PPWS 5114: Lectures, laboratories, and assignment due dates in Fall 2000.

Meetings / Due Dates	**Lecture topic**	**Laboratory Subject**
1) 27 August	Evolution of pathogens and genetic exchange among prokaryotes	No laboratory
2) # 30 August	Dispersal, survival, resident phases, and vector relationships	DNA sequencing: assignments and theory Basic techniques: Media prep,
3) * 3 September	Phylogenetics and Identification *Term paper topics due by laboratory	DNA sequencing: Primer selections Basic techniques: streaking,, counting

4) # 10 September	Cytochemistry and Anatomy	DNA sequencing: PCR amplification of template Basic techniques: Isolating from soil or plants
5) * 17 September	Cytochemistry and anatomy (cont.) *Term paper references due by laboratory	DNA sequencing: Electrophorese template Identification: BIOLOG
6) # 24 September	Root zone-inhabiting bacteria	DNA sequencing: Purify template Identification: BIOLOG analyses
7) * 1 October	Shoot- and stem-inhabiting bacteria *Term paper outline due by laboratory	DNA sequencing: Estimate and adjust template concentration
8) 8 October	Endophytes: Non-fastidious and fastidious prokaryotes	DNA sequencing: Cycle sequence reactions
1st Examination TBA	2 hrs outside class	Includes, lectures, readings, laboratories, and paper critiques
9) 15 October*	Plant damage: Enzymes and Toxins	DNA sequencing: Clean and dry sequence reaction products
10) 22 October	Plant damage: Wilts and Growth Regulators *Term paper 1st draft due	DNA sequencing: Software analyses demonstrations Due by midnite e-mail attachment
11) # 5 October	Plant damage: Molecular Biology of Crown Gall	DNA sequencing: Analyses Rep-PCR: Amplify DNAs

12) # 12 November	Host resistance: Preformed and systemic acquired resistances Term paper reviews due	Rep-PCR: Electrophorese products, image acquisition Due by end of laboratory
17-25 November	Thanksgiving Vacation	
13) 26 November	Host resistance: Hypersensitivity and recognition	Rep-PCR: Analysis software *BIOLOG & Rep-PCR reports due
14) 2 December	*Term paper 2nd draft due	by midnight e-mail attachment
	Thanksgiving Vacation	
14) 29 November	Control: Management and chemotherapy	DNA sequencing: Analyses Pectolytic enzymes: Isoelectric focusing, sandwich technique
15) 6 December	Control: Breeding and Biological Control	DNA sequenicing: Analyses
16) 9 December	Midnight by e-mail attachment	*DNA sequencing report due
17) 13 December	Final Examination 7:45 to 9:45 AM	
18) *16 December	*Term paper due	Midnight by e-mail attachment

*Term paper or laboratory reports due.

Critiques of journal research articles due by midnight e-mail attachment.

Grading: Final grades will be determined by curving points earned. Point distributions.

Measurement	Points	Percent
Two Hour Examination*	200	20
Final Examination	300	30
Biolog Characterization Project	50	5
DNA Sequencing Project	200	20

Rep-PCR Project	50	5
Term Paper	100	10
Research Critiques	50	5
Laboratory Demeanor	50	5
Total	1,000	100

General references. I also recommend a general list of reference literature with which phytobacteriologists should be familiar.

Agrios, G.N. 1987. Plant Pathology, 4th Ed. Academic Press, Inc. New York, NY, about 700 pp.

Brako, L., A.Y. Rossman, and D.F. Farr. 1995. Scientific and Common Names of 7,000 Vascular Plants in the United States. Am. Phytopatholog. Soc. St. Paul, Mn. 295 pp.

Dye, D.W., J.F. Bradbury, M. Goto, A.C. Hayward, R.A. Lelliot, and M.N. Schroth. 1980. International standards for naming pathovars of phytopathogenic bacteria. Rev. Plant Pathol. 59:153-168.

Fahy, P.C., and G.J. Persly (eds). 1983. Plant Bacterial Diseases: A Diagnostic Guide. Academic Press, Inc., Sydney, Australia. 393 pp.

Gerhardt, P. (ed). 1981. Manual of Methods for General Bacteriology. Am. Soc. Microbiol., Washington, D.C. 524 pp.

Hanlin, R.T., J.H. Chalkley. 1967. Index to genera of pathogens listed in the "Index of Plant Diseases in the United States"--Part one of four. Plant Dis. Rept. 51:235-240.

Hanlin, R.T., J.H. Chalkley. 1967. Index to genera of pathogens listed in the "Index of Plant Diseases in the United States--Part two of four. Plant Dis. Rept. 51:323-328.

Hanlin, R.T., J.H. Chalkley. 1967. Index to genera of pathogens listed in the "Index of Plant Diseases in the United States--Part three of four. Plant Dis. Rept. 51:419-424.

Hanlin, R.T., J.H. Chalkley. 1967. Index to genera of pathogens listed in the "Index of Plant Diseases in the United States"--Part four of four. Plant Dis. Rept. 51:515-520.

Klement, Z., K. Rudolph, and D.C. Sands (eds). 1990. Methods in Phytobacteriology. Akademiai Kiado, Budapest. 568 pp.

Krieg, N.R., and J.H. Hold (eds). 1984. Bergey's Manual of Systematic Bacteriology, Vol. 1. Williams & Wilkins Co., Baltimore, Maryland. 964 pp.

Mount, M.S., and G.H. Lacy (eds). 1982. Phytopathogenic Prokaryotes. Vol. 1. Academic Press, Inc., New York, NY. 541 pp.

Mount, M.S., and G.H. Lacy (eds). 1982. Phytopathogenic Prokaryotes. Vol. 2. Academic

Press, Inc., New York, NY. 506 pp.

Rhodes-Roberts, M., and F.A. Skinner. 1982. Bacteria and Plants. Academic Press, Inc., London, England. 278 pp.

Schaad, N.W. (ed). 1988. Laboratory Guide for Identification of Plant Pathogenic Bacteria. 2nd Ed. Am. Phytopathol. Soc., St. Paul, MN. 65 pp.

Skerman, V.B.D., V. McGowen, and P.H.A. Sneath. 1980. Approved list of Bacterial Names. Int. J. Syst. Bacteriol. 30:225-420.

Starr, M.P. (ed). 1983. Phytopathogenic Bacteria: Selections from Prokaryotes. Springer-Verlag, New York, NY. 176 pp.

Swings, J.G. and E.L. Civerolo (eds). 1993. Xanthomonads. Chapman & Hall, London 399 pp.

USDA. 1960. Index of Plant Diseases in the United States. Agriculture Handbook No. 165. US. Gov. Print. Off., Washington, D.C. 531 pp.

Last updated September 06, 1999 by Peter Sforza

EVOLUTION OF PHYTOPATHOGEN PROKARYOTES

I. RATIONALES FOR PATHOGENESIS

A. NUTRITIONAL DEPENDENCY. All life on planet Earth depends either directly or indirectly upon photosynthesis for nutrition. It is probably very likely that competition for nutrients influenced some bacteria to develop methods for obtaining their needs directly from plants.

Nutritional relationships. In the evolution of pathogenicity and parasitism we may hypothesize a chain of evolutionary events that first exposed prokaryotes to dead plant tissue. Selective advantage went to those organisms that could efficiently utilize these substrates with their enzymes systems. These organisms may be characterized as **saprotrophs**. This discussion ignores those ancestral endosymbiote prokaryotes that evolved with living plants and emphasizes those prokaryotes that `discovered' plants at a later time.

Some organisms may develop the ability to utilize materials exuded from the surfaces of living plants. These organisms that colonize the surface of living plants and obtain their nourishment there are symbiotrophs and usually referred to as **epiphytes**. Epiphytes of land plants are divided into phylloplane or rhizoplane inhabitants depending on whether they colonize aerial surfaces of leaves and stems or root surfaces, respectively.

Endophytes are those organisms that colonize the internal tissues of a plant. They may occupy intercellular spaces, intracellular locations, or be found inside xylem vessels. These organisms utilized products carried in phloem sap, xylem fluid, or constituents of living cells. Prokaryotic endophytes which cause damage to the host are classes as **pathogens**. Other endophytic prokaryotes may be **symbiotes**, sharing mutual benefits with their hosts. Some endophytic prokaryotes may derived their nutrients from the host without providing any, as of yet, measurable harm or benefit to the plant. These endophytes may be "**normal flora**" of plants. Much yet needs to be learned about these organisms.

B. ESCAPE FROM COMPETITION. Since less than 10% of the described species of bacteria are pathogens of plants, plant tissues are generally believed to support few if any prokaryotes. Therefore, one advantage to an endophytic existence would be the opportunity to occupy an under-utilized niche. Within this niche, protected by the plants resistance mechanisms, successful colonizers may exploit the resources using enzymes, toxins, plant growth regulators, or wilt-causing compounds.

C. GAME THEORY. Once prokaryote has established a nutritional association with a plant, the host and pathogen will make a series of predictable genetic accommodations. This may be thought of as a game in which to lose means to become extinct (Sands et al., 1982). Further, this game may not be completely won by a pathogen since its host, and thus the pathogen also, may become extinct. These moves are phenotypically characterized by cycles of resistance and virulence development. Obviously the moves are attenuated by the pathogen, which must respect the survival of its host or face extinction. Therefore, we may predict that "primitive" pathogens may be more aggressive and cause more damage than more sophisticated pathogens. Perhaps the final product of this line of selection is a very "mild" pathogen or even a helpful symbiotic relationship such occurs as between leguminous plants and *Rhizobium* spp.

D. SECOND LAW OF THERMODYNAMICS. As predicted by this law, a progression from order to disorder also occurs in the development of pathogenesis. Genetic isolation within a host promotes rapid divergence of a pathogen's gene pool from the mainstream. This may indicate that endophytes which are isolated either physically (*i.e.*, phytoplasmas or mycoplasma-like, cell wall-less pathogens of plants) or genetically as specific pathogens of only certain cultivars of one

species (*ie.*, spotting pseudomonads) may diverge genetically more quickly than generalist pathogens having wide host ranges (*i.e.*, soft-rotting erwinias).

II. EVOLUTION OF PATHOGENIC PROKARYOTES. (Reviewed in Madigan et al., 2000.)

Coevolution of prokaryotes with eukaryotes is ancient. For a period of time, bacteria were the only life-form on Earth. Today, one could argue strongly that bacteria remain not only the most numerous but also the most dominant life form on the planet. Since bacteria are so numerous and are involved in cycling such important elements as carbon, nitrogen, and sulfur, they would survive and proliferate if all eukaryotes including humans were to disappear from the Earth.

PRIMITIVE EARTH. The inner planets, Mercury, Venus, Earth, and Mars, were formed about 4.5×10^9 years ago from solid material depleted in hydrogen. This is in contrast to the hydrogen-rich formation of Jupiter, Saturn, Uranus, Neptune, and Pluto. The atmosphere on our planet was formed by out-gassing of volatiles trapped in the crust and mantle. Based on the relatively unchanged current mantle, this would indicate an atmosphere of mainly gaseous water, methane, carbon dioxide, nitrogen, and ammonia containing trace amounts of carbon monoxide and hydrogen. It is also likely that reaction of ammonia and methane may have produced significant amounts of hydrogen cyanide. The density and volume of the primitive atmosphere is controversial since the hot and turbulent nature of the planet would affect these parameters in a rapidly changing manner. Primitive earth may have had an atmosphere more massive than that of Venus today-->100 atm of carbon dioxide, >300 atm water. If the surface of the earth was molten, however, a good deal of these gases may dissolve under pressure into the molten rock (water is particularly soluble in molten silicates). Runaway glasshouse conditions may have maintained hydrogen as a gas only. During the first five hundred million years, liquid water may not have existed as temperatures exceeded 100 C.

Prebiologic organic synthesis. As earth continued to cool so that liquid water finally could exist, organic compounds began to accumulate. Multiple energy sources were available for synthesizing organic compounds from gases in the atmosphere and those dissolved with salts in the growing oceans. These sources included heat, lightning discharges, radioactivity decay, and volcanic activity. Probably the most important energy source for organic synthesis was ultraviolet, which without the protective absorbance of ozone (absorbs UV below 300nm) layer, was very much more intense than today. Molecules such as amino acids, fatty acids, nuleotides, purines, pyrimidines, sugars, and thioesters accumulated. Further, these metabolic building blocks, under prebiotic conditions and in the sterile medium of the world's oceans, could polymerize. Thus polypeptides, polynucleotides, and other macromolecules also accumulated. Without living organisms to scavenge and metabolize these chemicals, a very rich chemical soup was provided for time and chemistry to experiment with on a planet-wide basis.

PRECELLULAR LIFE. Self assembly of double-stranded nucleic acids may occur provided that template (single-stranded nucleic acid) and deoxyribose or ribose nucleotides are present. In other words, simple replication could occur. In relative hot water of that period in earth's development, denaturation of the double-stranded molecules to single-stranded molecules could occur, allowing cyclic amplification of existing molecules. **Ribozymes**, catalytic RNAs, may have arisen in this manner and competition for substrate was underway. Ribozymes, able to digest other molecules, probably had competitive advantages over non-catalytic RNAs and caused their extinction.

CELLULAR LIFE ARISES. It is much more difficult to imagine the how cellular life arose. Only by considering the richness of the primordial soup and the geologic period of time in which countless experiments were tried and failed can we grasp the next step. That is the creation of cells with cellular machinery. In the first step, the formation of protective lipid-protein vesicles from the primordial soup to contain primitive RNA life-forms may be imagined.

However, the development and coordination of the components for the **basic dogma**: DNA code giving rise to mRNA which in turn give rise to proteins is very difficult to visualize. We are presented with a series of circular arguments: proteins cannot exist without DNA codes, nucleic acids cannot exist with proteins to synthesize them, proteins may not be synthesized without synthesis machinery, ribosomes, consisting of both proteins and RNAs. Perhaps biological entities are actually an assembly of several pre-biologic entities (*i.e.*, self-assembling ribosomes, ribozymes, self-assembling proteins), each component providing a competitive advantage.

Very likely we do not have the technical ability to hypothesize how these components were welded together and then encoded in genomic nucleic acids. Alternatively, the complexity of assembly of the several parts of the composite aggregate we call life may currently be the most enduring evidence that development of life may have been guided rather than accidental. Whatever future generations discover, primitive cellular life appear about 1×10^9 years after the formation of life. These cellular creatures, being much more advanced than any other prebiologic life form quickly became the dominant life form--and began competing among themselves for nutrients and biological space.

BACTERIA SUCCESSION. Primitive prokaryotes, probably similar to the hyperthermophilic bacteria, evolved in an anoxic and hot environment possibly similar to those habitats existing in thermal environments including contemporary hot springs and deep sea thermal vents. Fossils of filamentous prokaryotes have been discovered in rock 3.5×10^9 years old. In rocks 3.8×10^9 years old, $^{12}C/^{13}C$ ratios are increased suggesting the accumulation of ^{12}C typical of living systems. No signs of life have been discovered prior to that point in time. Primitive prokaryotes would have depended upon reducing ferrous iron to derive biological energy via a primitive ATPase:

$$\text{Iron reduction: } FeS + H_2S \rightarrow FeS_2 + H_2$$

At that time, the atmosphere of earth was anoxic and the existing prokaryotes would probably have resembled the **chemolithotrophic bacteria** in deep underground aquifers and deep sea ocean vents which supply all of there metabolic needs from non-organic sources. Key metabolic reactions of these anaerobic prokaryotes include:

$$\text{Methanogenesis: } 4H_2 + CO_2 \rightarrow CH_4 + H_20$$
$$\text{Acetogenesis: } 4H_2 + H^+ + HCO_3^- \rightarrow CH_3\,C00^- + 4H_20$$
$$\text{Sulfate reduction: } 4H_2 + SO_4^{2-} \rightarrow HS^- + 4\,H_20$$

Chemoorganotrophic bacteria became common as enough organic material became available through the activities of chemolithotrophs to allow them to derive energy and metabolic building blocks from organic materials formed by other organisms:

$$\text{Methane oxidation: } CH_4 \rightarrow CH_3OH \rightarrow CH_2O \rightarrow HOO_2^- \rightarrow CO_2$$

Photosynthetic bacteria. Anoxic photosynthetic bacteria (similar to the purple sulfur and green sulfur bacteria) were the first photosynthetic bacteria. They oxidized hydrogen sulfide to elemental sulfur to obtain electrons to reduce carbon dioxide and created organic sugars. About 3×10^9 years ago, oxygenic photosynthetic bacteria (similar to cyanobacteria) developed. Their photsynthetic processes, as with higher plants, oxidized water to elemental oxygen to reduce carbon dioxide and form sugars. Over a period of about 1.5×10^9 years, oxygen increased to form nearly 10% of the gaseous atmosphere. As time passed, oxygen became an important part of the atmosphere via photosynthesis (2.5×10^9 years ago).

Eukaryotes appear. Finally, about 2.0 to 1.5 X 10^9 years ago compartmentalization of cells into organelles occurred via the establishment of endosymbionts in archeabacteria host(s). These endosymbiont aggregates were the prototypes for modern eukaryotes.

Eukaryotic cells harbor two physically and functionally distinct genomes--those of the nucleus and the mitochondrium. Synergism among prokaryotes lead to the formation of ancestral eukaryotic organisms including plants. A chief difference between these two groups of organisms is the existence of membrane-bound organelles in eukaryotes--**nuclei, mitochondria**, and **chloroplasts**. All three organelles are present in photosynthetic plants. Considerable evidence has accumulated that mitochondria and chloroplasts originated by internal (endosymbiotic) colonization by archeabacteria-derived cells by eubacteria (Gray & Doolittle, 1982). Using sequences of the highly conserved 16S ribosomal RNA (rRNA) of bacteria to construct a phylogenetic tree including 16S rRNAs from maize (*Zea mays*) chloroplasts and mitochondria group chloroplast 16S rRNA among the cyanobacteria and mitochondrium 16S rRNA among the Proteobacteria, a very large group also including most plant pathogenic bacteria (Olsen & Woese, 1994; **Fig. 1**).

Continuing endosymbiont evolution. Several dinoflagellates (photosynthetic protozoa) contain apparently recent endosymbiotic eukaryotic "chloroplasts" (Wilcox & Wedemayer, 1985). The dinoflagellate *Amphidinium wigrense* has chloroplasts with three bounding membranes representing the cytoplasmic membrane of the host and the double membrane of the true chloroplast. Other dinoflagellates, such as *Gymnodinium acidotum*, contain “chloroplasts" with four membranes representing an addition membrane remaining from the cytoplasmic membrane of its eukaryotic algal symbiont. Eventually, the endosymbiont may degrade to so that only the true chloroplast would remain and, thus, become indistinguishable from higher plants.

Development of introns. Introns, or RNA inserts among exons of the messenger RNA, are another character of eukaryotes not believed to be shared by prokaryotes including eubacteria or archaebacteria. Recently this view has changed. *Methanococcus jannaschii* is an archaebacterium in which definite evidence of introns have been discovered. The division between archaebacteria and true or eubacteria occurred over three billion years ago and is the deepest between the prokaryotes. Archaea represent the host for the endosymbiotic synthesis leading to the eukaryotes (Brown & Doolittle, 1995; Gogarten, et al., 1989; Iwabe et al., 1989; Zillig et al., 1989). The genome (1.66 Mb) of this organisms has been completely sequenced (Bult et al., 1996). Of the 1738 protein-coding genes only 38% have been assigned functions based on sequence analysis. Most genes related to energy production, cell division, and metabolism were similar to eubacteria. Genes involved in transcription, translation, and replication are more similar to eukaryotes. Moreover, 10 genes have been described with enteins (prokaryotic analog of introns) and exteins (analog of exons) that are spliced out of protein-coding mRNA sequences. Very possibly, inteins developed by archaebacteria were donated to the ancestral endosymbiont aggregate which became the progenitor eukaryote.

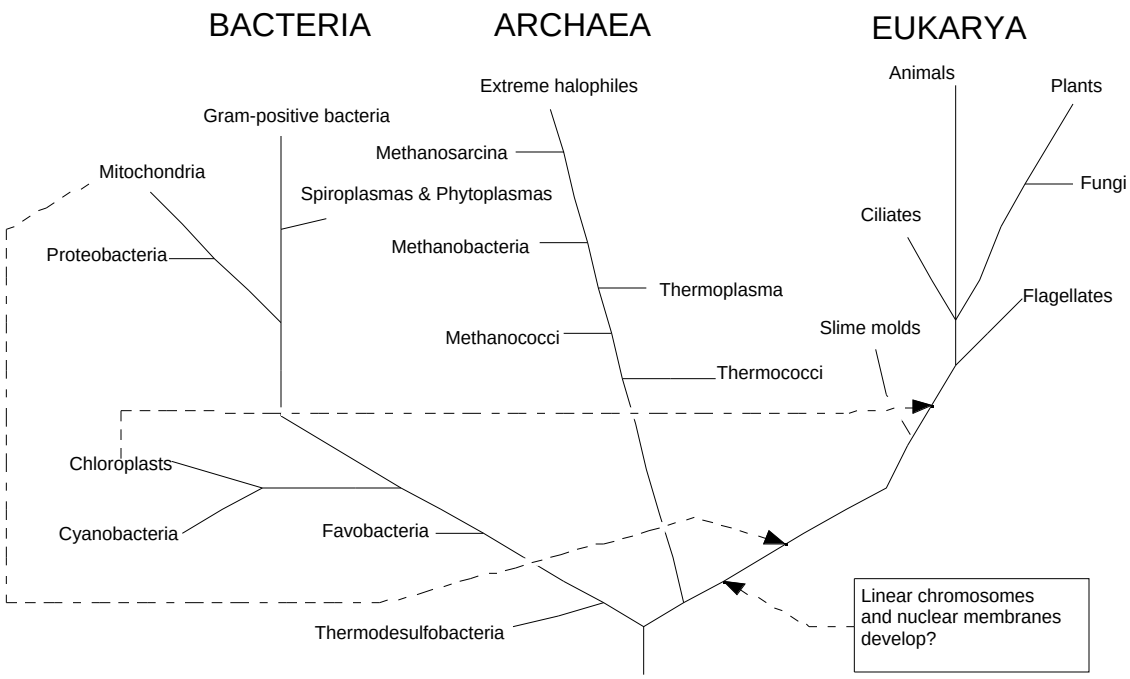


Figure 1. An outline of a phylogenetic tree based on DNA sequences of small subunit ribosomal RNA (rRNA) gene sequences from prokaryotes (16S), including bacteria and archaea, and eukaryotes (18S) small ribosomal subunit genes. Phytopathogenic prokaryotes are proteobacteria, Gram-positive bacteria, cyanobacteria, or belong in the cell wall-less group (mycoplasmas, phytoplasmas, and spiroplasmas). The dashed lines indicate points of intersection among bacteria and archaea leading to the evolution of ancestral eukaryotes. Synergism among prokaryotes is probably also lead to the formation of ancestral eukaryotic organisms including plants. A chief difference between these two groups of organisms is the existence of membrane-bound organelles in eukaryotes--nuclei, mitochondria, and chloroplasts. All three organelles are present in photosynthetic plants. Considerable evidence has accumulated that mitochondria and chloroplasts originated by internal (endosymbiotic) colonization by archaebacteria-derived cells by other bacteria (Gray & Doolittle, 1982). Using sequences of the highly conserved 16S ribosomal RNA (rRNA) of bacteria to construct a phylogenetic tree including 16S rRNAs from maize (*Zea mays*) chloroplasts and mitochondria group chloroplast 16S rRNA among the cyanobacteria and mitochondrium 16S rRNA among the a-subdivision of Proteobacteria, a very large group also including Agrobacterium tumefaciens (Olsen & Woese, 1994).

Sequenced eubacteria. Genomes of several eubacterial prokaryotes have been sequenced including Gram-positive *Hemophilus pneumoniae*, a mycoplasma, and, Gram-negative *Escherichia coli.* The *E.coli* genome, with 4.6 x 106 bp, contains over 4300 open reading frames which indicate putative genes. None of these genes have inteins. Unlike *M. jannaschii*, most of the genes in *E.* coli may be correlated with known functions. Further, *E.* coli is an excellent model for considering the genomic organization of Gram-negative plant pathogens because it is part of the same family, Enterobacteriaceae, as several plant pathogens included in the genera *Erwinia* and *Klebsiella*.

III. COEVOLUTION OF PROKARYOTES WITH PLANTS

Ancient associations among bacteria and plants have probably passed away as both groups of organisms evolved over geological time. Therefore, we may only hypothesize what these associations may been. In our modern world, it is easy to lose sight of the fact that bacteria appeared on our plant long before plants. Because bacteria represent both photosynthetic and non-photsynthetic organisms, we must expect that many of the models for pathogenesis were developed even before eukaryotic organisms including plants had evolved.

Primitive associations among prokaryotes. Likely, the first associations among photosynthetic organisms and other prokaryotes took the form of the interaction described for pseudomonads with the cyanobacterium *Anabaena oscillarioides*. Pseudomonads are attracted chemotactically to the nitrogen-fixing heterocysts of the blue-green alga, they attach at the vegetative cell-heterocyst junctions, and absorb nutrients secreted from the cyanobacterium (Paerl & Gallucci, 1985). Gradients of amino acids elicit positive chemotaxis and enhance pseudomonad attachment. Obviously, in this association no damage is likely to occur to the photosynthetic host. We may see a resemblance with contemporary epiphytic relationships among non-plant pathogenic bacteria and their host plants.

More invasive techniques for releasing nutrients from cells may have also developed in bacterium on bacterium interactions before plants had evolved. These techniques, including physical, enzymatic, or toxic principles, probably resulted in damage to the host--defining the beginning of pathogenesis. A present day example of such interactions might be bacteria of the genus *Bdellovibrio*, discovered first as parasites on *Pseudomonas syringae* pv. syringae. Bdellovibrios penetrate other bacterial cells and multiply within their hosts (Rittenberg, 1983). Bdellovibrios collides forcibly with their hosts, attach likely by lipopolysaccharide (LPS) interactions, rotates the seven-times larger host cell about its own axis, sheds its polar flagellum, and penetrates into the periplasm (space between the inner and outer cell wall membranes of Gram-negative bacteria) using a battery of enzymes. These enzymes include an lipopolysaccharidase (digests outer membrane protection), aminosugar glycanase (unlinks periplasmic peptidoglycans), deacetylase (removes N-acetyl groups from peptidoglycans), and diaminopimelic acid-ase (unlinks peptide bonds of petidoglycans). Once in the periplasm, bdellovibrios elongate in a filamentous manner inside the sphaeroplast (damaged bacterial cells become spherical). Just prior to lysis of the host, the filament is divided by septa, flagella form, and mature bdellovibrios emerge.

Primitive associations among prokaryotes and higher plants. Nutritional associations have also been artificially created between higher plants and bacteria *in vitro* (Carlson & Chaleff, 1974). In that study, tissue culture techniques were used to force an association between the free-living nitrogen-fixing bacterium, *Azotobacter vinelandii* and the callus tissue of carrot, *Daucus carota* cv. Danver's Half Long.). On a defined synthetic medium, lacking combined nitrogen, carrot callus alone fail to survive. However, in medium inoculated with the bacterium, callus was able to proliferate slowly because the bacterium converted nitrogen gas (N_2) to ammonium ion (NH^{+4}) usable by plant cells. Likewise, the adenine-auxotrophic strain of the bacterium could not survive in the defined medium unless it obtained adenine from the plant. Here the mutual nutritional dependence resembles the synergistic interactions between nitrogen-fixing bacteria and their host plants.

IV. MEASURING EVOLUTION.

Evolution of prokaryotes is difficult to measure since only scanty fossil records exist of these tiny organisms; no fossil records of phytopathogens are known. Therefore, to measure evolutionary distance, internal "fossil" records must be used. Central to defining evolutionary distance and phylogenetic relationships using DNA sequencing is the concept of the molecular clock. Comparison of amino acid and DNA sequences from species whose times of evolutionary divergence are known from fossil data suggests that genetic changes accumulate at a nearly constant rate and thus provide a reasonably reliable index for the passage of biological time. Several mathematical approaches to converting differences in homologous gene sequences into evolutionary distance since the existence of a common ancestor have been developed. The following model was developed by (Kimura, 1977, 1981).

$$Ks=1/2\ln (1-2P-Q)$$

Where Ks = evolutionary distance, and
P = transitions (purine to purine and pyrimidine to pyrimidine), and
Q = transversions (purine to pyrimidine or vice versa)

This model is based on the accumulation of neutral mutations in the third base of codons (**Table 1**) in open reading frames of homologous peptide genes.

Table 1. Codons in the open reading frame of messenger RNA and their conversion to amino acids in the resultant peptide. The genetic code. Listed here are all the sixty-four possible triplet codons along with their amino acid assignments. Three codons, UAA, UAG, and UGA (shown as 1, 2, and 3) are nonsense codons and are used as punctuation signals for termination of protein synthesis. The codon AUG is also a punctuation codon specifying the initiator amino acid formyl-methionine.

First code	**Second code**				**Third code**
	U	**C**	**A**	**G**	
U	phe	ser	tyr	cys	**U**
					C
	leu		Nonsense	Nonsense	**A**
			Nonsense	trp	**G**
C		pro	his	arg	**U**
					C
			gln		**A**
					G
A	ile	thr	asn	ser	**U**
					C
			lys	arg	**A**
	met				**G**
G	val	ala	asp	gly	**U**
					C
			glu		**A**
					G

A second type of evolutionary distance measurement encompasses other nucleic acid sequences not involved with protein synthesis such as the chromosomal origin of replication (*oriC*) and ribosomal RNAs (Takeda et al., 1982; Woese, 1987).

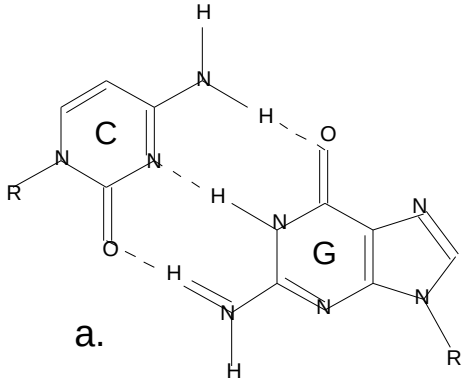
V. EVOLUTIONARY CHANGES ARE GENETIC.

A. METHODS FOR GENETIC CHANGE. **Role for mutations.** Mutations of genetic material fuel evolutionary change. Mutations accumulate in populations of organisms. While most mutations are not useful or even harmful for the efficient survival of an organism, some mutations are beneficial. Individual beneficial mutations probably affect small physiological changes such as minute differences in enzyme stability, thermoactivity, protein configuration, substrate specificity, *etc.* Under normal conditions, mutations including potentially beneficial mutations accumulate but harmful ones are selected against. Under conditions of environmental change, organisms containing beneficial mutations may have survival or competitive advantages and be selected. Environmental changes may include climatic changes or changes in interactions among organisms (*i.e.*, increased competition). Accumulated beneficial mutations may provide some small advantages leading to increased competitive ability for biological space and nutrients--and evolutionary change.

Role for lateral genetic exchange. However, such incremental mutational changes accumulating over geological time could not explain the diversity of organisms present in today's world. Additional mechanisms of more large scale genetic changes have been important in evolution. These include mechanisms for genetic transfer among the same species and among different species. Sexual recombination is obvious important for intra-species changes. Since sex has not been confirmed among bacteria, despite some very misleading names used to describe genetic processes (*i.e.*, "bacterial conjugation"), inter-specific genetic mechanisms may lead to lateral transfer of genetic material. Bacteria have several very effective lateral transfer genetic mechanisms which are most likely extremely important in lateral genetic exchange providing mechanisms for acquiring traits evolved in other bacteria.

Chromosomal rearrangement. Rearrangement of chromosomal material may be important in configuring more efficient genomes. For instance, placing genes expressed during pathogenesis in one area of a genome may be more efficient for control than have those genes scattered at random over the genome. This is a new concept and has not had general acceptance. However, it should be mentioned here because phytopathogenic prokaryotes often must survive under different connotations: *i.e.*, resident phase, survival phase, and pathogenic phase.

B. INCREMENTAL ACCUMULATING GENETIC CHANGES BY MUTATION. (Refer to reviews in Scaife et al, 1985 and Lewin, 1983). Mutations are random changes in the order, number, or type of bases in DNA (**Fig. 2**). These changes may result in no change (neutral mutations) in the function of the DNA region, make the region less efficient on non-functional (deleterious mutations), or make the region more efficient (beneficial changes). The mutations discussed in this section are relatively small-scale base substitutions, additions, or deletions usually limited to one or only a few bases. Later, we will discuss larger scale additive recombinational events in which transpositions of whole transposon, plasmid, or bacteriophage genomes into genes cause effects much like those caused by random mutations.



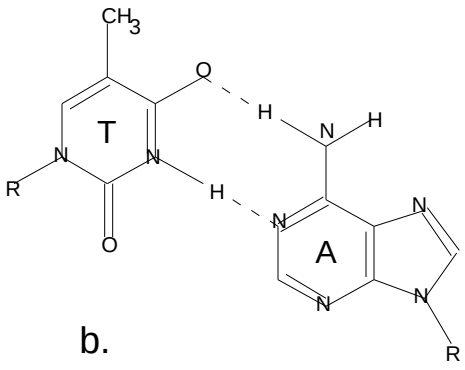


Figure 2. Normal base-pairing in DNA. **a.** Cytosine (C) pairs with guanine (G). **b.** Thymine (T) pairs with adenine (A).

Mutations may occur as the result of normal cellular functions or interactions with the environment. These are called spontaneous mutations and they occur at a characteristic rate in any particular bacterium. Spontaneous mutations per gene occur at a frequency of 1×10^{-9} to 1×10^{-7} per colony forming unit (cfu). The occurrence of mutations may be increased by treatment with mutagens and the changes they cause are referred to as induced mutations. Most mutagens act by either directly interacting with a base in the DNA or becoming incorporated in DNA.

Transition mutations. An alteration of a single base is called a point mutation. This may take two forms; a **transition** describes the substitution of one pyrimidine by a second pyrimidine or the replacement of a purine by a second purine (**Fig. 3**). Thus, a G-C pair is replaced by a A-T pair in double-stranded DNA. This is the most common form of point mutation. The second form is a transversion, in which a purine is replaced by a pyrimidine or vice versa; an A-T pair becomes a T-A or C-G pair.

Tranversion mutations. Transversions may be caused by depurination of purine bases and their replacement by pyrimidines during replication. For example, aflotoxin B1 binds directly to guanine, causes depurination which destabilizes the G-C hydrogen bonding to resemble T-A pair-hydrogen bonding. During replication, thymine replaces guanine resulting in G-C to A-T transversions.

Thymine-thymine dimers. Ultraviolet light at 256nm causes covalent linkages to occur among adjacent thymine moieties in a single strand of DNA. Cellular DNA repair mechanisms known as the SOS system cuts these pairs out and replaces them, occasionally inserting an incorrect cytosine base instead. This results in A-T to G-C transitions.

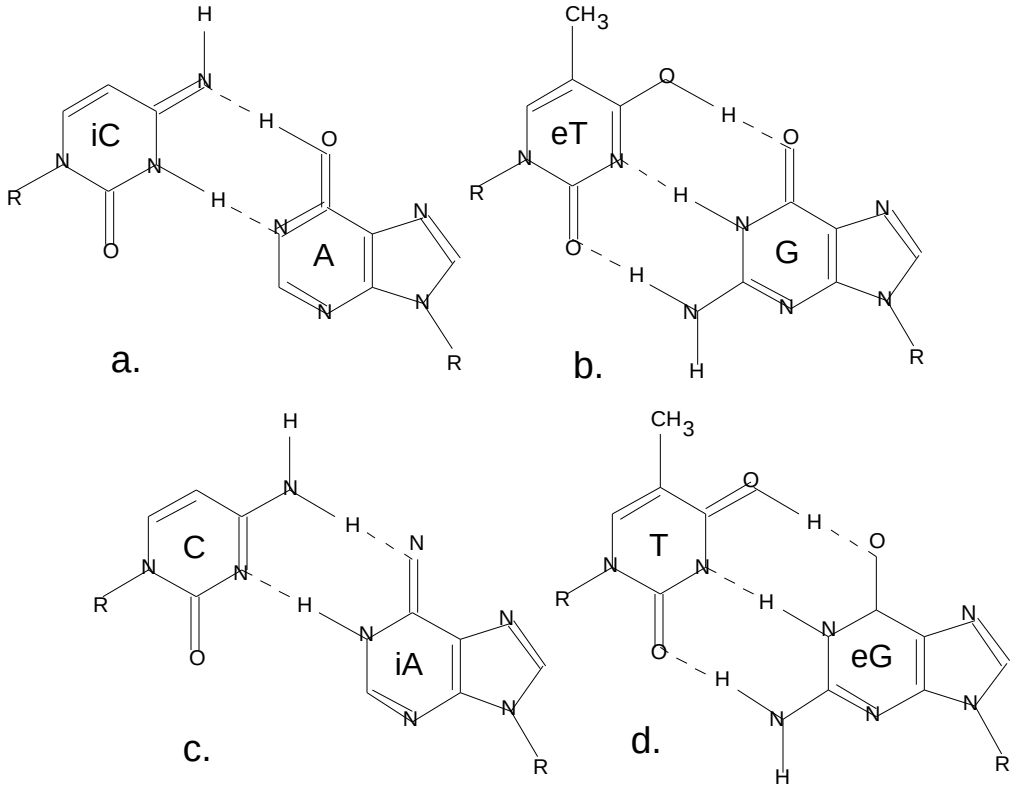


Figure 3. Tautomers are naturally occurring isomers of bases. They may be viewed as rare and extremely short-lived transitionary states of normal bases. If a base is in a tautomeric state (enol or imino forms), during nucleic acid synthesis DNA polymerase may recognize it incorrectly and place it in the wrong pair situation. When the tautomer shifts back to the normal and more stable isomer, following rounds of DNA replication with place the corresponding base to the normal isomer, causing a point mutation. **a.** Rare imino form of cytosine (iC) which pairs with adenine (A) rather than guanine (G). **b.** Rare enol form of thymine (eT) which pairs with guanine (G) rather than adenine (A). **c.** Rare imino form of adenine (iA) which pairs with cytosine (C). **d.** Rare enol form of guanine (eG) which pairs with thymine (T) rather than cytosine (C).

Frameshift mutations. Another class of mutagens is provided by acridines which intercalate within the DNA double helix distorting its structure. This causes misreading of bases and bases are deleted or extra bases are inserted; because such mutations have the effect of changing the reading of all downstream codons in reading frames, they are refereed to as frameshift mutagens (**Fig. 4**).

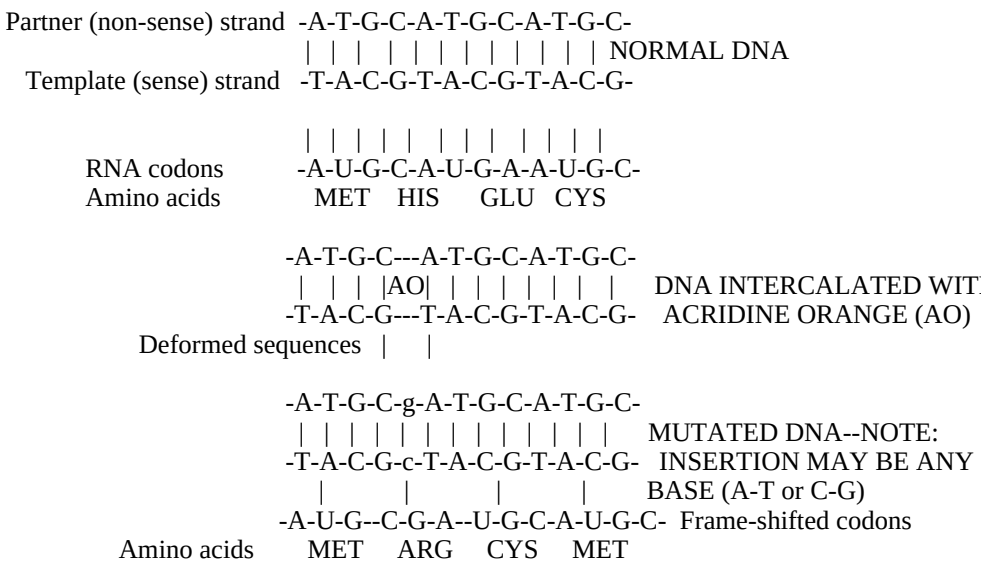


Figure 4. Frameshift mutation. The figure above indicates in a stepwise manner proceeding from the top of the page to the bottom, how frame shifts destroy downstream codon reading frames.

C. LATERAL GENETIC EXCHANGE. Large-scale genetic exchanges among bacteria may occur by several methods. These methods are so efficient among the eubacteria, that gene flow may be predicted to occur in almost any direction. Therefore, genetic isolation of bacteria coexisting in the same habitat may be difficult to accept. Geographic isolation of habitats may be a more effective barrier to rapid evolutionary change via lateral genetic exchange.

Extrachromosomal inheritance. Extrachromosomal inheritance in bacteria is mediated by plasmids which consist of circular double-stranded DNA molecules resident in the cytoplasm of the host bacterium (Lacy & Leary, 1979). Recently, extrachromosomal elements have been discovered that are linear instead of circular. *Borrelia burgdorferi*, the agent of Lyme disease of humans, a spirochete, and *Streptococous rochei*, a Gram-positive coccus, were found to contain linear plasmids (Barbour & Garon, 1987; Hirochika et al., 1984). Upon denaturation, the plasmids were found to be comprised of a covalently circular single-stranded DNA. The spirochete's plasmid upon denaturation had covalently closed ends and formed a circular single stranded DNA.

Two kinds of plasmids exist: **conjugative plasmids** capable of mediating their own transfer from bacterium to bacterium and non-conjugative plasmids incapable of self-transfer**. Non-conjual plasmids** often 'hitchhike' and are transferred with conjugative plasmids.

Conjugative plasmids are usually associated with pili, which are involved in cell-to-cell contact required for transfer of plasmid DNA. Non-conjugative plasmids are often transferred with conjugative plasmids. Plasmids may be derived evolutionarilly from degenerate bacteriophages. The critical difference is among plasmids and phages are that DNA is packaged within virions for transfer to new bacterial hosts; therefore, phage genomes are physically restricted in size by their protein capsule while plasmid genomes are not constrained to be a certain size. Thus plasmids

may carry genes not required for plasmid maintenance and replication. The resultant genetic flexibility allows plasmids to exist in symbiotic association with their bacterial hosts rather than a parasitic one. Most plasmids studied in detail are found to mediate functions beneficial to their hosts. **Table 2** on the following page lists some functions beneficial to plant pathogenic prokaryotes know to be carried on plasmids.

Plasmids have been shown to be transferred *in planta*. Kerr (1969; 1971) demonstrated that tumorigenicity was transferred in *Agrobacterium tumefaciens* in the manner of an extrachromosomal genetic element. Plasmids exchange in planta is often more efficient that in vitro (Lacy & Leary, 1975; Lacy, 1978). Transfer of antibiotic resistance into *Erwinia amylovora* may cause problems with oxytetracycline chemotherapy (Lacy, et al., 1984).

Table 2. Summary of plasmid and their phenotypes in plant pathogenic prokaryotes.

Plasmid function	Phytopathogenic bacterium	Reference
Ampicillin resistance	*Erwinia herbicola*	Lacy & Sparks, 1979
Thiamine biosynthesis	*Erwinia herbicola*	Lacy & Sparks, 1979
Pigmentation	*Erwinia herbicola*	Lacy & Sparks, 1979
Pigmentation	*Erwinia stewartii*	Coplin, 1982
Bacteriocin	*Agrobacterium radiobacter*	Kerr, 1980
Plant tumorigenesis		Reviewed by Shaw, 1987
Auxin biosynthesis	*Agrobacterium tumefaciens* *Pseudomonas syringae* pv. *savastanoi*	Reviewed by Shaw, 1987
Cytokinin biosynthesis	*Agrobacterium tumefaciens* *Pseudomonas syringae* pv. *savastanoi*	Reviewed by Shaw, 1987
Plant chromosome insertion sequences	*Agrobacterium tumefaciens*	Reviewed by Shaw, 1987
Opine synthesis	*Agrobacterium tumefaciens*	Reviewed by Shaw, 1987
Opine catabolism	*Agrobacterium tumefaciens*	Reviewed by Shaw, 1987
Opine permease	*Agrobacterium tumefaciens*	Reviewed by Shaw, 1987
"Virulence"	*Agrobacterium tumefaciens*	Reviewed by Shaw, 1987
Nodulation	*Rhizobium* spp.	Reviewed by Shaw, 1987
Host specificity	*Rhizobium* spp.	Reviewed by Shaw, 1987
Nitrogen fixation	*Rhizobium* spp.	Reviewed by Shaw, 1987

Substitutive recombinational events. Substitutive recombination requires that some DNA sequences on homologous segments be exchanged, *i.e.*, substituted by an even number of crossover events. The resultant composite molecule is usually about the same size as the original recipient molecule. In this section recombination resulting from transformation, conjugal transfer, and transduction are discussed.

Transformation, the process by which bacteria absorb exogenous DNA from its surroundings and integrate it functionally into its own genome. First observed among Gram-positive human pathogens, this process was thought to be accidental and of no consequence in nature. This conclusion should be re-examined since special proteins for the uptake of DNA have been described. Gram-positive organism take up linear strands of DNA.

Gram-negative bacteria do not seem to have cellular mechanisms for taking up exogenous DNA; however, they may be tricked into taking up circular DNA through treatment with various divalent cations. Ca^{2+} is the cation most often mentioned, but others such as Rb^{2+} are even more efficient under some conditions. Linear DNA is probably digested by periplasmic nucleases before it can be brought into the cytosol. Strains deficient in nucleases are transformed at higher frequencies.

Transduction is the transfer of parts of the chromosome of one bacterial cell (the donor) to another cell (the recipient) via phage particles (Smith, 1988). Phage DNA is normally packaged in a linear fashion from a concatemer containing many phage genome equivalents joined end to end. Packaging commences at a special phage DNA site (*pac*) and proceeds unidirectionally until the protein prohead is "full."

Accidental packaging of donor DNA may occur by either of two mechanisms. In the first, packaging is initiated at sites on the donor DNA with accidental resemblance to *pac*. For the second mechanism, recombination occurs between the phage DNA and accidental homologies on the donor DNA. Such a crossover event may link *pac* to the donor chromosome.

Generalized transduction occurs when phage particles may transfer any bacterial gene (Scaife et al, 1985). This sort of genetic exchange is useful for mapping over fairly long distances. Lytic phage are often used in generalized transduction for moving genes from a susceptible donor bacterium to a phage-resistant recipient bacterium. Transducing phage have been described for plant-associated bacteria including *Erwinia chrysanthemi* (Chatterjee & Brown, 1980) and *Rhizobium leguminosarum* (Buchanan-Wollaston, 1979).

Specialized transduction results from the insertion of a lysogenic phage into the genome of bacterium. DNA sequences flanking the insertion site are transduced. Since this type of transduction only occurs near the insertion point, specialized transduction is most useful for the fine mapping of regions very close to the phage insertion site. No specialized transducing phage have been described for phytopathogens.

Conjugal transfer of genes was originally attributed to bacterial "sex;" now we realize that like specialized transduction results from additive recombination of a plasmid with the bacterial chromosome. Far from being sex, this phenomenon was discovered to be related to the presence of molecular parasites--plasmids. Basically, plasmids integrate with the bacterial chromosome but retain their ability to transfer themselves as well as the bacterial chromosome into a recipient. The DNA enters the recipient cell as single-stranded DNA which is replicated to form double-stranded DNA. Provided the whole plasmid-donor genome is transferred (an unlikely proposition because of its great size) an entire replicon may be formed. More commonly, short regions are transferred in a linear manner forming transitory merodiploids (partial diploids). In areas of homology, double crossover events may result in the inclusion of donor DNA into the recipient genome. Conjugal transfer has been recorded for a number of phytopathogenic bacteria and has been used to create large scale maps.

Additive recombination. In additive recombination, genomes combine one with another to form composite molecules which are the sum of the individual molecules. Several mechanisms of additive recombination, including integration of bacteriophages, plasmids, and transposons, are known. The other side of the additive recombination coin is subtractive recombination; generally, additive recombinational events may be reversed to require the individual molecules from the composite molecule. Recently, (APS meeting Rochester NY, 1997) it has been reported the common human colon bacillus, *E. coli*, differs from the human pathogenic strains of the bacterium by only two or three chromosomal "loops". This may have resulted from additive recombination with other human pathogens such as *Shigella* spp. and *Salmonella* spp.

Insertion sequences. Insertion sequences (ISs) are short pieces of DNA (0.7 to 1.5 KB) with no detectable property except that they mediated insertional activities basic to additive recombination mechanisms. ISs mediate excision and insertion events. A sequence of DNA flanked by ISs may transpose--in fact any differences between transposons and ISs are probably limited to the fact that transposons carry effective genetic markers between two insertion

sequences. ISs occur in families with additive or subtractive recombination being more common among members of the same family. There is some evidence that ISs may produce proteins that participate in recombinational events. Reviewed in Lacy & Stromberg (1995).

Bacteriophage and plasmid insertion. Additive and subtractive recombinational events among plasmids or phage and bacterial chromosomes are mediated by ISs.

Lysogeny of phage, in which one to countless replications of the phage occur as an insertion on the bacterial chromosome, is an effective evolutionary method for propagation of phage without under going the lytic cycle. Lytic phage may be under some survival handicap if the number of receptive hosts are limited by dilution, starvation, stress, or lysis by phage.

Likewise plasmids may be lost by dilution from daughter cells during out of phase chromosome/plasmid replication caused by several contrasting factors including rapid division by the host, starvation of the host, and competition with other plasmids for plasmid replication sites. An effective method for plasmid survival is to insert in the chromosome at those times. Genetically, inserted conjugal plasmids mediate conjugal transfer of chromosomal genes from bacterium to bacterium. These strains are known as "high frequency of recombination" donors or Hfr strains. Plasmids have been used to transfer genes of phytopathogenic bacteria. *Escherichia coli* F'lac plasmids formed Hfr strains in *Erwinia chrysanthemi* (Chatterjee & Starr, 1977) and *Erwinia amylovora* (Pugashetti & Starr, 1975). Other plasmids have been used to move genes in *Pseudomonas syringae* pv. glycinea (Lacy & Leary, 1976) and to map loci associated with attachment to plant cells in *Agrobacterium tumefaciens* (Robertson, et al., 1988).

Transposons are genes flanked by inverted repeated DNA sequences usually related to ISs. These mini-genomes replicate in bacterial, plasmid, and viral genomes and are unique since they transpose or jump from place to place. Some transposons, carrying antibiotic resistance genes, are used to great advantage in bacterial genetics as mutagens (Lacy & Stromberg, 1995). Since insertion of a transposon in a regulatory DNA sequence or within the reading frame of a gene usually results in loss of gene expression, transposon mutagenesis is a powerful tool for discovering genes related to plant pathogenesis (Allen, et al., 1986; Roberts, et al., 1986).

Genome fusion**.** Cells of different strains of *Streptomyces* spp. may be fused by enzymatic treatment in the laboratory. The genomes in the fused cytoplasms my also fuse to form a very large circular genome. By subtractive recombination over time the super genome reduces in size to approximately its original size. The resulting genome retains parts of the different genomes from the original fusion.

D. CHROMOSOMAL REARRANGEMENTS. Large-scale rearrangement of chromosomes within a bacterium may be important in bacterial evolution, including in the development of pathogenesis. In *Erwinia carotovora* subsp. *carotovora*, two pectate lyase genes may be rearranged about a central *Bgl*II restriction endonuclease site to produce active molecules. Reciprocal exchanges of the front and back of two genes (*pel9.5* and *pel10.5*) produce active molecules. One hybrid is more active that wildtype genes and has a different affect on a range of host species tissues (Lacy et al., unpublished results). This may represent a mechanism to refine pectate lyase genes for more effective pathogenesis on particular host species. Keen & Staskawicz, 1989) found that *avr* genes that had evidently been rearranged to form hybrids. The hybrid *avr* gene triggered a different pattern of hypersensitive reactions in differential hosts and may represent a mechanism to avoid host detection. Louws and colleagues (Louws et al., 1995, 1997) have discovered multiple (50 to 70) sites for short repetitive DNA sequences in plant pathogens. These sequences are far shorter than the IS sequences discussed above. Intervening DNA sequences may be amplified by the polymerase chain reaction (PCR). These may represent sites where chromosomal rearrangement may occur.

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DISEASE DEVELOPMENT, DISPERSAL, AND SURVIVAL

I. CONCEPTS OF DISEASE DEVELOPMENT

The concepts associated with disease and its development are poorly understood and often misused. This situation causes difficulty in understanding among plant pathologists and between plant pathologists and the public and growers. The following pages attempt to lay out one concise use of terms associated with plant disease and point out areas of controversy.

Disease. Holliday's (1973) definition of disease "a condition where the normal functions are disturbed and harmed" attempts to encompass without contradicting several disease concepts (see below) and is, therefore, so general and politic as to contain little information. Generally, pathologists have follow one of these three concepts of disease: Disease is; **1)** A continuing relationship between a pathogen and its host plant in which the pathogen obtains nutrition while the host is damaged (*e.g.*, its growth, fertility, survival, or yield is compromised). **2)** Plant damage arising from any cause, abiotic or biotic (including senescence, drought, heat, nutritional imbalances, machines, man, animals, genetic abnormalities, chemical damage, *etc.*); **3)** Any abnormal physiological condition (including developmental changes (*i.e.*, senescence), abiotic stresses (*i.e.*, drought, ozone, mineral stress, mowing, pruning), and biotic stresses (*i.e.*, pathogens, grazing, genetic anomaly).

Disease definitions (2) and (3) do not require pathogens. These definitions have two advantages: They encompass all situations with which a pathologist may be ask to determine the cause of plant losses. And, these broad definitions have political usefulness. For instance, under Departmental leadership by Dr. Houston Couch, using a broad definition allowed our Department (PPWS) to expand and extend its influence into other areas (*e.g.*, mineral stress, often considered to be the province of other disciplines (e.*g.*, Agronomy).

However, the Federation of British Plant Pathologist (FBPP, 1973) rejected the broader definitions for more exact biology-based understanding of disease. They specifically recommended that "non-infectious" diseases (plant damage with abiotic causes) be termed "disorders" rather than diseases. Definition (1) closely supports the FBPP position, limits disease to interactions among living organisms, and is the most widely accepted biological concept for disease. Further, it suggests that pathogens have persistent nutritional associations with their host--clearly eliminating casual biological sources of damage (*e.g.*, grazing by cattle).

Definition (3) suffers from an additional problem. Its is difficult, or more likely impossible, to define "normal" and "abnormal" physiology. As our understanding of molecular biology grows it is very clear that plants have genetically coded (normal?) physiological mechanisms for attempting to deal with stress. That these pathways once, triggered, follow predictable (normal?) sequences of events in trying to deal with stresses--whether biological or abiotic. It is clear that some pathogens may evade or overcome genetically encoded plant responses and cause disease. Likewise, it is clear that the magnitude of abiotic stress may overcome plant stress responses and allow significant damage to occur.

An example of a physiological response in disease is the proliferation of cells and tissues accompanying colonization by *Rhodococcus fascians*, causal agent of fasciation of several plant species. In intimate contact and nutritional dependence, the pathogen produces cytokinins which accumulate until apical dominance is broken and multiple apical buds development usually at the crown. In no way is the proliferation of tissues normal, however, the physiological response to cytokinin resulting in apical bud proliferation is predictable (normal?) and the result of the plant's genomic coding (normal?). The phenotype, fasciation, is a predictable response dictated by the interaction of two organisms (pathogen and host) and their predictable physiological responses to each other encoded by their separate genomes.

Disorder. Plant disorders are harmful deviations from normal functioning of physiological processes arising from causes other than pathogens including: mineral toxicity, mineral deficiency, genetic anomaly, low or high temperature stress, chemical toxicity, phytohormone

imbalances, *etc.* (FBPP, 1973; Holliday, 1989). This definition, in my mind, contains a fossil of the past. In 1973, physiological plant pathology was making great strides as new technology became available and the excitement of discovery is indicated in the probably unnecessary inclusion of "physiological processes". We understand clearly that the phenotype of a plant (damaged or healthy) is a product of the interaction of environment (including stresses) on its genotype and is as expressed by changes induced in physiological processes. More simply stated, plant disorders refer to damage or injury caused by abiotic or biotic stresses other than pathogens.

Genetic abnormalities are caused by differences in the amount, arrangement, or base composition of DNA. Genetic abnormalities are often incorrectly called "diseases". That position is difficult to defend because no living pathogens or injurious abiotic agents are involved. The sole agent of the disorder is an aberration from the population norm in the genome of the individual. For instance, as it is difficult to consider a Down syndrome (trisomy 21) child (*Homo sapien*) as "diseased", it is likewise difficult to consider a dwarf peach tree (*Prunus persica*) as "diseased". In both cases, the individual organism is operating normally considering the genetic plan available to them. However, only when the genetic complement of a large number of people or peach trees is considered do we clearly understand that these individual are abnormal on population scale.

Pathogen. Plant pathogens cause plant disease. They are organisms (*e.g.*, usually bacteria, fungi, nematodes) or biotic agents (*e.g.*, viruses, viroids, TDNA) that derive nutritional and/or replicational benefit from persistent and intimate contact with plants. This definition varies from that of Holliday (1989) to include elements of the nutritional benefit of intimate and persistent contact with the host that differentiate pathogens from casual damage caused by other biological organisms (*i.e.*, grazing by insects or cattle; deer rubbing antlers on trees).

Pathogenicity. Pathogenicity is 1) the capability to cause disease; 2) the amount of damage caused to the host (*i.e.*, level of pathogenicity) (Shaner et al., 1992). The preferred usage is to denote an organisms ability to cause disease on a plant host (Shaner et al., 1992). The level of damage caused to a host is more correctly defined by levels of virulence (see below).

Pathogenesis. Pathogenesis is the sequence of processes from host and pathogen contact to plant damage or disease (Holliday, 1989). The phenotype, disease, depends upon the induction of physiological responses encoded in the genomes of the interactants, pathogen and host plant, as affected by environment (Lacy, 1986). This is a more genetic expression of the well known "disease triangle": host, pathogen, environment.

Pathogenesis may be divided into several steps (Walker, 1969; **Fig. 1**): Infection court: Effective proximity (contamination, infestation, or inoculation) of a susceptible host (plant genetically capable of being diseased by a particular pathogen) and compatible pathogen (pathogen genetically capable of causing disease on a particular host) under environmental conditions in conducive to further steps in pathogenesis. Proximity may include contact of a susceptible host (infection court) with a viable pathogen (capable of causing disease) that is compatible (pathogenic on that particular host plant), Penetration: Initial entry of pathogen into the host. Infection (establishment of a nutritional relationship with the host), Colonization: (development of a biomass of the pathogen through replication) without measurable (visible) symptoms of plant damage. Disease: Visible symptoms or measurable attributes (*e.g.*, its growth, fertility, survival, or yield is compromised) of plant disease develop. Mathematically, pathogenesis may be viewed as the product (ABC...N) of the probabilities (A,B,C....N) of the success of the sequential steps required for its occurrence. Other factors such as competition with another species or strain of pathogen my result in failure of pathogenesis (Stromberg *et al.*, 1990). Likewise competition with antagonistic microflora may cause failure of pathogenesis--which is the basis for biological control.

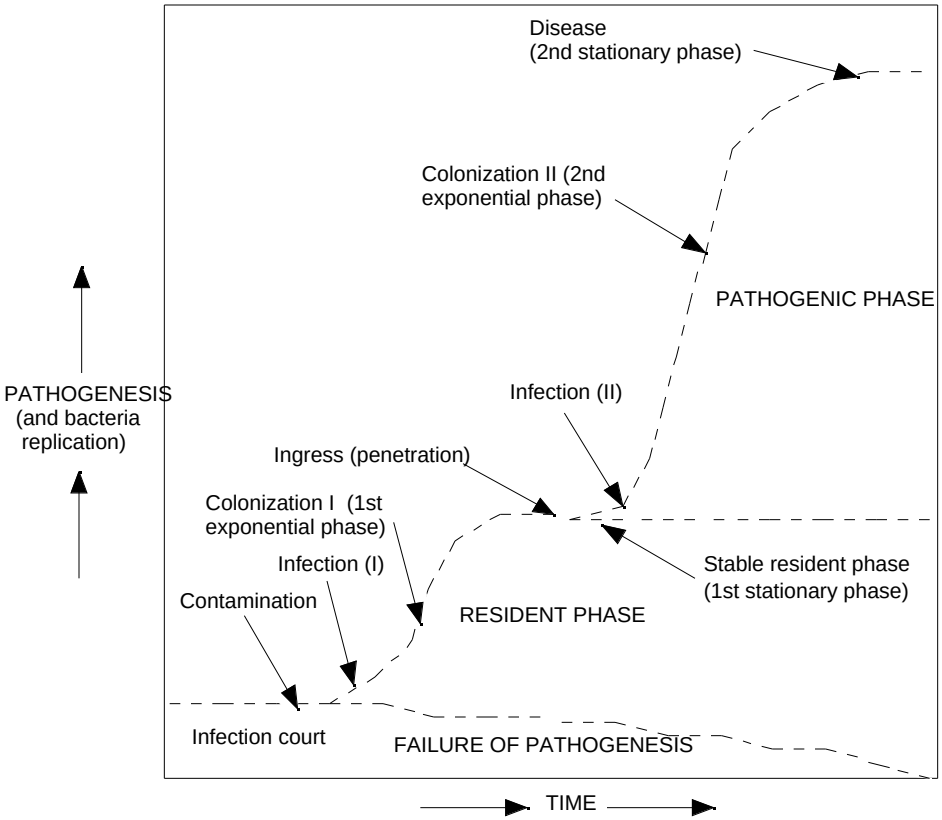

Figure 1. Pathogenesis and the resident phase of bacteria. In general, bacteria lack specialized resistant structures to survive environmental periods not conducive to pathogenesis. To overcome this problem, bacteria have developed non-pathogenic resident phases of active growth on or in plants to survive until environmental are conducive for pathogenesis. This figure cartoons steps in pathogenesis based on the growth curves of bacteria (shown by dashed lines and consisting of lag, exponential and stationary phases). One sequence, including contamination, infection (I), and colonization (I; first exponential phase), leads to the establishment of a stable resident phase population on or in plants (first stationary phase). This resident phase is of indeterminant length. Bacteria may survive days to years in this phase before initiating the pathogenic phase. A second sequence, ingress, infection (II) colonization (II; second exponential phase) and disease (indicated by the second stationary phase), occurs when conditions are correct for pathogenesis. In this figure, infection and/or the establishment of a nutritional association with the host is indicated by the end of the lag phases of growth and the points where bacterial growth curves begin to increase.

Virulence. The amount of disease caused by a particular strain of a pathogenic bacterium is related to the genetic make-up of the pathogen and the host (Lacy, 1986). The term most applicable for indicating the amount of disease, "virulence", is used in confusing ways by pathologists (Lacy, 1985; Shaner et al., 1992). **1)** Some use it to mean one strain of a pathogen causes more damage to a host plant than another. This usage is closest to the intention in medical terminology (*i.e.*, a virulent strain of influenza makes a person sicker than a less virulent strain) and is the primary usage recommended by Shaner et al. (1992). **2)** Some pathologist use it in place of pathogenicity ("avirulent" or "non-virulent") to indicate that an organism is or is not a pathogen. Obviously using the terms "pathogenicity" or "pathogen" should be used as recommended by Shaner et al. (1992). **3)** Some, especially molecular biologists, use the term to denote host range changes. (*e.g.*, "A pathogen is virulent on this cultivar but avirulent on a second cultivar of the same plant species."). They want to an should say that the pathogen is pathogenic on one cultivar and non-pathogen on the second. Unfortunately, this third usage is now firmly entrenched in the literature pertaining to the gene-for-gene hypothesis for host resistance.

The sum is that, we have made a mess of the usage of the term “virulence” which confuses us and makes our literature difficult for scientists from allied disciplines to understand. Remedy: Shaner et al. (1992) suggest that usage of the term "virulence" be avoided. That is to say , pathologist should write what they actually mean (*e.g.*, "one strain of the pathogen caused larger lesions than another..." rather than “one strain of the pathogen is more virulent that the another...”) or to carefully define the usage in each paper [*e.g.*, "In this paper, we intend "virulence" to denote gene-for-gene interactions with the host that lead to development of any lesions (virulence) or a hypersensitive resistant reaction and no disease (avirulence)"].

Aggressiveness. The aggressiveness of a pathogen is related to the amount of damage caused by a pathogen to its host. The first usage of the term “virulence” is synonymous (see above) as is the second usage of the the term pathogenicity (see above). Therefore the term is redundant and possiblely inaccurate because of the anthropomorphic suggestion associated with the term that an aggressive pathogen might have some human characteristics of planning violence, sadism, or boldness. General agreement exists that use of this term should not be discontinued in pathological literature (FBPP, 1973, Holliday, 1989, Shaner et al., 1992).

II. DISPERSAL (Reviewed in Venette, 1982).

Dispersal is critical to disease caused by phytopathogenic prokaryotes because these organisms usually lack spores as survival structures and do not have mechanisms to launch themselves into the air as do many fungi. Bacterial depend for their dispersal upon passive transmission by wind-splashed rain, irrigation water, insects, seeds, vegetatively propagated methods, and fomite infestation of cultural implements. Disease control, like wise depends heavily on bacterial dispersal, especially methods to limit pathogen transmission.

Sites of bacterial entry into plants. To understand the importance of mechanisms for the dispersal of pathogenic bacteria, we should have a basic level of understanding of how bacteria enter plants. Mechanisms of penetration, entry, or ingress (Reviewed in Huang, 1986; Goodman, 1982) include: Mechanical penetration. Generally, bacteria were believed to enter their hosts only in a passive manner. With the discovery of infection threads in rhizobia, cutinases in streptomycetes and pseudomonads, this thinking has changed. Cellulose infection threads produced by rhizobia penetrate into plants and deliver nitrogen-fixing bacteriods into plant cells. Cutinase digest the cutin layer of leaves and stems allowing bacteria, especially, streptomyces, access to the interior of plants. It is obvious that some bacteria may penetrate mechanically through cell barriers into plants. Passive ingress. Bacterial motility and chemotaxis are important in host entry. *Natural openings* in plants are susceptible to bacterial entry. These include stomata, hydathodes, nectarthodes, and lenticels. Bacterial movement is best facilitated by a continuous film of water from the outside to the inside of the plant. Alternatively, bacteria in water droplets may be forced into plant by the hydrostatic pressure created by droplets striking plant surfaces. *Insect vectors* are very efficient for introducing prokaryotes within plants. *Water congestion or hydraulic pressure.* Temperature differentials within plant tissues may create positive or negative pressures that will either resist bacterial entry or aid entry. Negative internal pressures created by washing warm plant parts in cold water are especially effective for increasing bacterial entry. This situation is commonly encountered as fruits or vegetable are washed after harvest at packing facilities.

Dispersal mechanisms are highly dependent on environmental conditions. Generally, bacteria are dispersed by wind, water, insects, or fomites. Plant pathogenic bacteria find their hosts by accident in long range transport (over some hundreds of meters to several miles), while in short range transport insect identification of feeding hosts (less than 100 meters) or chemotaxis (less than 1 cm) may be quite important.

Host plants and dispersal. Hosts may be the susceptible host in the disease interaction or resident phase hosts or reservoir hosts for the pathogen. Susceptible hosts are compatible for disease development and dispersal of the pathogen to other hosts. For instance pear (*Pyrus communis*) is susceptible for fireblight caused by *Erwinia amylovora* and oozing lesions on pear make good sources of inoculum for other pomaceous orchard plants.

Resident phase hosts usually provide epiphytic sites for replication and survival of the resident phase of the pathogenic bacteria. For instance, *Pseudomonas syringae* pv. syringae which causes common blight on field beans (*Phaseolus vulgaris*) but hairy vetch (*Vicia villosa*), on which the pathogen is a non-pathogenic resident, are the source of inoculum as weeds near the edge of the field. As a second example, *Clavibacter michiganense* subsp. *sepedonicum* was recovered from within roots of symptomless sugar beets (*Beta vulgaris*) grown in the field. The sugar beet strains were identical to potato (*Solanum tuberosum*) strains, caused ring rot in potatoes and wilts in eggplant and tomato (*Lycopersicum esculentum*). No symptoms were observed on sugar beets (Bugbee, et al., 1987).

Reservoir hosts are usually weed species diseased by the pathogen which serve as inoculum reservoirs for the pathogen to crop species. For instance, chokecherry (*Prunus virginiana*) develops X-disease, but serves as a reservoir host for the X-disease phytoplasma in wooded areas near peach (*Prunus persica*) orchards in the northeast and midwest.

Irrigation water. Overhead irrigation is one of the most effective methods for spreading bacteria from plant to plant. Halo blight of bean, caused by *Pseudomonas syringae* pv. phaseolicola, bacterial spot of pepper (*Capsicum frutescens*), caused by *Xanthomonas campestris* pv. vesicatoria, angular leaf spot of cotton (*Gossypium hirsutum*), caused by *Xanthomonas campestris* pv. malvacearum, and rhizome rot of iris (*Iris* spp.), caused by *Erwinia chrysanthemi* are some diseases spread by sprinkler irrigation.

Vegetative propagation. Systemic movement of prokaryotes in plants allows movement of bacteria into apparently healthy tissues which may be used subsequently for vegetative propagation.

Citrus (*Citrus* spp.) canker, caused by *Xanthomonas campestris* pv. citri, potato (*Solanum tuberosum*) soft-rot, caused by *Erwinia carotovora* subsp. *carotovora*, X-disease, caused by a phytoplasma, and potato (*Solanum tuberosum*) ring rot, caused by *Clavibacter michiganense* subsp. *sepedonicum* are examples of pathogens transmitted by vegetative propagation methods.

Agrobacterium tumefaciens was isolated infrequently from apparently healthy stem tissue distal to developing galls. However, wounds made aseptically above developing galls initiated gall development in 2.2% of 1400 wounds (Jones & Raju, 1988).

Seed. Like vegatative organs of plants, movement of the bacterium into fruits and seeds may allow external or internal seed contamination.

Pseudomonas syringae pv. lachrymans, causal agent angular leaf spot of cucumber (*Cucumis sativus*), moved from flower inoculations into fruits and seeds. As many as 60% of the seeds were infested externally and 16% internally in colonized fruit (Kritman & Zutra, 1983).

Black rot of crucifers, caused by *Xanthomonas campestris* pv. campestris, and *Pseudomonas syringae* pv. phaseolicola are outstanding examples of diseases spread by colonized seed.

Clavibacter rathayi is present in galls formed by the nematode *Anquina agrostis* in rye grass seeds (*Lolium* spp.). In association with the nematode the bacterium causes disease; without the nematode, the bacterium is innocuous.

Insects. (Reviewed in Purcell, 1982). The process of vector transmission may serve to selectively eliminate potential competitors for nutrients and biological space. In other words moving from plant to plant inside insect vectors reduces that likelihood of encountering competing organisms. Transmission of pathogens by chewing insects is probably the first method developed. Chewing insects may be effective in transmitting prokaryotes that are pathogens of parenchymatous cells or xylem vessels, but they are not effective transmitters of phloem pathogens since the wounds they cause lead to release of hydrostatic pressure of the phloem, effectively washing the inoculum away; collapse of the phloem system in the area, effectively destroying the phloem; and causing the plugging of phloem sieve plates, effectively stoppering the phloem system. In the late Carboniferous Period of plants, the appearance of Cordaitales (very common primitive dichotomously branching trees--now extinct) that had phloem near the stem surface may have been a key process leading to the widespread evolution of phloem-feeding Hemiptera. In the subsequent more than 300 million years, plant-insect-prokaryote relationships have become ever more complex.

Insect transmission efficiency. Phytoplasmas (mycoplasma-like organisms) and xylem-limited bacteria survive or multiply in a wide range of very different environments such as plant phloem sap, insect hemolymph, insect lumens, insect guts, xylem sap, and insect salivary glands. To complete their disease cycles, these nutritionally fastidious organisms have to complete an obstacle course of sequential steps (A, B, C,...etc.). If each transmission subprocess has a certain probability of success, (A, B, C, ...N), then the probability that the entire process will be completed is the product of each probability (ABC...N).

Persistence in/on the vector. For transmission, a prolonged inoculative phase increases the chance for inoculating and infecting a large number of plants. Multiplication of the pathogen within the vector provides two advantages: **i)** the amount of potential inoculum is amplified rather that diluted, and **ii)** inoculum may persist over a longer period of the vector's life. In other transmission systems, the bacterium may only attach to and persist on the surface of the vector.

Pathogenicity to the vector. Pathogen pathogenicity to vectors may be more deleterious to the pathogen's survival and dissemination than is its virulence to plants. The vector's ability to disperse, feed, survive, and reproduce may be impaired.

Horizontal transmission. Most insect vectors may transmit pathogens only during their life time. Therefore most insect transmission is “horizontal” among plants and not “vertical” between generations of insects. For instance, with leafhoppers, the period during which a nymph or aphid can transmit pathogens often ends upon molting. This is because the lining of the alimentary canal, where the pathogens reside, is lost upon molting as well as the external cuticle.

Vertical transmission. Only the clover club leaf bacterium is known to be transmitted through the leafhopper egg to the next generation.

Other arthropods. Springtails and mites have been found consistently in acid scab lesions on potatoes and studies have shown that these arthropods carry *Streptomyces scabies* on and in their bodies. Diazinon, a long residual insecticide, provided control as good as the best fungicides tested as soil or seed treatments (Manzer, *et al*., 1984).

Pollen and fungal spores. The following bacteria may be pollen disseminated:

Xanthomonas campestris pv. juglandis, the walnut blight organism is transported on walnut (*Juglandia regia*) pollen.

Erwinia stewartii, Stewart's wilt of corn (*Zea mays*), may be pollen disseminated.

Erwinia amylovora, causal agent of fireblight in roseaceous hosts may be pollen disseminated.

Erwinia uredovora, a pathogen on uredial of cereal rusts, is disseminated on uredospores.

Pseudomonas syringae pv. phaseolicola is disseminated on uredospores of *Uromyces phaseoli*, the rust fungus causing rust on bean (*Phaseolus vulgaris*).

Airborne dust and debris. The stronger the wind, the larger the particles of soil or plant debris that are airborne may be. Fine dust may remain airborne for hours and travel miles.

Xanthomonas campestris pv. malvacearum, the cotton blight pathogen, in dried cotton (*Gossipium hirsutum*) leaves was distributed from a point source over 40 hectares in less than 20 min by wind.

Streptomyces scabies, scab pathogen of potato (*Solanum tuberosum*), attached to dust particles was increased in the air by wind or agricultural activities.

Aerial strands. Several phytopathogenic bacteria produce copious amounts of extracellular polysacharides (EPS) that may form thin strands (100mm long and 6-300 _m wide) as they are exuded from plant surfaces. These strands dry, break off, and float in the air some distance. Evidently, the ooze protects the bacterium and prolongs its survival, possibly by maintaining some moisture surrounding the cell. Pathogens that produce aerial strands include: *Pseudomonas syringae* pv. mori, mulberry (*Morus alba*) pathogen; *Xanthomonas campestris* pv. phaseoli, common blight of bean (*Phaseolus vulgaris*); and *Erwinia amylovora*, fire blight of roseaceous plants.

Fog or dew drip. *Xanthomonas campestris* pv. pruni, causal agent of bacterial spot of stone fruits is disseminated in wind-blown fog and by dripping dew.

Activities of man. Humankind has been very effective at moving plant and animal diseases from regions where they are known to where they were unknown. World wide distribution was achieved by human activities for:

Erwinia amylovora, causal agent of fire blight of roseaceous plants, was introduced into Europe and Egypt from the US.

Clavibacter michiganense pv. michiganense, causal agent of tomato canker, was introduced on tomato (*Lycopersicon* esculentum) into England from the US.

Xanthomonas campestris pv. citri, causal agent of citrus canker, introduced with Citrus spp. into Florida and South America from Asia

Pseudomonas syringae pv. glycinea, causal agent of soybean (*Glycine max*) blight, introduced into the US from Asia.

Pear decline, caused by a phytoplasma, was introduced from Europe into California on imported *Pyrus communis* as was its vector host, *Psylla pyricola*.

III. SURVIVAL

Survival of bacteria is reviewed by Venette, 1982. A powerful tool in autecological research has been the use of spontaneous mutants to antibiotic resistance. Antibiotic resistance makes strains of bacteria placed into nature more efficient to recover than their antibiotic-sensitive indigenous counterparts. One critical point is that any mutant must be tested to determine if it behaves in a wildtype manner. Obviously, one cannot test all traits, but good ecological studies require that wildtype behavior in mutants must be confirmed (Hagedorn, 1986).

Dried plant debris. Survival in died, hypobiotic form is probably dependent upon protective extracellular polysaccharides (EPS).

Xanthomonas campestris pv. malvacearum, causal agent of angular leafspot of cotton (*Gossipium hirsutum*), has survived up to 17 years in dried cotton leaves.

Pseudomonas syringae pv. phaseolicola, casual agent of haloblight of bean (*Phaseolus vulgaris*), has survived more than 20 years in dried herbarium samples.

Xanthomonas campestris pv. campestris, causal agent of black rot of crucifers, was recovered from buried stems for at least 507 days. The pathogen persisted and

colonized leaves of radish (*Raphanus sativus*) and wild turnip (*Rapistrum* rugosum) externally and internally (Schultz & Gabrielson, 1986).

Overwintering of *Pseudomonas syringae* pv. glycinea in soybean (*Glycine max*) leaves buried 0, 10, 20 and 30cm beneath the soil surface was evaluated using a rifamipin and streptomycin resistant mutant. Survival of the pathogen was not affected by the depth of burial. was recovered from leaves buried in November was recoverable until February or March the following year. However, the pathogen was no longer detectable by April. The pathogen survived best under dry, cold conditions (Park & Lim, 1985).

Xanthomonas campestris pv. vesicatoria, causal agent of pepper (*Capsicum frutescens*) spot, was recoverable 6 months after infested plant parts were placed in the field. The pathogen was also recovered from six weed species including *Solanum americanum* and *Physalis pubescens*, solanaceous weeds, from volunteer crop plants, and seed lots. Volunteer plants and crop residue appeared to be most important in this tropical, continuously cropped area of Florida as sources of inoculum (Jones, *et al.*, 1986).

Survival in water.

Water suspensions. Soft-rotting erwinias species have survived more than 14 years in water suspensions stored at room temperature (Kelman, personal communication). Therefore, water is a good medium for survival of bacteria.

Airborne water droplets. Water droplets form by rain splash, sprinkler splash, and dew or fog drip. Water droplets strike leaves and remove bacteria. Size of drops determines the number and sizes of droplets formed. The larger the drop striking the leaf, the faster it is moving, causing it to shatter into more and smaller droplets. The initial velocity of the droplet striking the leaf imparts a similar velocity to droplets leaving the leaf. On dry and/or windy days, large droplets survive evaporation longer to be disseminated further than small droplets. However, on humid and overcast days, small droplets will be disseminated further because larger droplets settle out more quickly. On humid days, droplet dispersal has been measured to occur several kilometers from the source of the inoculum. Examples of pathogens known to be distributed by droplets:

Xanthomonas campestris pv. malvacearum, causal agent angular leaf spot of cotton (*Gossipium hirsutum*)

Clavibacter michiganense pv. michiganense, causal agent of bacteria canker of tomato (*Lycopersicon esculentum)*

Xanthomonas campestris pv. vesicatoria, causal agent of bacterial spot of pepper (*Capsium frutescens*)

Pseudomonas syringae pv. mors-prunnorum, causal agent of bacterial canker and blossom blight of stone fruit.

Pseudomonas syringae pv. syringae, brown spot of bean (*Phaseolus vulgaris*),

Xanthomonas campestris pv. campestris, causal agent of black rot of crucifers.

Pseudomonas syringae pv. phaseolicola, halo blight of bean (*Phaseolus vulgaris*),.

Pseudomonas syringae pv. glycinea, causal agent of bacterial blight of soybean (*Glycine max*).

Aerosols. Evaporation of small water droplets may form aerosols of only bacteria remaining suspended in air currents. Bacterial aerosols may also be caused by wind removal of bacteria directly by from plant surfaces or other agitation of the leaves. Mechanical pulverization of potato stems has been shown to release bacteria into aerosols from soft rot lesions caused by *Erwinia carotovora* subspp. *carotovora*. Survival of bacteria in aerosols has been studied for a few plant pathogens:

Erwinia amylovora, causal agent of fire blight of roseaceous plants, survives 3hr at 40-90 percent relative humidity (%RH).

Rhizobium meliloti, nitrogen-fixing symbiote of alfalfa (*Medicago sativa*), survives 5 hr at relatively high humidities.

Pseudomonas syringae pv. glycinea, causal agent of bacterial blight of soybean (*Glycine max*); *Pseudomonas syringae* pv. phaseolicola, causal agent of haloblight of bean (*Phaseolus vulgaris*); and *Xanthomonas campestris* pv. phaseoli, causal agent of bean spot, all survived for 3 hr in humid air indicating that long distance dissemination is possible.

Erwinia carotovora subsp. *atroseptica* survived 60-90 min after pulverization of potato vines (*Solanum tuberosum*).

Survival in soil (Reviewed in De Boer, 1982 and Breuhl, 1987) Resident or soil inhabiting bacteria. Soil resident bacteria maintain or increase their numbers in soil. These are indigenous organisms that persist for years with out plant hosts and include:

Streptomyces scabies, causal agent of scab on potato (*Solanum tuberosum*).
Pseudomonas marginalis , causal agent of soft rot many hosts.
Bacillus subtilis, causal agent of many seed rots, including "Essex" disease of soybeans (*Glycine max*) in Virginia.
Clostridium spp., causal agent of soft rot of many hosts.
Ralstonia solanacearum, causal agent of bacterial wilt of solanaceous hosts and banana (*Musa paradisiaca*).
Agrobacterium tumefaciens vector of the crown gall causal agent of many dicotyledonous plants.
Agrobacterium rubi, vector of crown gall causal agent of *Rhubus spp.*
Agrobacterium rhizogenes, vector of the hairy root causal agent affecting many dicotyledonous hosts.
Agrobacterium radiobacter a non-pathogenic, plant-associated bacterium.
Rhizobium spp. and *Bradyrhizobium* spp., nitrogen-fixing legume-nodulating bacteria.

Non-resident or soil invader bacteria. Populations of non-resident bacteria decline either rapidly or slowly when released into the soil. Generally, survival is increased greatly by the presence of colonized plant debris. This group includes *Erwinia amylovora*, soft-rotting erwinias, leaf-spotting pseudomonads and xanthomonads, and the coryneform group of bacteria. Non-resident bacteria have been confused with resident hosts**.** If a non-resident bacterium such as *Erwinia carotovora* multiplies on the roots of a host plant, careless surveys which contain host roots may indicate that the populations are increasing and erroneously attribute this to soil saprophytic ability. Some non-resident bacteria.

Clavibacter spp., causal agents of wilts of many plants.
Xanthomonas campestris pathovars, causal agents of leafspots of many plants.
Erwinia spp., causal agent of soft rots of many plants.
Pseudomonas syringae pathovars, causal agents of leaf spots of many plants.

Reservoirs of pathogenic bacteria in the rhizosphere (Reviewed in Stanghellini, 1982). Bacteria such as *Erwinia carotovora* subspp. *atroseptica* and *carotovora* and *Erwinia chrysanthemi* may exist as epiphytes on or near roots of many species of weeds. A similar situation has been shown for *Ralstonia solanacearum* which may be epiphytic on the roots of plants on which it is not a pathogen (*e.g.,* maize or *Zea mays*). This may cause problems with rotational control of wilts caused by the pathogen in tobacco or peanuts.

Microbial interactions. Microbial interactions with pathogens are often detrimental and limit pathogen numbers. *Bacterial yield.* Assuming 24 hr generation, 6-mo growing cycle, a 15 cm hectare slice, and 10^9 cfu/g, 2.3 x 10^6 kg/hectare minerals, and 2.5X 10^{-13}g/bacterial cell, 3.9 Kg/ha/day may be produced. No estimates are available to indicate how fast or how slow bacteria may replicate during the winter in temperate areas. Fortunately, several soil biological factors keep bacterial populations in control including: *Nematodes.* Nematodes harvest 800 kg of bacteria per hectare/yr. *Protozoa.* Protozoa may be the most efficient harvesters of bacteria in soil and on root surfaces; however, no good estimates seem to be available. *Antibiosis.* Antagonists to *Ralstonia solanacearum* were greatly affected by soil moisture. Antagonistic

actinomycetes were most numerous in dry soils while antagonistic bacteria were most numerous n wet soils. The pathogen survived less well in suppressive soils with high populations of antagonistic bacteria (Nesmith & Jenkins, 1985). *Bacteriocins.* See the section on Biological Control for a summary of bacteriocins. *Bacteriophage.* Bacteriophage populations may be very high ($>10^{10}$pfu/g) but actual numbers are difficult to ascertain since these biological agents have very narrow host ranges. *Bdellovibrio.* See the chapter on Evolution of Phytopathogenic Prokaryotes for a summary on bdellovibrio.

Environmental factors. Soil environmental conditions are important to bacterial survival. *Temperature.* Moderate soil temperatures (15 to 25 C) favor bacterial survival. *Moisture.* Soil moisture significantly affected the survival of *Ralstonia solanacearum* in field soils. Regardless of soil type, populations increased within 7 to 10 days of introduction into the soil at the highest soil moistures (flooded to -1 bar), but did not increase in drier soils (-5 to -15 bars). The most favorable matrix potential for the survival of the pathogen was -0.5 to -1 bar (Nesmith & Jenkins, 1985). *pH.* Moderate soil pHs in the neutral to slightly acidic range are best for bacterial survival. *Clay adsorption.* Adsorption to clay minerals especially montmorillonite increase bacterial survival in soil.

Survival of genetically engineered bacteria. Dispersal, survival, and pathogenic processes are undergoing a renaissance of interest and research. This resurgence in interest is related directly to the interest in releasing genetically engineered organisms into the environment (Anonymous, 1986; Comeaux *et al.*, 1990; Fulkerson, 1987; Lacy and Stromberg, 1991; Maranto, 1984; Porter, 1987). Using genetic markers and polymerase chain reaction amplification, soil populations may be examined in more detail than ever before. In the near future, we can look forward to understanding more about the survival and interactions of plant pathogenic bacteria in soil.

Survival *in planta*. An important survival tactic of phytopathogens is survival within plant debris. *Pseudomonas syringae* pv. syringae, causal agent of pear blast, was detected inside apparently healthy pear buds during growing and dormant seasons. The greatest populations were found during the fall and spring (Mansvelt, *et al.*, 1987). A rifampin-resistant mutant of *Pseudomonas syringae* pv. syringae, causal agent of bacterial canker of stone fruits, was inoculated on bud scars, leaf scars, or injected internodally. October inoculations resulted in populations decreasing to non-detectable levels within six weeks; February inoculations resulted in occasionally detectable populations eight months later. Most (98.8%) of the February inoculations resulted in cankers; few if any October inoculations resulted in lesion development (Endert & Richie, 1984). *Pseudomonas syringae* pvs. papulans , causal agent of Mutsu spot of apple (*Malus sylvestris*), and syringae, causal agent of bacterial dieback of apple, were isolated from apparently healthy and internally, necrotic buds in January to February. The bacterial were seldom recovered from bud scales and the highest populations were associated with central bud tissues (Burr & Katz, 1984).

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es of damage (e.g., grazing by cattle).

Definition (3) suffe*r*s from an additional problem. Its is difficult, or more likely impossible, to define "normal" and "abnormal"

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PHYLOGENETICS, TAXONOMY, AND IDENTIFICATION

I. PHYTOPATHOGENIC PROKARYOTES are microorganisms, including bacteria and phytoplasmas, that cause plant diseases. These plant pathogens, in general, have received less attention that the plant pathogenic fungi and viruses. This bias developed for several reasons, foremost of which is that most of the recognized and described plant parasitic diseases are caused by fungi or viruses. Therefore, training for plant pathologists traditionally emphasizes mycology. In addition, a large group of prokaryotic pathogens were mis-classified for many years as viruses or virus-like agents (including the phytoplasmas and xylem- or phloem-limited, nutritionally fastidious bacteria).

II. ECONOMIC IMPORTANCE. For numerous reasons, more emphasis has been given recently to diseases caused by phytopathogenic prokaryotes; chiefly, information about and interest in these pathogens has increased tremendously in the last few years. This increase in knowledge is largely a result of the usefulness of pathogenic prokaryotes as laboratory subjects and the increased awareness of the economic importance of diseases caused by prokaryotic agents (**Table 1**) and relative importance compared to phytopathogenic fungi (**Table 2**).

Table 1. Economic importance. Agricultural losses incited by prokaryotic pathogens

Disease and pathogen	Crop	Economic losses ($x106/yr)	Location	Citation
Soft rots caused by Pectolytic *Erwinia* spp.	Potato (*Solanum tuberosum*)	100	US	Pérombelon & Kelman, 1980
Crown gall vectored by (*Agrobacterium tumefaciens*)	Numerous orchard and ornamental crops	23	California	Kennedy & Alcorn, 1980
Leaf blight caused by *Pseudomonas syringae* pv. glycinea	Soybeans (*Glycine max*)	63	Nebraska	Kennedy & Alcorn, 1980
Alfalfa wilt casued by *Clavibacter michiganense* pv. michiganense	Alfalfa (*Medicago sativa*)	100	US	Hagedorn, 1982
Fire blight caused by *Erwinia amylovora*	Roseaceous crops including apples (*Malus sylvestris*) and pears (*Pyrus communis*)	5	Illinois	Van Der Zwet, 1979
Warm temperature frost damage incited by *Pseudomonas syringae* pv. syringae or *Pantoea heribicola*	Frost sensitive crops	1,500	US	Lindow, 1982

Table 2. Comparison frequencies of bacterial- to fungal-diseased vegetables

Crop	Observations	Diseases*	% Units affected	Reference
Celery (*Apium graveolens*)	9,946 shipments	Bacterial soft rot Gray mold Early blight	60.4 3.2 0.3	Cappellini et al., 1987
Carrot (*Daucus carota*)	3,451 shipments	Bacterial soft rot Gray mold Rhizopus rot	33.1 1.6 0.3	Cappellini et al., 1987
Potato (*Solanum tuberosum*)	13,757 tubers	Bacterial soft rot Fusarium tuber rot	37.8 18.4	Cappellini et al., 1987
Pepper (*Capsicum frutescens*)	5,055 shipments	Bacterial soft rot Gray mold	69.1 23.0	Ceponis et al., 1987
Cucumber (*Cucumis sativus*)	3,060 shipments	Cottony leak Bacterial soft rot	58.4 11.2	Cappellini et al., 1988
Squash (*Cucurbita maxima*)	1,332 shipments	Bacterial soft rot cottony leak	55.3 11.9	Cappellini et al., 1988
Watermelon (*Citrullis lanatus*)	895shipments	AnthracnoseBacterial soft rot	19.8 1.5	Cappellini et al., 1988
Cabbage (*Brassicae oleracease* var. *capitat*)*a*	1,952 shipments	Bacterial soft rot Alternaria rot	63.4 2.3	Cappellini et al., 1987
Broccoli (*B. oleraceae* var. *botrytis*)	1,967shipments	Bacterial soft rotGray mold	12.8 3.9	Cappellini et al., 1987

*Bacterial soft rot is caused by *Erwinia* spp., Gray mold is caused by *Botrytis*; Early blight is caused by *Alternaria*; cottony leak is caused by *Pythium aphanidermatum*; and watermelon anthracnose is caused by *Colletotrichum lagenarium*II. DISCOVERY OF PHYTOPATHOGENIC PROKARYOTES. It is generally accepted that the American T.J. Burrill first reported a disease of plants caused by a prokaryote. Actually, other researchers may have preceeded him into print, (Ainsworth, 1981), but his description of fire blight of roseaceous plants in 1878, partially based on conjecture, incited a great deal of scientific interest as well as controversy. His hypothesis, that prokaryotes could cause plant disease, was questioned rigorously by the German Alfred Fischer and defended by Burrill's countryman, Erwin F. Smith (Campbell, 1981). These debates forced improvements in experimental design and analyses of the experimental data that lead to the firm establishment of the principle that prokaryotes could cause plant disease. In 1883, the pathogen was named *Micrococcus amyloviraus* but later renamed *Erwinia maylovora* after Erwin F. Smith, another noted American phytobacteriologist (Campbell et al., 1999). We may see in this scientific debate similarity to the controversies that surrounded Pasteur's theories that promoted careful and intensive experimentation leading to the rejection of the theory for spontaneous generation.

E.F. Smith published an exhaustive treatise on the prokaryote-incited diseases of plants recognized in the first decade of the 20th century. Charlotte Elliot (1951) expanded upon this list. Currently, the list of prokaryotes causing plant diseases has grown so large that this field of study would benefit greatly from another such treatise. Fahy and Persly (1983) attempted a short summary of the most important disease descriptions. In this section, I will introduce the methods used for the identification and phylogenetics of prokaryotes. In no way should this brief lecture be construed as a complte taxonomy of the prokaryotes.

III. PROKARYOTES ASSOCIATED WITH PLANTS. Over 1,800 species of prokaryotes have been described. Of these only about 120 cause disease in plants. However, the list of prokaryotes that associate in other ways with plants is much longer than the list of prokaryotes causing plant disease. Many prokaryotes contribute to the air, plant surface, water, and soil microbiota that comprise an important part of the environment for growing plants. **Epiphytes** (those bacteria on the surface of plants which are nutritionally dependent on the plant) and rhizobacteria (bacteria found in the rhizoplane [root surface], or in the rhizosphere [soil affected chemically, physically, or biologically by plant roots]) may benefit from association with the plant without directly affecting the plant. This

group includes *Actinomyces*, *Azotobacter* (A free-living nitrogens-fixing bacterium), *Achromobacter*, *Arthrobacter*, *Bacillus*,*Chromobacter, Clostridium, Streptomyces, Pseudomonas,* and many others. Another group of prokaryotes benefit from their association with the plant, but also contribute some of their beneficial metabolic products to the plant. These include the **non-symbiotic** bacteria such as - *Azospirillum* and the **symbiotic** nitrogen-fixing genera *Bradyrhizobium, Rhizobium, Sinorhizobium,* and *Frankia*.
Evidently, most phytopathogenic prokaryotes have **resident phases** as epiphytes or rhizobacteria. During the resident phase, the putative pathogens exist in low numbers on plant surfaces as apparently harmless residents among the other natural microflora of the host plant or supplementary hosts. Other phytopathogenic prokaryotes, such as the causal agent of Stewart's wilt (*Pantoea stewartii*)on maize (*Zea mays*) do not have resident phases on plants but on the external surfaces of insects. Finally, most phytopathogenic prokaryotes colonize internal plant tissues and are known as **endophytes**. This group includes a very nteresting collection of pathogens that are vascular-limited and nutritionally fastidious existing only in plant xylem or phloem tissues or within the bodies or hemolymph of their alternate insect hosts.

IV. BASIC CHARACTERISTICS OF PHYTOPATHOGENIC PROKARYOTES. All prokaryotes share three invariant characters. They have cell membranes, cytoplasmic 70S ribosomes, and a non-membrane-limited nuclear region. Eukaryotes differ from prokaryotes since they have 80S cytoplasmic ribosomes in addition to 70S ribosomes associated with their mitochondria and chloroplasts. Further, these mitochondria and chloroplasts are membrane-bound organelles existing in the cytoplasm of eukaryotes. The nucleus of eukaryotes is bound by a double membrane. Phytopathogenic and phytosymbiotic prokaryotes have an unique character that separates them from all other prokaryotes--the ability to colonize plant tissues. Pathogens increase from a low number to a high number in a remarkably short time within a diseased host plant. No other feature distinguishes them so thoroughly from the myriad of non-pathogenic and epiphytic prokaryotes that occupy every other plant-associated habitat but are unable to colonize plant tissue. The essence of pathogenicity is this ability to live and multiply within plant tissues. Much is known or guessed about how prokaryotes damage plants once they have colonized host tissue, but exceedingly little is known about how they colonize plant tissue--this then is the greatest remaining frontier in the biology, ecology, and genetics of phytopathogenic bacteria.

V. TAXONOMY OF PROKARYOTES. A taxonomy is a classification devised by humans of living organisms according to their current understanding of natural or phylogenetic groupings. These phylogenetic taxons have been discovered by a variety of methods, each with its own strengths and weaknesses. Therefore, taxonomies have their own strengths and weaknesses and change constantly in response to the development of the new technologies used to explore natural relationships among prokaryotes.

A. Taxonomy methods. In this section we will examine the methods and weaknesses of these methods that have been used to explore the natural groupings of phytopathogenic prokaryotes.

1. Morphology. The color, size, and shape of colonies of prokaryotes growing on media. (Many fastidious prokaryotes will not grow on media; differences in media make differences in the color, size, and shape of colonies of prokaryotes; and many prokaryotes that are very different in cellular size, shape, and flagellation will produce colonies that are similar to each other).

2. The shape, size, and flagellation of bacterial cells. (Bacterial morphology under the light microscope is remarkably devoid of distincive shapes and sizes).

a. Shape: rods, cocci, spirilla, pleomorphic

b. Flagellation: atrichous, peritrichous, monotrichous, amphitrichous, lophotrichous

c. Capsulation: acapsular, microcapsules, large capsules

3. Biochemical differences.

a. Gram reaction: Cells of different ages or that have complex life cycles (*e.g.*, *Arthrobacter*) will stain differently.

b. Antibiotic resistances: These may change by acquisition of antibiotic resistance mediated by chromosomal mutations or plasmids.

c. Metabolism or nutrition: Utilization of sub strates, specific requirements for growth, aerobic or anaerobic nature, and enzymatic reactions may be affected by mutation or the presence or absence of plasmids carrying genes for new pathways or enzymes. For instance, fluorescence on single-carbon sources may be used to differentiate *Pseudomonas syringae* pathovars syringae and tomato and *Pseudomonas viridiflava* (Jones, *et al.*, 1986). Using large batteries of colorimetric biochemical or metabolic tests has been used to overcome these difficiencies. The BIOLOG^{TM} System uses 95 reactions in a 96-well plate (one well is a negative control). This system has enough reactions to allow slight differences among strains of bacteria and still allow accurate identification.

d. Host range: Host range, although the best biochemical and genetic system for phytopathogenic prokaryotes, is difficult since it requires great expense in greenhouse space, technical assistance, and time. Further, different results may be obtained if plants are inoculated or incubated under different conditions. Dickey (1981) illustrated this method using the reaction of *Erwinia chrysanthemi* strains on eight host species while Haygood (1982) pointed out that different methods of inoculation may lead to different results with the - *E. chrysanthemi.* Pizano (1986) discovered that envrionmental conditions could cause - *Curtobacterium flaccumfaciens* pv. poinsettiae, causal agent of poinsettia blight, to cause symptoms or remain as an apparently harmless endophyte. Host range has problems. If the same symptoms are produce on one host, pathologist have assumed that only one pathogen is involved. For instance in the case of bacterial spot of pepper (*Casicum frutescens*) caused by *Xanthomonas campestris* pv. vesicatoria, modern phylogenetic studies indicate that three different xanthomonads cause the same symptoms and that the differences are so great among these bacteria that they should be reclassified into three separate species.

e. Fatty acid methy ester analyses. Fatty acid methyl esters (FAME) formed with primarily cell wall components of bacteria serve as the basis for a very powerful method for profiling bacteria species. Separation of FAME components by gas chromatorgrappy or high pressure liquid chromatography forms the basis for rapid identification of bacterial species. The equipment is very expensive and is usually owned by commercial or government facilities. The entire collection of British national pathogenic bacteria collection is being processed by FAME analyses and put into a very valuable data base for species identification.

4. Numerical taxonomy: This method employs a mathematical method for seeking natural groupings by comparing many traits, usually 100 or more different tests per organism, using a computer. Each trait is given the same weight. Surveying many organisms in this manner allows the development of a taxonomy based on the percentage of similarities among the organisms. Sands, et al. (1970) developed such a taxonomy for phytopathogenic pseudomonads. The weakness of this system is that it is time consuming and expensive to run so many tests. Finally, not all traits of organisms may be weighted equally in importance. For instance, in this study the authors consisdered that the trait phytopathogeniciy was important enough to exclude all non-phytopathogenic pseudomonads from consideration.

Methods: Results of all tests were recorded as plus, minus, or indeterminate. Occasionally, as no test was made. Simple matching coefficients (SM) of similarity are obtained by dividing all, plus and minus matching tests by a total of all the tests. Positive only coefficients (PO) of similarity are obtained by dividing all plus matches by all tests minus negative matches. Consequently, SM estimates tend to give high coefficients, while PM estimated give lower coefficients. The SM or PO coefficients are clustered by the weighted-pair group method and dichotomous branched relatedness trees.

5. Polyacrylamide gel electrophoresis in SDS. Denaturing protein profiles have been used in phylogenetic studies. The weakness in this system is that profiles may differ since organisms may not express the complete complement of proteins at one time and some of these proteins may be expressed at different levels in different strains of the same species.

6. Serological relationships: Serology suffers from the same problem as the PAGE analyses indicated above. Further, since most organisms will have a core of highly conserved proteins cross reactions may be expected among closely-related and less-closely related organisms. Selection of the antigens must be done carefully. Choices among extracellular and intracellular antigens must be made. Research development of effective antibodies is slow, but serological identifications are rapid. Examples of the use of serology in identification or taxonomy of phytopathogenic bacteria follow:

Yakrus & Schaad (1979) use serological methods to identify *E. chrysanthemi* strains.
Malin, *et al.* 1983 used indirect immunifluorescent staining for detection of *Xanthomonas campestris* pv. *phaseoli* in naturally infested bean seed.
Van Laere, *et al*. (1985) describe an immunogold and immunogold silver staining method for rapid identification of *Erwinia amylovora*.
Elisa is used for rapid identification of *Xanthomonas campestris* pv. *campestris* by Alvarez & Lou (1985).
Monoclonal antibodies have been developed to the phytoplasma causing aster yellows (Lin & Chen, 1985).

7. Bacteriocin typing: Bacteriocins are narrow range compounds produced by some bacteria that kill other bacteria. Some persons limit this name to high molecular weight compounds that are usually defective phage; others include low molecular weight-antibiotics produced by bacteria in this group. These definitions are controversial. However, bacteriocins, like antibiotics and bacteriophage, suffer from the weakness that genetic resistance may develop. Like antibiotic and bacteriophage testing, batteries of bacteriocins should be employed in typing to eliminate ambiguity.

8. Selective media. Although the design of selective media may have some bearing on the physiological and metabolic properties of bacteria used classically to describe bacterial species, they have no place in taxonomy. Some may argue that host range differences among bacteria are actually selective medium differences with the plant serving in this case as a selective medium. This argument is weakened since selective media do not respond to provide wound healing and defensive responses as do plants. Further, dead plants are colonized by a wide range of saprophytic organisms not usually able of colonizing living plants. Selective media do speed the isolation and identification of prokaryotes. Schaad, 1988, provides a comprehensive review of methods for several selective media; below I list some selective media or slective techniques for culture of phytopathogenic prokaryotes:

Agrobacterium spp. (Kado & Heskitt, 1970; Kado & Heskitt in Schaad, 1980 & 1987), *A. radiobacter*, (Schroth *et al.*, 1965) *A. tumefaciens* (New & Kerr, 1971; Schroth *et al.*, 1965), *Clavibacter michiganense* pv. nebraskense (Gross & Vidaver, 1979), Coryneform bacteria (Kado & Heskitt, 1970), non-pectolytic *Erwinia* spp.including *Pantoea stewartii*

(Kado & Heskitt, 1970), pectolyic *Erwinia* spp. (Cupples & Kelman, 1974; Meneley & Stanghellini, 1976), *Erwinia amylovora* (Miller & Schroth, 1972), *Pseudomonas* spp. (Kado & Heskitt, 1970), fluoresent oxidase-positive pseudomonads (Sands, *et al.* 1972), fluorescent oxidase-negative pseudomonads (Sands in Schaad,1980 & 1987), *P. fluorescens* (Cuppels & Kelman, 1980), *P. marginalis* (Cuppels & Kelman, 1980), pectolytic, fluorescent, and oxidase positive pseudomonads (Cupples & Kelman, 1974), *P. putida* (Cuppels & Kelman, 1980), *Ralstonia solanacearum* (Nesmith & Jenkins, 1979; Chen & Echandi, 1982; Granada & Sequeira, 1983), *P. syringae* pv. morsprunnorum (Moustafa *et al.*, 1970), *P. s*. pv. papulans (Burr & Katz, 1982), *P. s*. pv. phaseolicola (Moustafa *et al.* 1970), *P. s.* pv. syringae (Moustafa *et al.* 1970; Burr & Katz, 1982), *P. s.* pv. tabaci (Moustafa et al. 1970), *P. s.* pv. tomato (Jones et al. 1981), *Spiroplasma citri* (Davis in Schaad, 1980), *Xanthomonas* spp. (Kado & Heskitt, 1970), *X. c.* pv. campestris (Schaad & White, 1974; Randhawa & Schaad, 1984), *X. c.* pv. juglandis (Mulrean & Schroth, 1980), *X. c.* pv. phaseoli (Claflin et al, 1987), *X. c.* pvs. phaseoli and fuscans (Trujillo & Saettler, 1980), *X. c.* pv. pruni (Civerolo, *et al.*, 198?), *X. c.* pv. vesicatoria (McGuire & Jones, 1986), *Xylella fastidiosa* (Hopkins in Schaad, 1980 & 1987).

9. Bacteriophage susceptibility: Bacteriophages are often very host specific and may be used to identify various strains of bacteria. However, successful bacteriophage infection may require only an appropriate attachment site. For bacteriophage _ the *Escherichia coli* maltose permease protein is such an attachment site. Placing the genes for this protein in a species of bacterium not susceptible to _ attachment changes that bacterium to a susceptible strain. Further, single gene mutation may eliminate susceptibility. For bacteriophage typing, a battery of phage are more useful than a single phage. Several researchers have isolated bacteriophages useful for identifying phytopathogenic prokaryotes:

Agrobacterium tumefaciens (J. Virol. 2:651, 1968), *Clavibacter michiganense* subsp. - michiganense (Phytopathology 63:1398, 1973), Erwinia amylovora (reviewed in Van Der Zwet & Keil, 1979), Erwinia chrysanthemi (J. Bacteriol. 143:1444, 1980), Ralstonia (Burkholderia or Pseudomonas) solanacearum (Rept. Fac. Agri. Shizuoka Univ., Japan, 5:57-62, 1955), Pseudomonas syringae pv. - glycinea (Thomas & Leary, 1983), P. s. pv. phaseolicola (J. Virol. 11:799, 1973), P. s. pv. tomato (Cuppels, 1983), Spiroplasma citri (J. Bacteriol. 115:367-386, 1973), Xanthomonas campestris pv. - phaseoli (J. Virol. 4:300-308, 1969), X. c. pv. pruni (J.Genl. Microbiol. 12:402-405, 1955)

10. Nucleic acid similarities: The ultimate differences in evolutionary grouping may be discovered by examining the genetic material. Genospecies ae groups of bacteria that exchange genetic material by some manner. Grouping bacteria into genospeices has not been useful because so little is understood about the methods of genetic exchange among most species of bacteria and bacteria possess promiscous genetic exchange mechanisms that allow virtually every group of Gram-negative bacteria studied to exchange genetic materia with any other Gram-negative bacterium either directly or indirectly.

a. G+C content: This is an expression of the relative percent of the nucleotide bases in the DNA that contain guanine plus cytosine. The weakness is that it does not indicate the order of the bases, e.g., the sequences of nucleotide bases ATGTCAATGC and GGGGATATAT both have 40% G+C ratios but have different sequences of bases. G+C ratios are not useful for phylogenetic separation of bacterial taxons due to the overlap of similar ratios.

b. Restriction endonuclease analyses: Restriction endonucleases are enzymes that cut DNA at specific locations. The most common enzymes recognize sequences of four (TaqI; 5'-T/CGA-3") or six (EcoRI; 5'-G/AATTC-3') nucleotide bases which would be randomly expected to cut DNA into 44 (256) or 46 (4096) basepairs (kb) fragments, respectively. Closely related organisms may have very similar size fragments generated by endonuclease digestion. The weaknesses of this system are that 1) usually too many fragments (732 to 350,000) often of overlapping or similar sizes are generated from a bacterial genome (contains 3x106 to 9x106 bp) to be useful for mapping and 2) endonuclease sites may not be in highly conserved portions of the genome and thus may mutate and change fragment sizes at different rates. Using "rare-cutting" endonucleases that recognize larger DNA motifs is a strategy that usually works for bacterial genomes (e.g., Escherichia coli genome is 4.2 x 106 bp). An endonuclease such as

NotI (5'-GC/GGCCGC-3') will cleave DNA about every 65,536 bp. On the average, it will cleave a bacterial genome about 260 times. Restriction endonuclease profiles have not been very useful in phylogenetic separation of bacterial taxons unless combined with another type of analyses such as RFLPs (see below).

c. Restriction fragement length polymorphisms (RFLPs): Mutations interruptin or creating restriction endonuclease binding sites in DNA will alter the length of digestion fragments. Selective use of gene probes and DNA:DNA hybridizationof electrophoresed restriction fragments will detect such changes. RFLP analyses are especially useful for detecting intra-specific differences..

d. DNA Similarity: DNA-DNA hybridization. Provides a measure of genetic "likeness" by reassociation of labeled single-stranded (ss) DNA from a type strain and ssDNA from an unknown isolate. Unless precautions are taken, mismatching may make results difficult to interpret. One solution is to remove ssDNA with S1 nuclease (Fig. 1).

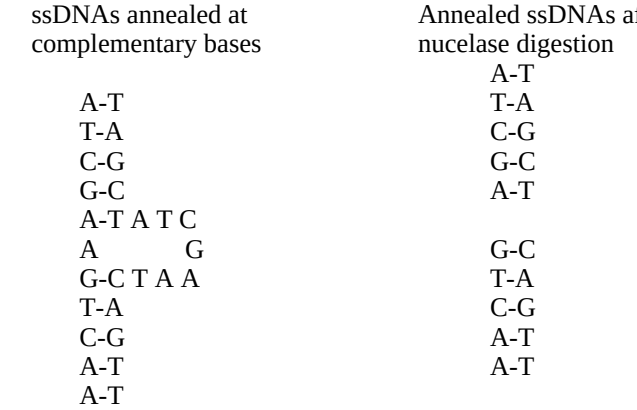

Figure 1. S1 nuclease disgestion removes single-stranded DNA (ssDNA). Complete digestion removes even single unmatched bases.

DNA similarity values of 20% or more indicate a high degree of relatedness. Valuses greater than 70% are accepted as intra-species level of relatedness. DNA similarity is the standard for establishing bacterial species. Recent DNA similarity studies of xanthomonads (Lacy and Stromberg, unpublished) are controversial becasue they contradict the concept of Begian scientists (Swings and Vauterin, 1995) that the Xanthomonas axonopodis contains over 37 pathovars of xanthomonads. the problem is directly related to the use of S1 nuclease by the American group and the lack of use of the enzyme by the second group. The American assays were performed with 125I or 33P labeled probe DNA making up only one part in 1000 parts of the target DNA. The Belgians use equal parts unlabeled, measure reassociation by a reduction in A260nm absorbance. The high back ground caused by using as much target as probe DNA and the failure to remove non-complemented bases reduced their ability to discriminate between high levels of DNA similarities.

g. Polymerase chain reaction methods. Sequencing. Because of the difficulty in sequencing entire genomes, molecular bacterial taxonomists prefer to use 16s ribosomal RNA sequences for measuring evolutionary distance among strains because they are highly conserved. Sequencing the whole ribosome is very tedious. Using oligonucleotide primers to highly conserved portions of the genes for 16S ribosomal RNA it is possible to amplify and sequence the gene without tedious cloning and subcloining. Kits are now available.

RAPD. Randomly amplified polymorphic DNA methods use 10-mers (oligonucleotides with 10 random bp). These should occur naturally about every 1,048,576 bp in bacterial genomes (e.g., about 4 times in an E. coli genome). Polymerase chain reaction (PCR) amplification between closely bound primers will amplify the DNA between them. Electrophoresis of the PCR products will give a particular pattern. By testing a number of these random primers, one may choose several that will give characteristic patterns with strains of bacteria within a species. This metho is used by Dr. Charles

Hagedorn, (CSES), housed in PPWS, to discriminate among human, wildfowl, cattle, and deer strains of E. coli isolated in wateersheds.

Rep-PCR. In contrast to the random primers of the RAPD methods, Rep-PCR primers are naturally occurring. They are designed to be similar to REP, ERIC and BOX DNA motifs that are found in both prokaryotic and eukaryotic DNA. The sixe of these DNA motifs (17- to 20- mers) indicates that they should be very rare; for a 17-mer occurring only about once every 6.6 x 1010 bp. In other words, on a random basis, we would not expect to find these sequences occurring in either a human (Homo sapiens; 3.3 X 109 bp) or a plant (Zea mays: 5.4 x 109 bp). Actually bacteria seem to ahave 50 to 75 of each of these motifs. What the purpose of the motifs in DNA structure is we don't understand. That they are important is clear from their frequency. However, we can amplify the DNA between these sites and obtain profiles that are extremely useful for discriminating between strains of bacteria. In a collaboration between VPI&SU (Lacy and Stromberg) and North Carolina State University (Frank Louws) we have used Rep-PCR to confirm 21 xanthomonads taxons described by DNA similarity studies.

f. Nucleotide sequencing: Determination of the sequence of each nucleotide base in a bacterial chromosomes is the ultimate method for detecting differences or similarities among bacteria strains and isolates. Sequencing is very time consuming and expensive. For instance the genome of Haemophilus influenzae, a human pathogen has been completly sequenced, but the effort was not trivial and required a huge team (see the authorship on the reference) (Fleischmann et al., 1995). Sequencing of relatively small sections of highly conserved DNA sequences such as the 16S RNA genes of bacteria is more reasonable than sequencing whole genomes. 16S RNA gene sequences have been used effectively for estimating the longterm evolution of bacteria (Olsen et al., 1994). However, nucleotide sequencing is not useful for identifying differences among strains or pathovars within a species.

g. Dimensional models of DNA homology. Evolution of bacterial DNA differences is not linear. Coevolution with hosts, geographic isolation, selective pressures, and recombination among bacteria cause variations. Hildebrand et al. (1982) presented two and three dimensional models for homology relationships among phytopathogenic pseudomonad pathovars. Although systematic bacteriologists have refused to accept species based on host ranges, significant homology differences exist among the pathovars to allow discrimination.

VI. GENERA OF PHYTOPATHOGENIC PROKARYOTES. Pantoea
ENTEROBACTERIACEAE Rahn 1937.

Erwinia spp. includes non-pectolytic species such as Erwinia amylovora and pectolytic species such as Erwinia carotovora. Some argue that the pectolytic erwinias belong in the genus Pectobacterium.

Pantoea spp. Recently, some yellow, non-pectolytic erwinias have been reclassified into this genus they include Pantoea (Erwinia) stewartii and Pantoea (Erwinia) herbicola.

PSEUDOMONADACEAE Windslow, Broadhurst, Buchanan, Krumwiede, Rogers, & Smith 1917. Gram reaction negative rods.

Acidovorax Willems, Falsen, Pot, Jantzen, Hoste, Vandamme, Gillis, Kersters, & De Ley, 1990. Straight to slightly curved rods, 0.2 to 0.7 by 1.0 to 5.0 (motile by a polar flagellum, oxidase positive, and %G+C = 62 to 66. Acidovorax avenae subsp. citrulli causes bacterial fruit blotch of watermelon (Citrullis lanatus; Latin & Hopkins, 1995).

Pseudomonas Migula, 1894. Straight or slightly curved rods, 0.5 to 1.0 by 1.5 to 5.0 (m, motile by one or more polar flagella, strictly aerobic, and %G+C = 58 to 70. Many plant pathogens produce water soluble pyoverdine pigments that fluroesce with long-wave ultraviolet light blue to greenish-yellow. Phytopathogenic species, often divided into pathovars or biotypes, usually cause soft rots and leaf spots. Pseudomonas marginalis is an example of the soft-rotting pathogens. Pseudomonas syringae, which is subdivided into many pathovars depending upon the genus or species of plants diseased, is an example of the leaf-spotting pathogens.

Rhizobacter Goto & Kuwata, 1988. Straight or slightly curved rods, 0.9 to 1.3 by 2.1 to 2.5 (m, motile by polar or lateral flagella or non-motile, and %G+C = 66 to 71. Rhizobacter daucus is the only recognized species and causes carrot (Daucus carota) bacterial gall (Goto & Kuwata, 1988).

Xanthomonas Dowson, 1919. Straight rods, 0.4 to 0.7 by 0.7 to 1.8 (m, motile by one polar flagellum, strictly aerobic, %G+C = 63 to71, do not use asparagine as a carbon or a nitrogen source. Colonies are

usually yellow due to the production of carotene-like xanthomonadin pigments. Almost all xanthomonads are plant pathogens usually causing leaf spots. Xanthomonas campestris is subdivided into over 140 pathathovars usually by their ability to cause disease on specific families, genera, or species of plants.

Xylophilus Willems, Gillis, Kersters, Van Den Broecke, & De Ley, 1987. Straight or slightly curved rods, 0.4 to 0.8 by 0.6 to 3.3 (m, motile by one polar flagellum, obligate aerobes, oxidase negative, and %G+C = 68 to69. Xylophilus ampelinus, causal agent of bacterial necrosis and canker of grapes (Vitis labrusca), is the only species recognized.

IREGULAR, NON-SPORE BEARING GRAM-POSITIVE RODS.

Arthrobacter spp. Arthrobacter ilicis is the causal agent of bacterial blight of American holly (*Ilex opaca*).

Clavibacter spp. include important pathogens of such as *Clavibacter michiganensis* and its subspecies *michiganensis* (tomato [*Lycopersicon esculentum*] canker) and sepedonicus (ring rot of potato [S*olanum tuberosum*]), and *nebraskensis* (Goss's bacterial wilt of maize [*Zea mays*]).

Curtobacterium spp. *Curtobacterium flaccumfaciens* pv. poinsettiae causes poinsettia (*Euphorbia heterophylla*) canker.

NOCARDIOFORMS

Rhodococcus fascians is the causal agent of fasciation of sweet pea (*Lathyrus odoratus*), geranium (*Pelargonium hortorum*), and several other hosts including Shasta daisy (*Leucanthemum maximum*).

STREPTOMYCETES

Streptomyces scabies and *S. acidiscabies* cause scab of potato.

UNDEFINED AFFILLIATION

Xylella fastidiosa is a leaf-hopper vectored, xylem-limited bacterium that affects many plants causing scorches of almond (*Prunus dulcis*), elm (*Ulmus americana*), oak (*Quercus* spp.), and citrus (*Citrus* spp.) leaf blight. These bacteria have Gram-negative type cell walls.

Phytoplasma spp. are polymorphic cell-wall less mollicutes that are phloem-limited, fastidious and usually vectored by leafhoppers. These organisms are affiliated with Gram-positive bacteria.

OTHER BACTERIA

Acetobacter spp. and *Gluconobacter* spp. are cause, respectively, pink disease of pineapple (*Ananas comosus*) and browning and rot of apple (*Malus sylvestris*) and pear (*Pyrus communis*) fruits.

Bradyrhizobium japonicum is a nitrogen-fixing bacterium symbiotic on soybean (*Glycine max*) that under high nitrogen conditions may produce the phytotoxin toxin rhizobitoxin.

Serratia marcesens usually understood to be a pathogen of insects has occasionally been reported as a pathogen of alfalfa (*Medicago sativa*) causing crown rot.

Enterobacter cloaceae causes brown discoloration of papaya (*Carica papaya*) fruits.

Liberobacter spp. include the fastidious phloem-limited citrus (*Citrus* spp.) greening pathogen.

SPORE-FORMING RODS

Bacillus spp. are obligate aerobes which may cause rots of tobacco (*Nicotiana tabacum*) leaves, tomato (*Lycopersicon esculentum*) seedlings, soybean (*Glycine max*), and white stripe of wheat (*Triticum aestivum*; *Bacillus megaterium* pv. *cerealis*).

Clostridium spp. are obligate anaerobes which may cause plant disease. Pink, pectolytic clostridia have been associated with wetwood of poplar (*Populus* spp.) and elm (*Ulmus* spp.) and soft rot of potato (*Solanum tuberosum*).

VII. RAPID IDENTIFICATION OF PHYTOPATHOGENIC PROKARYOTES. Rapid identification of prokaryotes for disease control and epidemiological purposes is different from taxomonic studies. Speed is the goal rather than precision. The plant disease clinician identifies the pathogen only to the level required to achieve successful control. If the species or species identity is not important to the control of a particular disease situation, the clinician need not attempt additional analyses. Some plant pathologists confuse taxonomic identification for supplying disease conrol information. Among the

systems we discussed above BIOLOG, FAME, and Rep-PCR seem to have the greatest potential for rapid identification. A new guide for the identification of phytopathogenic prokaryotes should be out by next year (Schaad et al., 2000a).

VIII. WHY TAXONOMY CHANGES. A list of all names of plant pathogenic bacteria which have been validly published (in a peer-reiview scientific journal for comments from the scientific community) from 1864 to 1995 is available (Young et al., 1996). Obviously, as technological advancement occurs the phylogenetic concepts of relationships among phytopathogenic prokaryotes has changedÑresulting in changes in the taxonomic nomenclature. Major changes in the nomenclature for phytopathoenic prokaryotes began in 1973, when the Judicial Commission of the International Committee on Systematic Bacteriology (ICSB) appointed an *Ad Hoc* committee to prepare a list of currently valid names of bacteria that were adequately described. This list of names was compiled and published in 1980 (Dye et al., 1980) by members of The Bacteriology Taxonomy Committee of The International Society of Plant Pathology and included in the "Approved Lists of Bacterial Names" (Skerman et al., 1980).

Pathovars are artificial taxons. Because few plant pathogenic species of bacteria could be differentiated by classical techniques and biochemical tests when the Approved List of Bacterial Names was published, most species were lumped together under an infrasubspecific subdivision as pathovars (a temporary name with no taxonomic rank and no nomenclatural standing) under a very few species (Dye et al., 1980). This was done as a compromise according to the International Code of Nomenclature in order to preserve the name of economically important plant pathogens (Young et al., 1978a&b). The organisms were to be automatically elevated to their original proper species rank once appropriate phenotypic and genetic data were obtained and validly published. Previously most species of plant pathogenic bacteria were named on the basis of the host of origin and in many cases included very little genetic and phenotypic data. Designations of infrasubspecific names are not covered by the Rules of the Code of Nomenclature (Lapage et al., 1975; Sneath 1992).

1976 Taxonomy for xanthomonads. Prior to 1976, fluorescent pseudomonads causing lesions on leaves and xanthomonads constituted the largest groups of named species of phytopathogenic. Consequently, these groups were most affected by the use of pathovars prokaryotes (over 120 species of xanthomonads and almost 100 species of pseudomonads). Of the fluorescent group of plant pathogenic pseudomonads, only *Pseudomonas aeruginosa, P. agaricae, P. asplenii, P. cichorii, P.* (*Burkholderia*) *glumae, P. marginalis, P. tolaasii, P. viridiflava, P. woodsii,* and *P. syringae* were retained (Dye et al., 1980; Skerman et al., 1980). Over 90% of all plant pathogenic *Pseudomonas* species were grouped as pathovars into *P. syringae*. The only species of *Xanthomonas* included on the 1980 list were *X. albilineans*, *X. ampelina* (since reclassified as *Xylophilus ampelinis*, [Willems et al., 1987]), *X. axonopodis*, *X. campestris*, and *X. fragariae* (Dye et al., 1980; Skerman et al., 1980). Again, over 90% of xanthomonads were grouped as pathovars with the type species *X. campestris* (**Table 3**; left column).

Although considerable data have accumulated on numerical analyses (Van der Mooter & Swings, 1990; Vera Cruz et al., 1984), serology (Bouzer et al., 1994; Ovod et al., 1997; Thaveechai & Schaad, 1986), membrane protein profiles (Thaveechai & Schaad, 1986; Vauterin et al. 1991 & 1993), and DNA analyses (Berthier et al., 1993; Gardan et al., 1992, 1997, & 1999; Hartung & Civerolo, 1989; Hildebrandt et al., 1990; Lapage et al., 1975; Palleroni et al., 1993) of *Xanthomonas* and *Pseudomonas* spp. since 1980, there have been few pathovars that have been elevated to the rank of species. However, recent proposals to place several pseudomonads into new genera and elevate several pathovars of *Pseudomonas* and *Xanthomonas* to species rank and to rename several of them have been published (Gardan et al., 1992 & 1999; and Vauterin et al., 1993 & 1995).

1995 Proposal for xanthomonad taxonomy. Vauterin et al. (1995) proposed a major reclassification scheme based on DNA similarity groups (**Table 3**; middle column). We acknowledge and salute the effort of these researchers to provide the large amounts of excellent data on which they based their

proposal for firing the the opening the controversial proposing the elevation of several pathovars to the rank of species. The strength of these proposals is that they include DNA similarity data on over 180 xanthomonad strains with almost 800 pairwise comparisons. However, it is not clear from these reports which of the DNA similarity data is new and which is a compilation of DNA similarity assays using different techniques from the literature or reciprocal tests were included. These researchers depended chiefly on spectrophotometric methods for studying DNA relatedness. Their results are generally in agreement with results (Hildebrand et al., 1990) showing that the type species, *X. campestris* pv. *campestris* has, DNA similarity values of only 26% or less with over 20 named pathovars including *vesicatoria, phaseoli, glycines, vignicola, poinsetticola, begoniae, manihotis, oryzicola, juglandis, carotae,* and *pelargonii*.

2000 Proposal for xanthomonad taxonomy. DNA similarity assays, however, they are performed allow general comparisons. However, spectrophotometric methods have high backgrounds because the probe and target DNAs are used in equal proportions allowing upto 25% self re-hybridization for each DNA source. Therefore small differences in hybridization levels between the probe and target are difficult to observe. To overcome these technical problems and to increase the number of comparisons, VPI&SU (J.L. Johnson [Anaerobic Microbiol/Biochem] and V.K. Stromberg and G.H. Lacy [PPWS]) and American Type Culture Collection (ATCC; R.L. Gherna) investigators performed over 2,000 pairwise tests using DNAs representing 122 strains from 87 species or pathovars of xanthomonads (Lacy et al., 1997a&b, 1998). They used radioisotope (^{125}I or ^{33}P) labeled probe DNA mixed with 1000-fold excess target DNA to eliminate the problem of self re-hybridization. Following hybrization, remaining single-stranded DNA (ssDNA) was removed using S1 nuclease digestion from the double-stranded DNA (dsDNA) molecules resulting from hybridization of target and probe DNA. Finally, purified dsDNA is precipitated on glass filters, washed free of nucleotides released by enzymatic digestion, dried, and the dispersions per minute from the remaining radioisotope counted, and, compared with controls, % DNA similarity is calculated. The taxonomy reflecting the DNA similarities is shown in **Table 3** (right column).

Table 3. Past, current, and proposed taxonomies for xanthomonads.

PAST 1976 Taxonomy (Dye et al., 1980; Hayward 1993; Sneath et al., 1980)	CURRENT PROPOSAL 1995 Taxonomy (Vauterin et al., 1995)	ALTERNATIVE PROPOSAL Accepted by the Bacteriological Committee, American Phytopathological Society (Schaad et al., 2000b)
	Xanthomonas maltophilia (previously *Pseudomonas maltophilia*)	*Stenotrophomonas maltophilia*
Xanthomonas albilineans	*Xanthomonas albilineans*	*Xanthomonas albilineans*
		Xanthomonas arrhenatheri pvs. arrhenatheri, graminis B, phlei, poae
Xanthomonas axonopodis	*Xanthomonas axonopodis* pvs. axonopodis, vasculorum A,	Rejected: See *X. vasculorum* pvs.
	aurantifolia, dieffenbachiae, phaseoli-fuscans, vignicola,	Rejected: See *X. diffenbachiae* pvs.
	malvacearum, cajani, citri, glycines, vitians A	Rejected: See *X. malvacearum* pvs.
	cassiae, citrumelo, corocanae, cyamopsidis, desmodii, demodiigangetici, erythrinae, lespedezae, poinsetticola A, ricini, tamarindi, vesicatoria A	Rejected: See *X. pruni* pvs.
	phaseoli	Rejected: See *X. phaseoli* pvs. phaseoli, manihotis,
	begoniae	Rejected: See *X. begoniae*
	bauhiniae, clitoriae, desmodi-ilaxifolorii, desmodiirotundi-folii, patelii, rhynchosiae, sesba-niaevasculorum A, vignaeradiatae	Rejected: See *X. phyllovora* pvs.
		Xanthomonas badrii
	Xanthomonas bromi	Rejected: See *X. phyllovora* pvs.

Table 3. Continued.

PAST	CURRENT	ALTERNATE
Xanthomonas campestris pvs. aberrans, alfalfae, amaranthicola, amorphophalli, aracearum, arecae, argemones, armoracieae, arracaciae, arrhenatheri, azadirachtae, badrii, barbareae, bauhiniae, begoniae, betae, beticola, bilvae, biophyti, blephardis, boerhaaviae, brunneivaginae, cajani, campestris, cannabis, cannae, carissae, carotae, cassavae, cassiae, celebensis, centellae, cerealis, citri, cleodendri, clitoriae, convolvuli, corocanae, coriandri, corylina, cucurbitae, cyamopsidis, daturae, desmodii, demodiigangetici, desmodiilaxifolorii, desmodiirotundifolii, dieffenbachiae, durantae, erythrinae, esculenti, eucalypti, euphorbiae, fasicularis, fici, glycines, graminis, guizotiae, gummisudans, hedare, heliotropii, holcicola, hordei, hyacinthi, incanae, ionidii, juglandis, khayae, lantanae, laureliae, lawsoniae, leeana, leersiae, lespedezae, maculofoliigardeniae, malvacearum, mangiferaeindicae, manihotis, martyniicola, melhusi, melonis, merriemiae, mirabilis, musacearum, nakataecorchori, nigromaculans, olitorii, papavericola, passiflorae, patelii, paulliniae, pedalii, pelargonii, pennamericanum, phaseoli, phaseoli-fuscans, phlei, pheipratensis, phormiicola, phylanthi, physalidicola, physalidis, pisi, plantaginis, poae, poinsetticola, populi, pruni, punicae, raphani, rhynchosiae, ricini, secalis, sesbaniae, spermacoces, syngonii, tamarindi, taraxaci, tardicrescens, theicola, thespesiae, thirumalacharii, translucens, tribuli, trichodesmae, undulosa, uppalii, vasculorum, veroniae, vesicatoria, vignaeradiatae, vignicola, vitians, viticola, vitiscarnosae, vitistrifoliae, vitiswoodrowii, zantedeschiae, zingibericola, zinnae	*Xanthomonas campestris* pvs. aberrans, amoraciae, barbarae, campestris, incanae, raphani	*Xanthomonas campestris pvs.* campestris, incanae, papervicola, plantaginis, raphani, vasculorum B

Table 3. Continued.

PAST	CURRENT	ALTERNATE
	Xanthomonas cassavae	*Xanthomonas cassavae*
		Xanthomonas carotae
		Xanthomonas celebensis
	*Xanthomonas codiacei (*pv. *poinsetticola C)*	Rejected: See *X. phyllovora* pvs.
	Xanthomonas cucurbitae	*Xanthomonas cucurbitae*
		Xanthomonas dieffenbachiae pvs. diffenbachiae, aurantifolia, phaseoli-fuscans, vignicola
		Xanthomonas eucalypti
	Xanthomonas vesicatoria (pv. vesicatoria B [excitosa])	*Xanthomonas excitosa*
Xanthomonas fragariae	*Xanthomonas fragariae*	*Xanthomonas fragariae*
		Xanthomonas graminis pv. graminis A
	Xanthomonas holcicola	*Xanthomonas holcicola* pvs. holcicola, musacearum
	Xanthomonas hyacinthi	*Xanthomonas hyacinthi*
Xanthomonas populi	*Xanthomonas arboricola* pvs. corylina, juglandis, pruni poinsetticola C, populi	*Xanthomonas juglandis* pv. juglandis, corylina, pruni B, spermacoces Rejected: See *X. phyllovora* pvs.
		Xanthomonas malvacearum pvs. malvacearum, cajani, carissae, citri, glycines, lawsoniae, mangiferaeindicae, melhusi, thirumalacharii, vitians A
	Xanthomonas melonis	Rejected: See *X. phyllovora* pvs.
		Xanthomonas nigromaculans pvs. nigromaculans, gardneri, taraxaci
	Xanthomonas oryzae pvs. oryzae, oryzicola	*Xanthomonas oryzae* pvs. oryzae, oryzicola

Table 3. Continued.

PAST	CURRENT	PROPOSED
	Xanthomonas hortorum pvs. pelargonii, hederae, vitians B	*Xanthomonas pelargonii*
		Xanthomonas phaseoli pvs. phaseoli, hederae, manihotis
	Pathovars not studied: alfalfae, amaranthicola, amorphophalli, araceae-rum, arecae, argemones, arracaciae, azadirachtae, badrii, betae, beticola, bilvae, biophyti, blephardis, boerhaaviae, brunneivaginae, cannabis, cannae, carissae, carotae, cassavae, celebensis, centellae, clerodendri, convolvuli, coriandri, daturae, durantae, esculenti, eucalypti, euphorbiae, fasicularis, fici, guizotiae, gummisudans, heliotropii, ionidii, khayae, lantanae, laureliae, lawsoniae, leeana, leersiae, maculofoliigardeniae, mangiferaeindicae, martyniicola, melhusi, merriemiae, mirabilis, musacearum, nakataecorchori, nigromaculans, olitorii, papavericola, passiflorae, paulliniae, pedalii, pennamericanum, phormicola, phylanthi, physalidicola, physalidis, plantaginis, punicae, spermacoces, syngonii, taraxaci, tardicrescens, thespesiae, thirumalacharii, tribuli, trichodesmae, uppalii, vernoniae, viticola, vitiscarnosae, vitistrifoliae, vitiswoodrowii, zantedeschiae, zingibericola, zinnae	*Xanthomonas phyllovora* pvs. aberrans, amorphophalli, aracearum, arecae, argemones, armoracieae, arracaciae, azadirachtae, barbareae, bauhiniae, betae, bilvae, biophyti, boerhaaviae, bromi, brunneivaginae, cannabis, cannae, cassavae, centellae, cerealis, clitoriae, convolvuli, daturae, desmodiilaxifolorii, desmodiirotundifolii, durantae, esculenti, euphorbiae, fasicularis, fici, guizotiae, gummisudans, heliotropii, hordei, khayae, lantanae, laureliae, leeana, leersiae, martyniicola, melonis, merriemiae, mirabilis, olitorii, passiflorae, patelii, paulliniae, pedalii, phleipratensis, phormiicola, phylanthi, poinsetticola C, populi, punicae, rhynchosiae, sesbaniae, syngonii, tardicrescens, theicola, thespesiae, tribuli, vignaeradiatae, vitians B, viticola, vitiscarnosae, vitistrifoliae, vitiswoodrowii, zantedeschiae, zingibericola, zinnae
	Xanthomonas pisi	*Xanthomonas pisi*

onas translucens pvs. secalis, translucens, undulosa graminis arrhenatheri, phlei, poae cerealis, hordei, phleipratensis		*Xanthomonas translucens* pv. translucens, secalis, undulosa Rejected: See *X. graminis* pv. graminis A Rejected: See *X. arrhenatheri* pvs. Rejected: See *X. phyllovora* pvs.
		Xanthomonas vasculorum pvs. vasculorum A, axonopodis
Xanthomonas ampelina	*Xylophilus ampelinis*	*Xylophilus ampelinis*

Xanthomonad type species. Previously, a problem existed regarding the precedence of the epithet *X. campestris* pv. *campestris* (type species for the genus *Xanthomonas*) based on the fact that it was described and published in 1895 whereas *X. campestris* pv. *vasculorum* was described two years earlier. According to Rule 24b, consolidated species epithets should be derived from the earliest published epithet by Rule 24b of the International Code of Nomenclature (Dye et al., 1990; Lapage et al., 1975; Sneath 1992). Fortunately, Vauterin et al. (1993 & 1995) pointed out that DNA similarity assays indicated that type ÒAÓ and ÒBÓ forms of pv. *vasculorum* are more related, respectively, to pv. *axonopodis* and pv. *campestris* than each other. Unpublished data of G. H. Lacy confirm these multiple DNA similarity groups among strains of pv. *vasculorum* and support species-level relatedness between the type strain of *X. campestris* pv. *vasculorum* (ATCC 35938) and pv. *axonopodis* which are similar to pv. *vasculorum* type ÒAÓ strains studied by Vauterin et al. (1993 & 1995). This suggests that the pv. vasculorum type ÒBÓ strains are mis-named, probably because of similar host reactions, making moot any arguments for the precedence of *X. vasculorum* as the species epithet replacing *X. campestris*.

One diseaseÑone pathogen concept. Pathologist in using host range as the measure for describing species of plant pathogens have made their share of mistakes. For instance, it is obvious that similar lesions on a single host species have been considered to be caused by a single pathogen. For instance, lesions on tomato (*Lycopersicon esculentum*) from which xanthomonads have been isolated are assumed to be caused by *Xanthomonas campestris* pv. vesicatoria. From the careful work of J.B. Jones (Univ. Fla. and a VPI&SU graduate) has shown that strains identified as *X. campestris* pv. vesicatoria actually represented three different species of xanthomonads. Two of these species have been mistakenly classified together as *X, campestris* pv. vesicatoriaÑtype ÒAÓ and ÒBÓ strains. The third species is now recognized as *Xanthomonas campestris* pv. gardneri orignially described in Europe. The taxonomic question is which ÒvesicatoriaÓ strains, ÒAÓ or ÒBÓ, should retain that epithet. The type strain (ATCC 35937) represents the type ÒAÓ group and should retain the epithet ÒvesicatoriaÓ. DNA similarity data (J.B. Jones, unpublished, and confirmed by G.H. Lacy, also unpublished) confirm that the type "A" group strains have less than 20% similarity with the type ÒBÓ group of strains. Both ÒAÓ and ÒBÓ have less than 10% with *X. campestris* pv. gardneri. Fortunately, type ÒBÓ strains were originally described as *Phytomonas excitosa* and that epithet should be a strong candidate for the new species epithet (Gardner & Kendrick, 1921).

Re-instatement of species from pathovars. To avoid unnecessary changing of names and resulting confusion, all original species epithets of xanthomonads, which were disallowed from the list of accepted bacterial names (Skerman et al., 1980), have been retained as pathovars of *X. campestris* (Dye et al., 1980) to be re-used when adequate data are available to elevate a particular pathovar to species or subspecies rank (Young et al., 1978a&b). When a group of pathovars is grouped together in

a re-elevated taxon at the species level, the species name should be first validly published (oldest recognized pathovar) included in the 1980 list of names according to Rule 24b (Lapage et al., 1975; Sneath 1992). Unfortunately Vauterin et al. (1995) proposed *de novo* species epithets to encompass groups of established pathovars including: *Xanthomonas arboricola, X. codiaei, X. hortorum*, and *X. vasicola*. We believe this to be a premature decision causing confusion in plant pathological literature. For instance, names of plant pathogens are extremely important to national and international trade, scientists and others who ship cultures, and even funding agencies and organizations. The recent use of the proposed names *X. axonopodis* pv. *phaseoli* (for *X. campestris* pv. *phaseoli* or *X. phaseoli*) in some journal papers and in kits developed by some plant disease diagnostic companies, (*Viz.* Genes kits distributed by AES Laboratories, Combourg, France), illustrates the type of confusion this problem is causing in use and in recognition of pathogen names. Further, creation of new names for long standing pathogens of great economic importance will cause considerable uncertainty among government regulatory officials, seed companies, and scientists.

For example, Vauterin et al. (1995) proposed *ÒX. aboricolaÓ* for re-grouping pathovars *corylina, juglandis*, and some strains of pv. *pruni* (described in 1940, 1901, and 1903, respectively). Because this name is not derived from the earliest legitimate pathovar epithet and the usage of the pathovar it should be rejected (Rule 24a of the Code, [25]) because it was not derived from the earliest legitimate epithet. By DNA similarity analyses, confirmed by G.H. Lacy (unpublished), these pathovars do represent a species-level taxon. Because it was the first of the three epithets validly described, the name *X. juglandis* should be reinstated including as subspecies the pathovars juglandis, corylina, and pruni (**Table 1**; compare middle and right columns). Similar arguments could be advanced by pathologists to reject the epithets *X. codiaei, X. hortorum*, and *X. vasicola*.

Xanthomonads of uncertain classification. Confusion on a large scale may potentially be caused by renaming xanthomonads to more accurately approximate their phylogenetic relationships. This confusion results when some xanthomonads are renamed on the basis of new information while others are left behind in their current classifications, usually as pathovars of *X. campestris,* due to insufficient information. The result is that pathovars of *X. campestris*, rather than reflecting actual phylogenetic relationships also include xanthomonads placed in that group only because of lack of information. One suggestion is to correct this problem for pathologists by creating an artificial neutral taxon as a repository for all pathovars which are inadequately described. This taxon should be reserved for present and future xanthomonads whose descriptions are inadequate for further classification but cause important plant diseases. Possibly a name such as Ò*Xanthomonas phyllovora*Ó, carrying no indication of host specificity, may be useful for this ÒtemporaryÓ file (proposed by Klaus Rudolph, a noted German phytobacteriologist; Schaad et al., 2000b). An artificial taxon may be useful for several to many years, until enough information has been gathered that all the present pathovars of *X. campestris* are moved into phylogenetically acceptable taxons. Such epithets may also have long-term usefulness for newly discovered xanthomonads which have not yet been described adequately for more precise identification. While the former suggestion is interesting, we seek comment from other pathologists on the concept. If acceptable, a brief description of *X. phyllovora* could be published in the International Journal of Systemic Bacteriology.

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ANATOMY AND CYTOCHEMISTRY

I. GENERAL CHARACTERS. General characteristics of bacteria (plural; singular = bacterium):

Physical characters:	Dimensions: Size 1 X 3 _ m	Dry matter: 2.5 X 10^{-13}g
	Volume: 10^{-12} cm^3	Refractive index: 1.4-1.55
Composition (%):	Phases: Water=70, Solids (dry wt)=30	
	Macromolecules: Protein=70, RNA=12, Lipids=6, Phospholipids=4, Polysaccharaides=5, DNA=3 ($3x10^6$kb)	
Elemental composition:	Ash:=13% dry wt):	
	Major elements: C=50%, N=8-15%, P=2-6%	
	Minor elements: Na=1.5%, K=1.4%, Ca=1.4%, S=1.0%, Cl=0.5%, Mg=0.5%, Fe=0.2%	
	Trace elements (_ 0.01%): Co, Zn, Mn, Mo	

II. SURFACE ANATOMY

A. Flagella (Flagellum = singular). Most flagellar studies have been conducted with *Escherichia coli*, a peritichously (**Table 1**) flagellated bacterium. Certain cell wall division mutants of these bacteria are extremely long. Attachment of flagella by anti-flagellar antibodies to solid substrates allow the bacterium to rotate around flagella fixed to the substrate. Therefore, the direction of rotation of these bacteria may be examined. Among phytopathogenic bacterial groups erwinias have peritrichous flagella, xanthomonads and pseudomonads have or polar flagella.

1. Arrangement of flagella on bacterial cells:

Table 1. Flagellar arrangements among bacteria.

atrichous	no flagella
monotrichous	one flagellum
multitrichous	several flagella in clumps with separate basal bodies
lophotrichous	several single flagella arising from separate basal bodies
pertrichous	flagella all around

2. Rate of travel: Flagella propell bacteria at speeds approaching 50_ m/sec

3. Size: Flagella are extremely narrow structures 12-30nm wide X 3.7_ m long.

4. Flagellin protein subunits arranged in a right handed-helical manner. However, in some paralyzed mutants the subunits may be arranged in a linear manner

5. Flagellar filaments are composed of flagellin and are hollow. Growth proceeds by flagellin being passed throught the hollow core to the tip of the flagellum (**Fig. 1**).

6. Flagellar hook attach flagella the flagellar motor assembly outside cell membranes (**Fig. 1**).

7. Flagellar basal bodies are actually mechanical components of the flagellar motor (for components see **Table 2** and **Fig. 1**)

Table 2. Comparison of the flagellar basal body components of Gram-negative and Gram-positive bacteria.

Component	Gram negative	Gram Positive	Position
Rod	+	_	Connects flagellar hook to rings
L-ring	+	-	Surface of outermembrane
P-ring	+	-	Peptidoglycan layer
S-ring	+	+	G-:Above cell membrane G+:Cell wall surface
M-ring	+	+	G- and G+: in cellmembrane (M is divided into inner switch protein and outer rotor protein)
MotB protein	+	?	Partially inserted in the periplasm and in the inner membrane around the M-ring-electromotive motor (Chun & Parkinson, 1988)

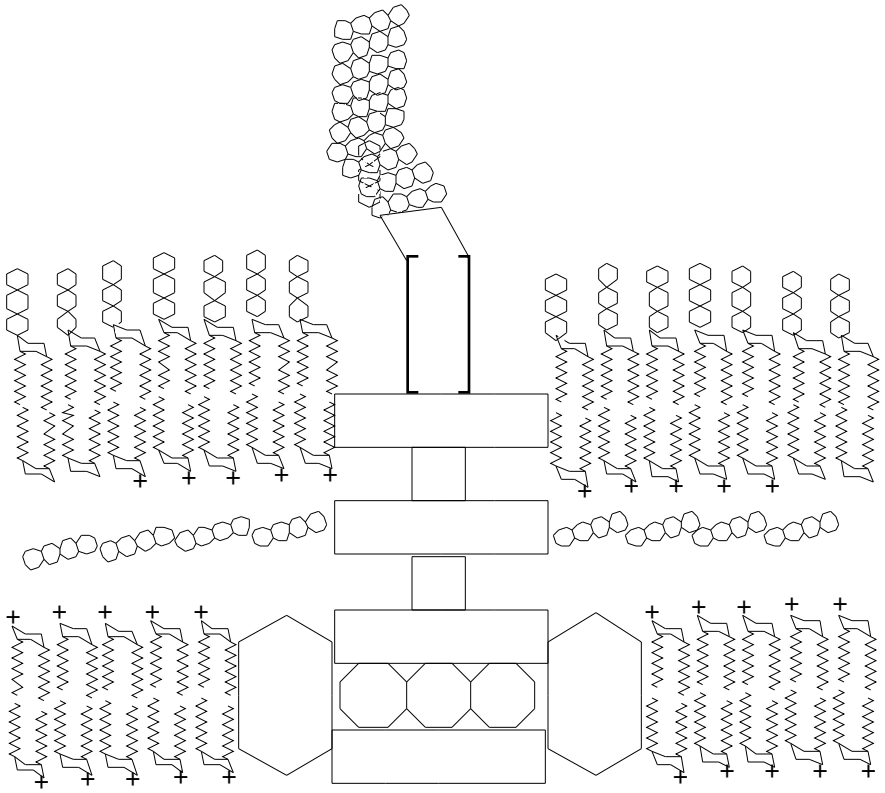


Figure 1. Cross section diagram of a flagellar basal body in a Gram-negative bacterium. Top to bottom. Exterior to the bacterial cell, flagellum made up of flagellin protein subunits (only part of the flagellum shown) attached to the flagellar protein hook. Protein L-ring in the lipopolysaccharide-containing lipid bilayer outer membrane. Protein rotor shaft protein connecting the L- and P-rings. Protein P ring in the peptidoglycan layer between the outer and inner membranes of the Gram-negative cell wall. Rotor proteins attach the P-ring to the switch rings. Paired protein switch rings (S-rings) sandwich internal Fli proteins which comprise the motor switch. Mot B proteins surround the S-rings and transfer electromotive circular force to the rotor. Switch and MotB proteins are buried in the inner lipid bilayer membranewhich surrounds the cytoplasm (bottom of the figure). From Madigan et al. (2000).

8. Rotational movement drives flagella by electromotive force (**Figure 2.** Akira, et al., 1983).
   a. Each flagellum is powered by a rotary motor at its base. This motor derives it power from the by the oxidation of NADH by:

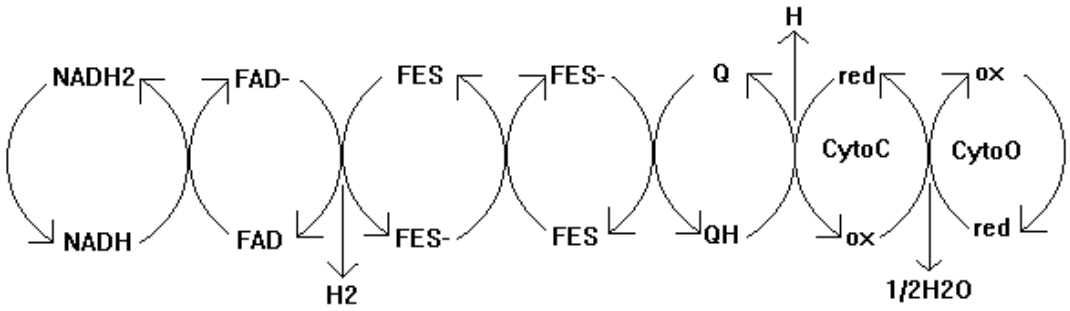


Figure 2. Electron movement produces energy for flagellar rotation. Left to rights. Cytoplasmic nicotinamide adenine dinucleotide ($NADH+H^+$) is oxidized to ($NAD^{+)}$ releasing two protons (H^+) and two electrons in the presence of a cytoplasmic membrane-embedded flavin adensoine dinucleotide (FAD)-associated dehydrogenase. This reaction is accompanied by the expulsion of two protons (H^+) to the extracellular environment and a pair of electrons (e^-) are transferred to FAD. Two e^-s are transferred via two iron-sulfur proteins (FeS) embedded in the cytoplasmic membrane to ubiquinone (Q) which is reduced to hydroquinone (QH^2) by the addition of two cytoplasmic-derived H^+'s. Two e^- and two H^+ are passed to cytoplasmic-embedded cytochrome C (CytoC) which releases two H^+ to the extracellular environment and reduces cytochrome oxidase (cytoO). Intracellularly, cytoO reduces molecular oxygen to water. For each molecule of NADH oxidized, four H^+ are translocated outside the cell. The electromotive force (or proton gradient) created by the imbalance of H^+'s leads to an influx of H+ via systems such as sugar transport (not shown) or ATPase complex (two H+ running into the cell can generate one ATP). 256 H^+ are required per revolution of a flagellum. (comparable to 64 NADH oxidations or the formation of 128 ATP molecules).

   b. Counterclock wise drive. When the flagellar motors turn **counterclockwise**, the filaments work together in a bundle that drives the cell steadily forward for about 1.1 sec.

   c. Clock wise tumble. When the motor runs **clockwise**, the bundles fall apart and the cell tumbles for about 0.14 sec. When movement is resumed, the cell will move in a random angle in relation to its prior direction.

   d. A global signal affects the bias for motor direction, but reversal of the motor to counterclockwise motion occurs spontaneously without indication of any signal.

   e. The time for the counterclockwise rotation of filaments is increased as the concentration of chemoattractants is increased and/or bound to specific receptors. Therefore bacterial cells tend to swim strongly until they reach a particular chemical gradient and then begin to tumble and move erratically. This allows the number of cells to increase in the vicinity of the attractant.

9. Genetics: 30 genes for flagella. Three genes of *Salmonella typhimurium* are multifunctional and associated with non-flagellated (Fla^-), paralyzed (Mot^-), and non-chemotactic (Che^-) with clockwise motor bias and Che^- with counterclockwise motor bias. Results indicate that within the corresponding gene products of these genes are specialized subregions for flagellar assembly, rotation, and rotation direction. Interactions among these genes and others result in motility (Yamaguchi et al., 1986).

10. Shape: Wavy shape--paralyzed mutants straight or very curly. References: J. Bacteriol. 140: 267(1979), 105: 384(1971), 105: 282(1971), 113: 1474(1973), and 125: 68(1979) and Annu. Rev. Microbiol. 31: 397(1979)

11. Flagella and pathogens: Flagella of a plant-growth-stimulating *Pseudomonas fluorescens* required for colonization of potato roots. Four Tn*5*-induced flagella-less mutants appeared to be impaired in their ability to colonize growing potato roots (De Weger, et al. 1987).

12. Role of motility: A motile revertant of a non-motile mutant of *Erwinia amlyovora* caused a greater incidence of blossum infection in *Malus domestica* (apple) cv. Jonathan. Chemotatic repellents, including sodium benzoate and sodium salicylate, or chemotactic attractants, including sodium maleate and sodium tartrate, applied to blossoms did not consistently protect blossoms from blight (Bayot & Ries, 1986).

13. Role of motility in nodule formation:
    a. A motile strain of *Rhizobium meliloti* formed more nodules than expected when mixed at various unfavorable ratios with flagellated or non-flagellated non-motile mutants. The results indicate that motility confers a competitive advantage on rhizobia (Ames & Bergman, 1981).
    b. *Bradyrhizobium japonicum* was chemotactically attracted to the aromatic acids shikimate, quinate, protocatechuate, and vanillate, and the dicarboxcylic acids succinate and _ -ketoadipate at low threshold levels (10^{-6} M) (Parke, et al., 1985).
    c. *Rhizobium trifolii* was chemotactically attracted to shikimate (10^{-4} M) but only weakly attracted to quinate and other aromatic and dicarboxcylic acids (Parke et at., 1985).

14. Attractants. *Erwinia herbicola* was attracted to cv. Jonathon apple nectar and to organic acids, amino acids, and the neutral and basic fractions of nectar. *E. herbicola* at > 10^8 cfu/ml inhibited the migration of *Erwinia amylovora*. Culture fluids of *E. herbicola* also inhibited the chemotaxiis of *E. amylovora* (Klopmeyer & Ries, 1987).

15. Negative association. Kelman and Hruschka (1973) found that motile, aerotactic *Ralstonia solanacearum* cells were non-pathogenic and that non-motile, non-aerotactic cells were pathogenic. Pathogenic cells has morphologically different flagella from non-pathogenic cells.

16. Phenolics. Acetosyringone, catechol, gallate, _ -resorcylate, protocatechuate, *p*-hydroxybenzoate, and vanillin induce expression of virulence (*vir*) genes located on pTi plasmid in *Agrobacterium tumefaciens*; of these seven compounds, the latter five serve as chemoattractants and the last three as growth substrates. Strains of *A. tumefaciens* lacking pTi had the same expression as the wildtype strain indicating that the chemotactic response is expressed constitutively from the bacterial and not the plasmid genome (Parke et al., 1987).

17. Epiphytic fitness is conferred by flagellar motility of an ice-nucleation-active (INA) strain of *Pseudomonas syringae* pv. syringae. Loss of flagellar motility reduced the epiphytic finess of the non-motile bacterium compared to its wildtype motile parent in co-inoculation studies on bean leaves. In this study, when not fully expanded leaves were inoculated and fully expanded leaves sampled, the non-motile strain reached only 0.9% of the population of the motile wildtype. Revertants to motility from non-motile mutants behaved in co-inoculation studies with the non-motile strain in the same manner as the motile wildtype.

B. Pili. (Pili = pl., pilus = singular; archaic term = fimbrae)

1. Physical nature. 7nm X 0.2-2_m length, 2-5nm diameter, protein=pilin in right-hand helix, (Crit. Rev. Microbiol. 1:105(1971)

2. Plasmids. Pili are correlated with the presence of plasmids. The genes controlling pili production are located on plasmids rather than on the chromosome of the bacterium.

3. Adsorption. *Klebsiella pneumoniae*, plant-associated and nitrogen-fixing strains, produce hemaagglutinating, pili (0.5 to 2.0 _m X 4 to 5 nm), purified and used as haptens, blocked attachment to *Poa pratensis* (Kentucky bluegrass) roots supporting the hypothesis that pili are important in bacterial-plant adhesion (Korhonen et al., 1983).

4. Hypersensitivity. Pili may bind bacterial cells to plant cell walls and this may be involved in the elicitation of the hypersensitive response. Purified pili and pili extracts agglutinated tobacco cell wall fragments. Pretreatment of the cell wall fragments with *Ralstonia solanacearum* extracellular polysaccharides greatly reduced agglutination by the pathogen's pili (Young & Sequeira, 1986).

C. Extracellular polysaccharides

1. **Slime** are loosely attached polysaccharides that may be washed off.

2. **Capsule** polysaccharides are tightly attached and microscopically visible outside cell walls and are less easily removed by washing.

3. **Microcapsule** polysaccharides are very tightly attached to cell wall and may not be visible microscopically.

4. Anatomic types: continuous, banded or striated, discontinuous, complex depositions of polysaccharides may occur. The banded or striated capsules often cause light refraction that may be observed by dissecting microscopes.

5. Chemical composition

   a. *Erwinia amylovora*
      i. Slimey capsules: Phytopathology 17:405-440(1927) J. Agric. Res. 56: 239-256
      ii. Ooze: Phytopathology 29:142-156(1939) 80% carbohydrates; 20% bacteria
      iii. J. Genl. Microbiol. 81:509(1974): water soluble ooze, alcohol soluble "coleweas" (spelling?)
      iv. Science 183:1081-1082, 1974. amylovorin = 98% galactose and 0.375% protein stable at 100 C dry or wet

   b. *Agrobacterium tumefaciens* and *Sinorhizobium meliloti* produce acidic extracellular polysaccharides composed of succinoglycan. *Agrobacterium tumefaciens* also produces a second major polysaccharide, and 1,2-_ , D-glucan (Gangelosi et al., 1987).

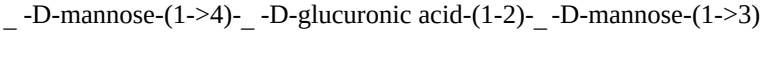
   c. *Pseudomonas syringae* pv. glycinea produces levan (polyfructan with C-2-->C-6 backbone and C-2-->C-1 branches) and an acetylated alginate (linear polyuronide of C-1-->C-4-linked mannuronic and guluronic acids) in culture. *In planta*, acetylated alginate was the only extracellular polysaccharide isolated in a compatible interaction with *Glycine max* (soybean) leaves. The alginates were acetylated 3 to 14% and contained 1 to 20% guluronic acid. The *in planta* alginates were higher in MW (2 X 10^4) than those isolated from cultures (4 to 5 X 10^3) (Osman et al., 1986).

d. *Spiroplasma citri* may have extracellular polysaccharides (J. Bacteriol. 116:1421,1973).

6. Genetics of extracellular polysaccharide production: J. Polymer Sci. 5:519(1961): *Xanthomonas campestris*, xanthan gum, MW 10^6 D-glucose, D-mannose, D-glucuronic acid as main structural units and some pyruvate: used in foods to stabilize and emulsify. Mutations in *Xanthomonas campestris* pv. campestris blocking the synthesis of xanthan gum (Xgs^+) were complemented using DNA fragments cloned in cosmids. Complementing DNA fragments compared by restriction analyses and DNA sequence homology and found to have clustered regions of complmentation. Results indicated that three unlinked regions contain loci related to xanthan gum biosynthesis (Thorne et al., 1987). Harding et al (1987) in a separate study basically confirmed this report but added that within a 22 KB region, five complementation regions (genes?) exist. Four of these genes are linked on a 12.4 KB insert cloned in a plasmid increased xanthan gum production by 10% and pyruvulation 45%. They described xanthan gum structure as:

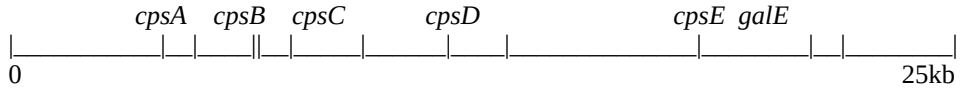
Xanthan gum

BACKBONE



SIDECHAIN

Extracellular polysaccharide production in *Erwina stewartii* is a primary determinant of pathogenicity since a single Mu-induced mutation results in loss of extracellular polysaccharides and pathogenicity. One large gene cluster (19 kb) is required for extrapolysaccharide production. This cluster of genes is divided into five regions (*cpsA-E*) and represents at least three operons and includes the *galE* gene. A controling region of the cluster contains a region very similar to the *Escherichia coli rcsA* gene, a positive regulator for capsular polysaccharide synthesis. In *Erwinia stewartii*, this gene promotes transcription of two operons in the cluster. The *rcsA* gene increased *cps* expression and pathogenicity in the pathogen. The *rcs*-like gene of the pathogen complemented *Escherichia coli rcsA* mutants. Both genes produce proteins of about 25-27Kd (Torres-Cabassa et al., 1987). This study suggests that extrapolysaccharide biosynthesis in plant pathogens and non-plant pathogens are similar.



KB (Dolph et al, 1988)

Mutants of *Rhizobium meliloti* and *Agrobacterium tumefaciens* deficient in extracellular polysaccharide production have been isolated that are complemented by cloned _exo_ genes from the reciprocal species. In two rhizobacterium *exo* mutants, agrobacterium DNA fragments not only restored *exo* expression but complemented symbiotic defects that prevented or reduced nodulation. An agrobacterium *exo* mutant deficient for production of succinoglycan failed to form tumors (Gangelosi et al., 1987). May have effects on resistance to changes in osmolality.

7. Survival mechanisms: *Azospirillum brasilense* and *A. lipoferum*, nitrogen-fixing associates of forage grasses and cereals, produce flocculent masses of cells and extracellular polysaccharides that contain refractile `encysted', dessication-resistant cells (Sadasivan & Neyra, 1985).

D. Cell wall

1. Supplies rigidity to the cell and protection against osmotic extremes.

2. Mollicutes: lack cell walls, but live in osmotically-protected phloem sap

3. L-forms are mycoplasmalike forms of bacteria that may be selected for in the presence of cell wall-inhibiting antibiotics. L-forms have been reported for:

a. *Erwinia. carotovora* subsp. *atroseptica* [J. Appl. Bacteriol. 36:729 (1973)] may occur in cucumber tissue intracellularly.

b. *Agrobacterium. tumefaciens* (3rd Int. Conf. Plant Path. Bacteria, Munich, 1978 abstr)-- L-forms selected on antibiotic-containing media were pathogenic.

c. *Spiroplasma citri* may be a natural sphaeroplast. It has elements of a cell wall because it has attachment sites for T-like bacteriophages. Rigidity is maintained by axial rod-like proteins in the cell membrane. [J. Bacteriol. 115:367(1973); J. Bacteriol. 117:904(1974); Phytopathology 62:672(1972)].

d. Protoplasts of bacteria with the total cell wall removed enzymatically do not re-generate; spheroplasts in which the cell wall is damaged do regenerate.

4. Types of cell walls (...=peptidoglycans; //// = polar portion of lipid bilayers)

Table 3. Comparison of Gram-negative and Gram-positive cell walls.

a. Gram-positive (22-25nm thick)	b. Gram-negative (15-20 nm thick)
....._ ....._ ....._ ...._ 15nm ....._ ....._ ....._ ////////////////////////////_ _ 7.5nm ////////////////////////////_	////////////////////////////_ _ 7.5nm ////////////////////////////_ .....} 1.4nm ////////////////////////////_ _ 7.5nm ////////////////////////////_

Photomicrographs of bacterial cell walls:

Xylella fastidiosa (causal agent of Pierce's disease of grapes and numerous other woody hosts) is rippled in appearance but otherwise a typical Gram-negative cell wall. [Science 199:75-77(1978)]

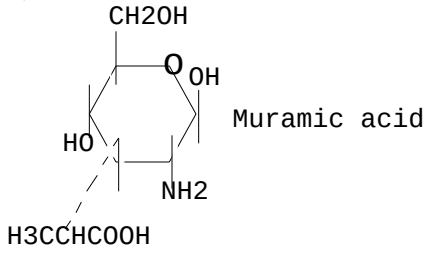
Erwinia amylovora, causal agent of fireblight of roseaceous hosts has a typical Gram-negative cell wall [J. Bacteriol. 113:953-962(1973); J. Bacteriol. 107:361-364(1973); J. Bacteriol. 102:862-866(1973); Can. J. Microbiol. 20:643-648(1974)].

5. Chemistry of cell walls

Table 4. comparison of the components of Gram-negative and -positive cell walls.

Character	Gram-positive	Gram-negative
Peptidoglycans	50-80%	1-5%
Polysaccharides	More	Less
Teichoic acid	Found in most	Found in few
Protein	13%	62%
Lipid	2%	23%
Lipopolysaccharides	Less	More
Lipoproteins	Less	More

a. Peptidoglycans (also called mucopeptides) form apolymerized aminosugar back bone of sugars derived from muramic acid: N-acetylmuramic acid (NAMA) and (N-acetylglucosamine [NAG])



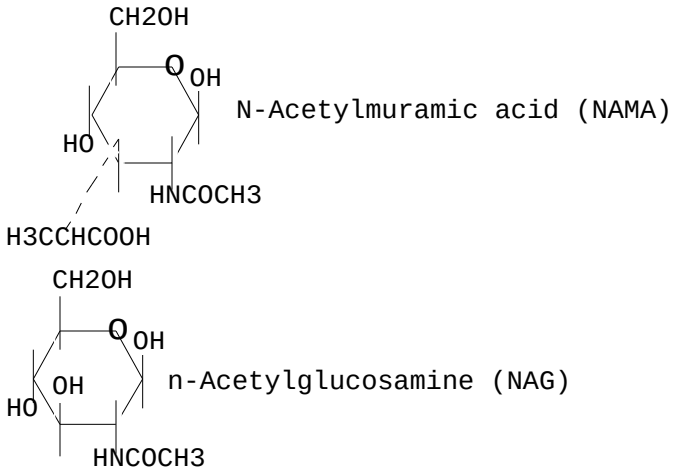


Figure 3. Important sugars in the peptidoglycan polymers of bacterial cell walls. Muramic acid, N-acetylmuramica acid (NAMA), and N-acetylglucosamine (NAG).

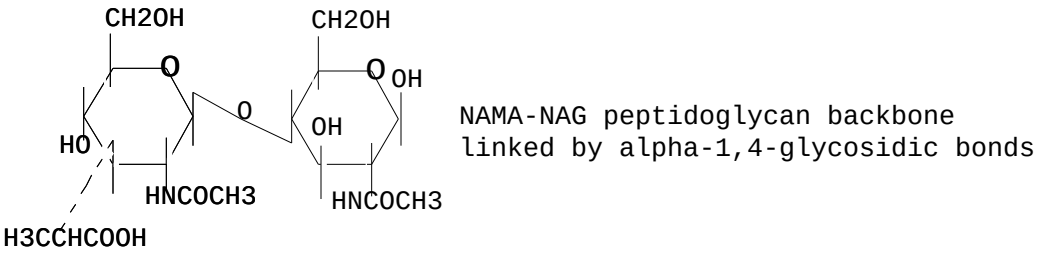


Figure 4. Basic polymer unit of peptidoglycans. N-acetylmuramic acid (NAMA) and N-acetylglucosamine (NAG) are covalently bonded into a sugar backbone in bacterial cell walls. Note that the enzyme lysozyme breaks the linkage between NAMA and NAG.

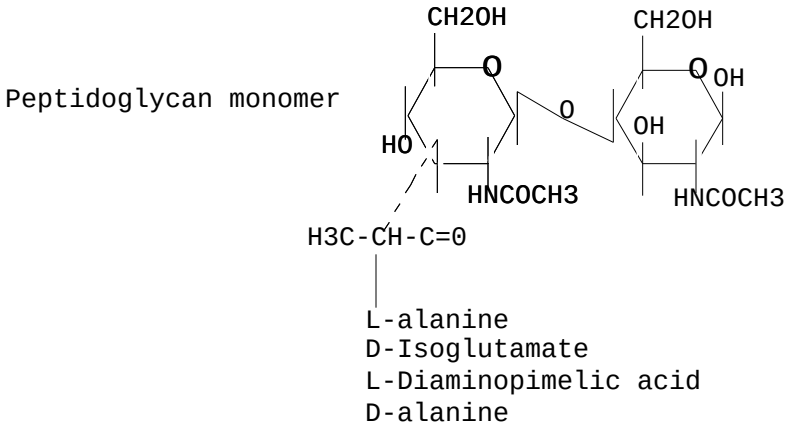


Figure 5. Tetrapeptides are linked to the sugar back bone to form a flexible mucopeptide. 2,4-diaminopimelic acid (DAP) is an amino acid unique to prokaryotes.

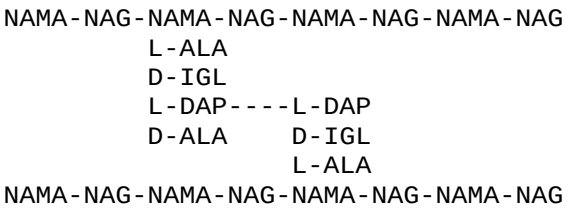


Figure 6. Rigidity is imparted to the mucopeptide (peptidoglycan) by cross-linking between the tetrapeptides. This reaction is blocked by the antibiotic penicillin. Note that in the cross-linking reaction, one D-alanine is liberated from one tetrapeptides but not the other.

Table 5. Occurence of peptide moeites fourn in the tetrapeptides liniking peptidoglycan molecules. Occurrence of specific amino acids in peptidoglycan peptides:

Always found	Usually found	Rarely found	Never found
Alanine	L-Lysine	Glycine	Phenylalanine
Glutamate	Ornithine	D-Aspartate	Tyrosine
	L-Diaminopimelate	Histidine	Tryptophan
	2,4-Diaminopimelate		Arginine
			Cysteine

c. Teichoic acids are usually found in Gram-positive organisms, but rarely in Gram-negative ones. These are linear polymers of a polyol (glycerol of ribitol) linked by phosphate bonds. Evidently, although they are found in cell walls, they are not structural components of cell walls. Note that the ribitoly phosphate group is linked to alanine through the 2 and 3 hydroxy groups.

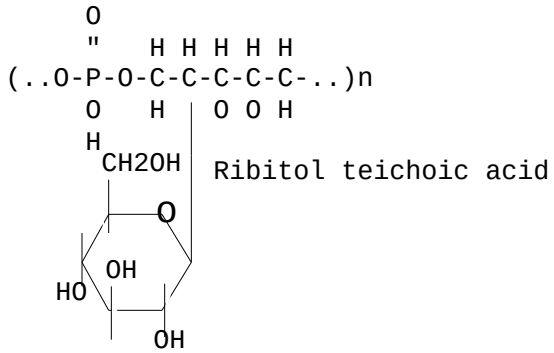


Figure 7. Ribitol techoic acid, monomeric unit. The ribitol phosphate sugar is shown in linearized form linked via its fourth carbon to the the first carbon of the six-carbon sugar. These macromolecules may link to alanine in the peptidoglycan peptide bridge betweenn --(NAG--NAMA)-- repeating units at the 2 or 3 hydroxyl group (located at the bottom of the six member sugar).

d. Polysaccharides. Amino sugar polymers are present in the cell wall. Evidently some are linked to the teichoic acids.

e. Proteins. Gram-positive cells have little protein in the cell wall while Gram-negative cells have quite a bit of protein in the outer cell membrane. Please note that although we refer to the Gram reaction of cells when discussing their cell wall anatomy and chemistry, the cell walls are NOT responsible completely for the reaction. The Gram reaction results from the accumulation of an iodine-crystal violet complexes inside cells and the exact mechanism continues to elude researchers. Finally, some bacilli and clostridia, with "Gram positive"-cell walls actually stain Gram negative.

f. In Gram-positive and Gram-negative cells the cytoplasmic membrane contains: **permeases** (penetrate entire membrane) and provided channels for uptake of small molecules into the cell; **structural proteins** (actin-like molecules in *S. citri* (Annu. Rep. John Innes Inst. 68:102-104, 1977) structural proteins may be charged and bonded ionically with peptidoglycans. (Actin is also reported in *Mycoplasma pneumoniae*--J. Bacteriol. 144:390-399,1980); **binding proteins** (associated with permeases and embbeded in upper layer of membrane) that bind substrates in proximity to the permeases; **cytoplasmic proteins** (embedded in lower side of membrane) such as the F_1 subunit of ATPase; and **enzyme systems** that may traverse the membrane as a linked chain of separate proteins. See **Fig. 8** for a schematic representation of these proteins in regards to the lipid bilayer matrix of the inner membrane.

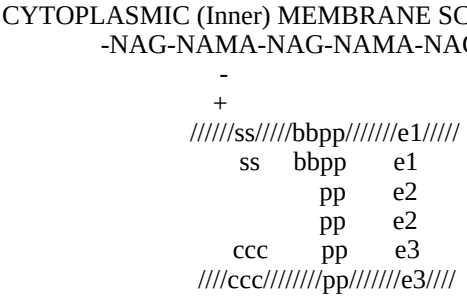


Figure 8. Schematic representation of the inner membrane or cytoplasmic membrane of bacteria showing lipid layers (///), structural proteins (ss), enzymes (ee), binding proteins (bb), permeases (pp), and cytoplasmic proteins (cc). Peptidoglycans (-NAG-NAMA-) are bound to the cytoplasmic membrane either to proteins or polar groups of the lipids by both covalent and ionic bonds (an ionic bond is indicated above).

Outer membrane. This membrane is present only in Gram-negative cells. Gram-positive cells contain a very thick and rigid peptidoglycan layer but no outer membrane. Outer membrane proteins including **structural proteins**, **enzymes**, and **lipoproteins.** Lipoproteins with one end buried in lower surface of the outer membrane are attached covalently to elongated lipoproteins that are covalently linked to the peptidoglycan layer (**Fig. 9**).

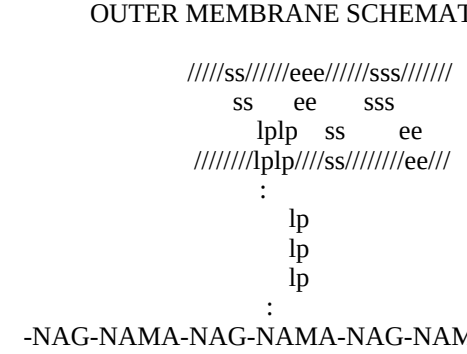
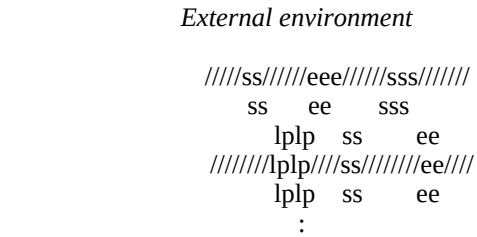


Figure 9. Schematic representation of the outer membrane of the Gram-negative bacteria consisting of lipid layers (///), structural proteins (ss), enzymes (ee), and lipoproteins (lp). Attachment is shown to the peptidoglycan macromolecules (-NAG-NAMA-). Note that the outer lipid layer contains lipopolysaccharides.



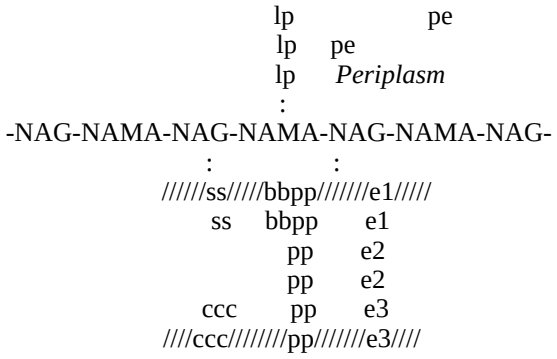


Figure 10. Combined scheme for outer and inner membranes of Gram-negative bacteria. See **Figs. 8 & 9** for abbreviations. Note that periplasmic proteins (pe_ are secreted into and remain in the periplasm or space between the outer and inner membranes of the the cell wall.

h. Lipids: Lipids form the bilayers typical of biological membranes. These membranes separate the cytoplasm from the external environment. Membranes are usually composed of glycerol phosphates with various covalently bonded moieties (**Fig. 11**).

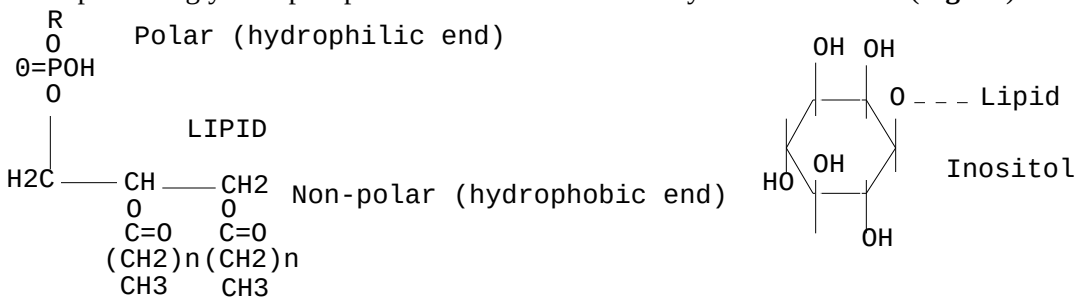


Figure 11. Glycerol phosphate (left) has a polar (wetable) end and a non-polar (non-wettable) end. The non-polar ends are oriented towards each other forming a bilayer of glycerol phosphates. The polar ends face out into either the environment or the cytoplasm. Glyerol phosphates may be decorated with various moieties (at R-- shown above) such as R=-CH2-CH2-NH2 (phosphatidyl ethanolamine, R=-CH2-CH-NH2-COOH : (phosphatidylserine), R=H-(phosphatidic acid), or inosine (see above right).

Ice nucleation activity (INA) and phosphatidylinositol. Kozloff et al. (1984). Biophysical studies predict that *m*-inositol forms a structure highly compatible with the hexagonal ice lattice. Phosphatidylinositol is a rare component of Gram-negative bacteria and has not been demonstrated in *Erwinia herbicola* or *Pseudomonas syringae* pv. syringae. INA was reduced by interaction with hemagglutinins (lectins) and hydrolysis with phosphatidylinositol-specific enzymes. INA genes were cloned and active in *Escherichia coli*. Extracts from cultures of INA^- deletion mutants of cloned genes carried on plasmids in *E. coli* were deficient for phosphatidylinositol synthetase activity while INA^+ clones had phosphatidylinositol activity.

Kim et al (1987) have reported that *Xanthomonas campestris* pv. translucens are INA^+. The INA^+ phenotype may be ecologically as well as epidemiologically important, since anecdotal evidence links epidemics of bacterial leaf streak of barley with frost injury. Other bacterial species that catalyze INA include *Pseudomonas fluorescens* and *Pseudomonas viridiflava*.

The gene for ice nucleation activity (*ina*) has been sequenced and found to have repititious sequences that may be related to either membrane insertion or formation of a ice nucleation site (Green & Warren, 1985).

Proteins have been isolated and antibodies produced that indicate that polypeptide formation may be constituitive (in *Pseudomonas fluorescens*) or appear during the stationary phase (in *Pseudomonas syringae* pv. syringae), or may be manipulated by media constituents (*Erwinia herbicola* and *P. syringae* pv. syringae). Evidently, the protein is degraded by proteases produced from the same organism (Deininger, et al., 1988).

i. Lipopolysaccharides (*Salmonella typhimurium*)

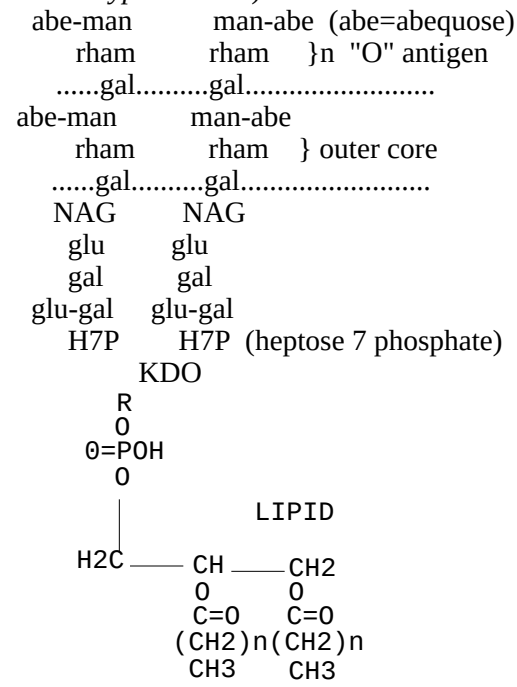


Figure 12. Lipopolysaccharides. In lipopolysaccharides, chains of sugars (top) are attacted via heptose 7 phosphate (H7P) through 2-keto-3-deoxyoctonate (KDO) to glycerol phosphate (bottom). Common sugars include glucose (glu), galactose (gal), N-acetylglucosamine (NAG), rhamnose (rhn), mannose (man), and abequose (abe). Lipopolysaccharides are divided by their reaction with antigens into the outer "O" antigen, the outer core, and the inner lipid A core (including sugars attached to H7P through KDO to glycerol phosphate).

Spiroplasma citri contains no detectable LPS-J. Bacteriol. 125:916-922, 1976, however, some *Mycoplasma* spp. do contain LPS.

Agrobacterium tumefaciens: Suppression of virulence was caused by the introduction of the IncW plasmid pSa into cells containing a pTi plasmid is accompanied by loss of site adherence in pinto bean (*Phaseolus vulgaris*) tumorigenesis assay and by loss of site adherence on the part of lipopolysaccharide isolated from these strains. When pSa was cured from these strains, tumorigenesis and adherence were restored (New et al., 1983).

Agrobacterium tumefaciens: LPS from several strains was used as haptens to block attachment sites. Only one of of five strains provided a significant reduction in tumor formation consistent with site blockage. Galacturonans with increasing methylation also reduced the incidence of tumorigenesis consistent with the idea that the pathogen attachs most efficiently to non-methylated galacturonans (Pueppke & Benny, 1983). Both lipopolysaccharides and cell wall sugars may be involved in *A. tumefaciens* attachment.

Characterization of the LPS from a *Rhizobium leguminosarum* biovar. *phaseoli* mutant that is defective in infection thread development indicated that it had the lipid A core but is missing the antigenic O chain (Carlson, et al., 1987).

Table 6. Differences in the composition of lipopolysaccharides from wildtype and rough mutants of *Ralstonia solanacearum.*

Bacterium	Composition of LPS by percentage sugar					
	KDO	**Hep**	**Glu**	**Rham**	**GA**	**Xyl**
Ralstonia solanacearum wt	8.8	6.5	13.3	45.1	24.7	1.5
Ralstonia solanacearum r	12.4	12.4	20.9	32.4	20.9	0.7

[a] KDO = 2-keto-3-deoxyoctonate, hep = heptose phosphate, Glu = glucose, GA = glucosamine, xyl = xylose

j. Membrane-bound pigments. Phytopathogenic bacteria contain lipid soluble pigments that are usually related to carotenes (**Figs. 13-15**). In both xanthomonads and curtobacteria, carotenoid pigments have been shown to protect cells from photodynamic destruction. Pigmentless mutants die faster when exposed to light than pigmented wildtypes. The major mechansims for protecting against this photosensitized oxidation are: (1) quenching of triplet sensitizer, (b) quenching of singlet oxygen, and (3) inhibition of free radical reactions.

In other bacteria, polyene pigments stabilize membranes by reinforcing the fluid matrix of n-acyl chains in the membranes similar to steroids in eukaryotes. Other suggested roles for pigments include: (1) modifying membrane permeability, (2) altering antibiotic sensitivity, (3) electron transport, and (4) enhancing enzyme activity.

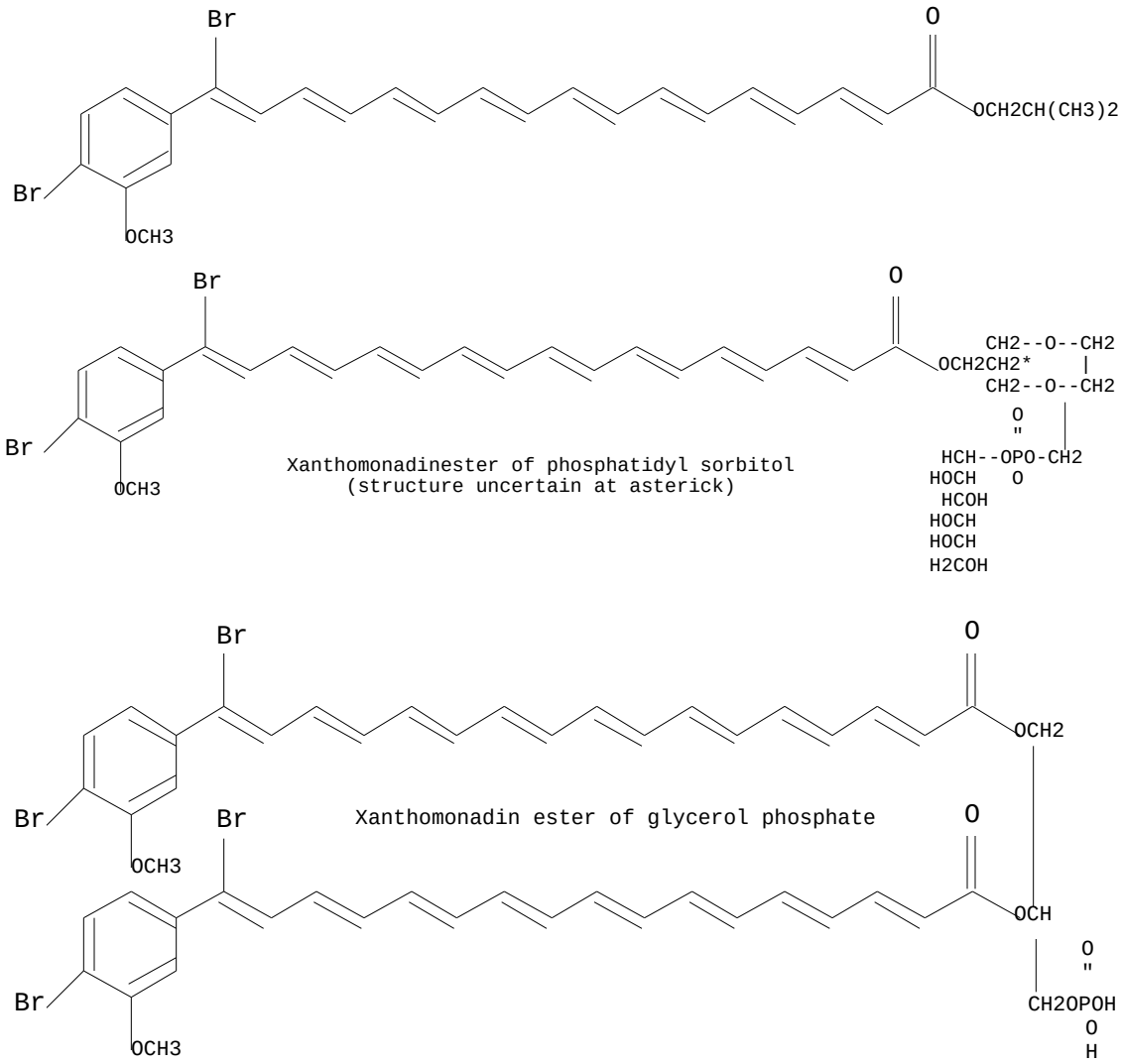


Figure 13. Pigments of xanthomonads. *Xanthomonas* spp. contain a lipid-soluble pigment arylopolene bromide (a brominated aryl prolenes) known as xanthomonadin [J. Bacteriol. 87:293-xxx, 1963; Acta Chemica Scandinavia 27:2383-2395, 1973]. Xanthomonadin may be complexed

in the membrane with a 16.4 KD protein as esters of glycerol phosphate or phosphatidyl sorbitol.

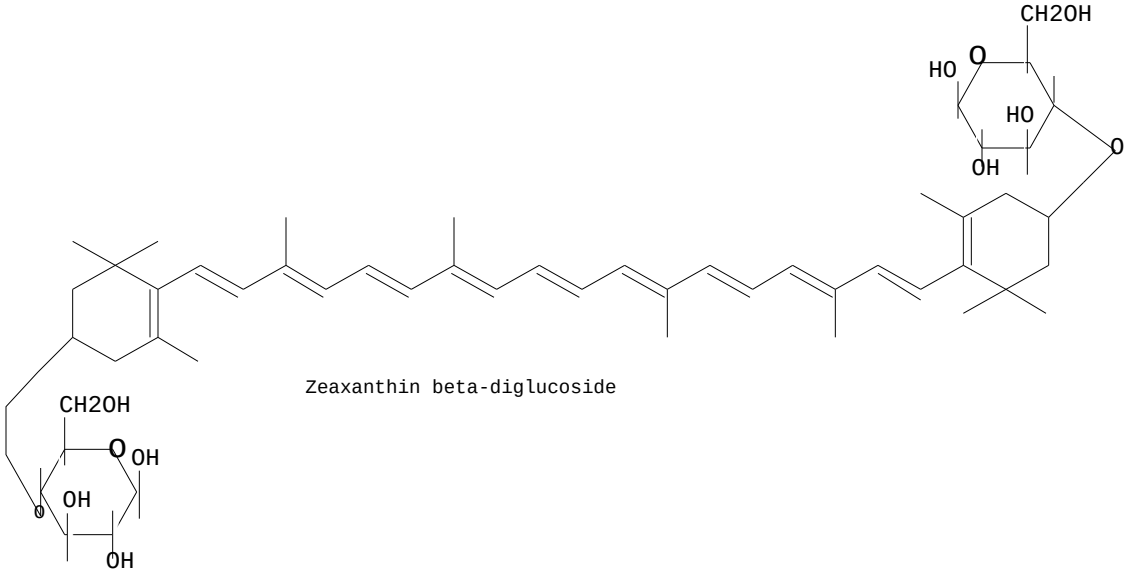


Figure 14. Pigments of erwinias and pantoeas. Pigments of *Erwinia* and *Pantoea* species. *Pantoea herbicola* (a common epiphytic bacterium on plants) and *Erwinia uredovora* (pathogen of rust fungi) and, probably, *Erwina stewartii* (causal agent of Stewart's wilt of maize) also produce yellow carotenoid pigments such as zeaxanthin-_-diglucoside. These pigments are considered to protect bacterial cells from ultraviolet rays from the sun which cause DNA lesions or damage cell membranes (Goto, 1992).

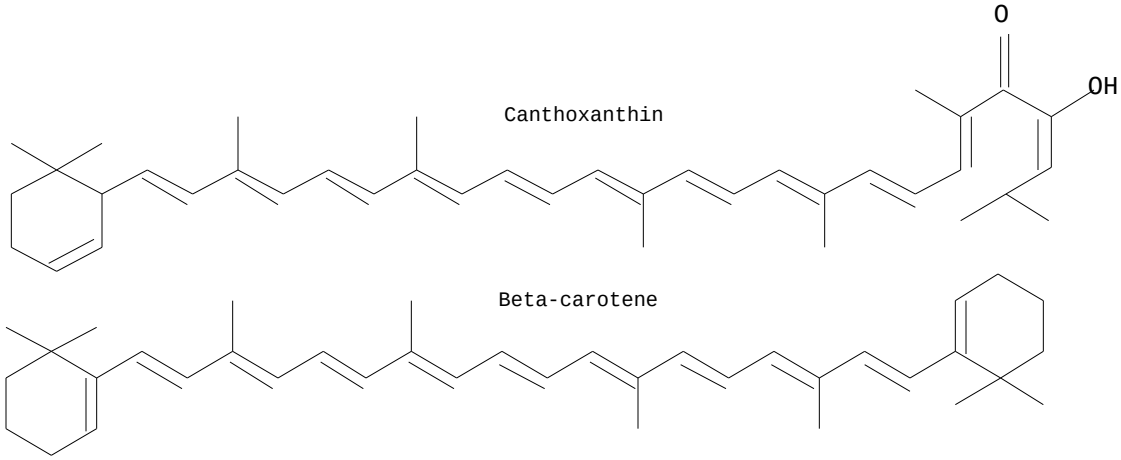


Figure 15. Pigments of curtobacteria. *Curotobacterium flaccumfacien* pv.poinsettiae has pink or yellow pigments depending on thiamine levels (0.01 _g/liter provide pinkcells; 100 ug/liter give orange-yellow) and pH. The pigments are predominantly due to carotenoid pigments such as bisanhydro-bacterioruberin (a C_{50} diol, pink, acyclic) and (2-dihydroxyisopentenyl)-2-isopenteny _-carotene (C_{50}diol, yellow, cyclic). Thiamine may be important in cyclization of the carotenoids. These pigments are complexed in the cell membrane to a protein of about 15 KD.

Clavibacteri michiganensis subsp. michiganensis has yellow carotenoid pigments predominantly. They are also complexed to the cell wall via proteins (Goto, 1992). The structures of several of these pigments and changes due to mutation were detailed (Saperstein et al., 1954).

k. Fatty acids: Cellular fatty acids of six fastidious, Gram-negative, xylem-limited bacteria (Wells & Raju, 1984):

Fatty acid class	% Total fatty acids
Saturated straight chains	
16:0	26.5 to 31.8
17:0	4.1 to 9.9
18:0	0.6 to 6.7
Unsaturated acids	
16:1	18.7 to 34.5
18:1	9.4 to 15.5
Hydroxy acids	
2-OH, 10-16:0	ND to 1.6
Branched-chain acids	
20:0	0.5 to 2.3

Saturated >17:0 acids are typically absent or trace (<0.2%) levels in plant pathogenic pseudomonads and xanthomonads. Xylem-limited, Gram-negative, fastidious bacteria lack cylopropane acids as do xanthomonads and pseudomonads. Erwinias have minor quantities of cylic acids, no branched acids, minor quantities of hydroxy acids, and less than 4% of saturated 17:0 acids.

l. Density, chemical analysis, and enzymatic assays of inner and outer membranes of Xanthomonas campestris pvs. manihotis, cassave, and campestris (Dianese & Schaad, 1982; dos Santos & Dianese, 1986).

Character measured	**Membranes of *Xanthomonas campestris* pvs.**					
	manihotis		**cassave**		**campestris**	
	Inner	**Outer**	**Inner**	**Outer**	**Inner**	**Outer**
Density (g/cm^3)	1.142	1.255	1.142	1.255	1.143	1.163
Protein (_g/mg)	50	73	36	83	314	574
Phospholipid (_g/mg protein)	122	6	180	47	143	145
2-keto-3-deoxyoctanol (KDO; nM/mg protein)	0.0	0.5	0.1	1.7	0.7	2.3
NADH oxidase (_M/min/mg protein)	370	64	289	64	15	7
Succinate dehydrogenase (nM/min/mg protein)	227	36	64	21	34	5
β-**mannase** (nM/min/mg protein)	NT	NT	NT	NT	4	26
Xanthomonadin (nM/mg protein)	NT	NT	NT	NT	1.3	0.0

E. Cytoplasm
1. Chemistry.
a. Lacks definite structure.
b. Solution/suspension of:
i. Water content is 70% or greater.
ii. Small molecules: amino acids, organic acids, sugars, cofactors (NAD, FAD, etc.), nucleotide bases,
iii. Large molecules: proteins, carbohydrates polymers, lipids, nucleic acids (tRNA, mRNA, DNA, ribosomal RNA)
iv. Ribonucleoproteins (ribosomes and associated structures) 70 S ribosomes contain two nucleoprotein subunits; 30 and 50 S, which in turn are composed around a few RNAs and many proteins:

Nucleoprotein subunits:	30S	50S
RNA molecules (rRNA) in subunits:	16S	23S & 5S
Proteins molecules in subunits:	30	40

The ribosomal proteins bind mRNA, the nacent polypeptide, and tRNA to the subunits and decode the mRNA during protein synthesis. Proteins and rRNA are disassociated with $LiCl_2$ 8M urea). Polyribosomes (polysomes) are composed of several ribosomes attached to a single mRNA and associated elongating polypeptide chains.

2. Inclusions.
a. **Mesosomes**: Invaginations of the cytoplasmic membrane to form septa, chloroplast-like structures, and mitochondria-like organelles.
b. **Bacterial nuclear region**: Skein of dsDNA fibrils not separated from the cytoplasm by any membrane structure. Appears as a area of high electron transparency by TEM (transmission electron microscopy). The bacterial genome is a circular DNA molecule 3 X 10^9 daltons in size (2 x 10^6 bp; 2 to 3 x 10^3 genes). The genome or bacterial chromosome is attached to the membrane by a protein (Nature 277:572-xxx, 1979) and is not associated with histones as in eukaryotes.
c. **Glycogen granules**: May constitute up to 50% of the dry weight of cells. They form electron transparent spheres withour limiting membranes and accumulate during nitrogen starvation.
d. **Lipid granules**: Composed of poly-_ -hydroxbutyric acid (HBA) is accumulated by several species of *Bacillus* as well as the phytopathogens *Burkhartii (Pseudomonas) solanacearium*, *P. carophylli*, *P. avena*, *P. corrugata*, *P. gladioli*, and *Burkhartii (Pseudomonas) cepacia*. To observe these granules may be induced by growing the bacterium on either nutrient agar or a defined medium containing DL-HBA. Staining the cells with 0.3% aqueous Sudan Black B, clearing with xylene, and counter staining with Safrannin O reveals black, spherical droplets.
e. **Metachromatic** (or volutin) **granules**: Granules of polymerized inorganic metaphosphate stain with methylene or toluidene blue. These constitute storage bodies.
f. **Sulfur droplets**: Some anaerobic bacteria deposit elemental sulfur derived fromn the oxidation of H_2S inside the cytoplasm.
g. **Endospores**: Bacteria of the species *Bacillus* and *Clostridium* produce very resistant (survive 80 C for 15 min) spores. These spores are produced internally and are composed of a thin exosporium, several layers of protein, surrounding a cortex composed of dipicolinic acid, peptidoglycan, and calcium, a cytoplasmic membrane, and dessicated cytoplasm containing ribosomes, mRNA, and DNA.

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BACTERIAL INTERACTIONS IN THE RHIZOSPHERE AND ON THE RHIZOPLANE

Interactions of phytopathogenic bacteria with soil organisms, soil, and roots is most complex. This section will consider the disease court in soil.

I. Physical Environment. The rhizosphere, or that part of the soil containing roots of living plants, has several suble variations in definitions which cause scientist, laymen, and producers to have difficulty in communication about pathogenesis. For the soil scientists and soil microbiologists, the rhizosphere is usually the A1 horizon and contains as an important part of its organic content plant roots. To the pathologist, the meaning is more complex as we look at the ecological niches closer to or actually on the root. First, let us consider briefly the nature of soils before we consider the rhizosphere.

A. Ecological niches. The environmental niches we will consider includes bulk soil, the rhizosphere, and the rhizoplane.

1. SOIL ENVIRONMENT. Agricultural soils usually predominantly contain **mineral particles**, graded by size, as sand, silt, loam, and clay. **Soil water** is capillary and free on and between the surfaces of mineral particles or bound usually on the surface of clay and organic particles. Soil **organic materials** includes lignin, cellulose, as well as the carbon and nitrogen of living soil organisms. Soil water contains **nutrients** for microbial growth including dissolved gases (O_2, N_2, CO_2, *etc.*), dissolved minerals (Ca^{2+}, NH_4^{1+}, NO_3^{1-}, *etc.*), and dissolved organic compounds. **Spaces** among mineral and organic particles not wetted with water allow exchange of atmospheric gases with dissolved gases.

Speaking as populations, the **biotic component** of soil is predominantly made up of bacteria and their parasites. Total bacterial in agricultural soils total about 10^9colony forming units (cfu)/g. This population is made up of mostly Gram-positive eubacteria (10^8cfu/g), actinomycetes (10^8cfu/g), and cyanobacteria (10^6cfu/g). Archeabacteria are not an important component because conditons are not extreme enough (halophiles) or the proper gaseous environment is not available (CH_4, H_2S, *etc*.). Bacteriophages, or bacterial viruses, make up a variable part of the biotic agents in soil (10^{6-10} plaque forming units [pfu]/g). Eucaryotic soil microflora include fungi (10^{4-5}cfu/g), protozoa (10^{4-6} viable cells/g), nematodes (10^{4-5}worms/g), and arthropods, usually mites, 10^{4-6}orgnisms/g. From the point of view of volume and surface area interacting with the soil, bacteria have greater contact with the soil environment than fungi (compare calcuated cylindrical volumes and surface areas from bacterial [1 x 2 _m] and fungal [6 x 20 _m] average dimensions multiplied by population sizes).

2. RHIZOSPHERE. To pathologists, the **rhizophere** is that body of soil influenced chemically, physically, and biologically by the presence of a root. Note that this definition, used by plant pathologists and soil microbiologists, differs greatly from that of soil sicentists. In their parlance, the rhizosphere contains roots and is often probably viewed as identical to the A1 horizon. Soil microbiologists usually indicate agricultural soils as "disturbed" soils with the duff, **A1**, and lower layers mixed by tillage. In our own Department, weed scientists define rhizophere soil as **furrow soil**--or soil from between rows of plants growing on the "hills" on each side of the furrow. For instance, I failed to isolate herbicide-degrading bacteria from “rhizosphere” soil until I understood that Dr. Kriton Hatzios had provided, in good faith, furrow rather than soil containing maize (*Zea mays* L.) roots. Once we learned to communicate, we were able to located herbicide-degrading bacteria from soil adherent to plant roots.

Several important differences are evident when comparing rhizosphere to non-rhizosphere soils. Rhizosphere soil is enriched for **Gram-negative bacteria** over Gram-positive bacteria. Gram-positive bacteria predominate in non-rhizosphere soil. However, in cultivated lands, non-rhizosphere soil is often mistaken for rhizosphere soil in samples. Soil in the root zone differs dramatically in its microflora from soil in the tilled but non-root zone. **Populations** of bacteria are 5- to 15-fold greater in rhizosphere compared to non-rhizosphere soil. For specific species this increase may be even higher; *e.g.*, *Bradyrhizobium japonicum*, a nitrogen-fixing symbiote of soybean (*Glycine max* [L.] Merr.), may be enhanced 100-fold or more in rhizosphere soil compared to non-rhizosphere soil. **Replication** rates of some bacteria may be increased in rhizosphere soil, *e.g., Bradyrhizobium japonicum* doubles in 241 to 361 h in soil away from plant roots compared to division every 9 to 12 hr in rhizosphere soil.

3. RHIZOPLANE: The rhizoplane is the two-dimensional interface between the root and the soil. The bacteriology of the rhizoplane is more difficult to study than that of the rhizosphere. The physical difficulty of separating the microbes associated with the mineral component of the rhizosphere from those on the rhizoplane discourages any but the most rigorous studies. The following section describing the development of roots in soil will cast further light on this subject.

B. Primary root. The root and its effects on the surrounding soil define the rhizosphere and the rhizoplane environments. Primary roots are emerging roots or new roots. The root of a germinating seed is a primary root. Roots may be considered in at least four parts:

1. ROOT CAP. The root cap is an amorphous **granular gel** composed of rapidly produced lysing cells (up to 10^4 cells/day), polysaccharides derived from cell walls, and plant mucilages composed of pectins and hemicelluloses. The cap appears as smooth cone on the distal end of the root. It provides an organic "**lubricant**" for the penetration of the root tip into soil.

The cap is constantly and rapidly generated from a meristem at the tip of the root. This meristem also the cells differentiating upward as part the root itself. The root cap is largely devoid of bacteria since they are constantly scraped off as the root elongates and pushes through the soil. However, discarded root cap components provide nutrient sources for rhizosphere microbes.

2. ELONGATION ZONE. The zone of elongation occurs just behind the root cap. The cells in this portion of the root elongate by growth of secondary cell walls to be 10-fold longer than they are wide. The pressure of these elongating cells forces the root tip deep into the soil. By scanning electron microscopy (SEM), the outlines of the cells are visible on of the elongating root. The edges of the cells are depressed, while the center of the cell bulge outward. Plant-secreted **mucilages** (pectins and hemicelluloses) accumulate over the depressed intercellular areas between the cells on the root surface. The mucilage secreted by root hairs is covered with a distinct **cuticle** which stains withelectron-dense OsO_4 and is composed by poly-1,2-diglycols, is persistent, and usually well-developed especially in legumes.

3. ROOT HAIR ZONE. Root hairs are extensions of the secondary walls of plants that protrude through the primary walls. Again, the mucilage secreted by root hairs is covered with a distinct cuticle composed by poly-1,2-diglycols. Mineral particles often rupture the cuticle allowing bacteria to interact with the mucilage. Plant mucilages together with bacterial degradation products of mucilages, and bacterial extracellular polysaccharides form **mucigels**.

4. ZONE OF AUTOLYSIS. Following suberization and lignification of epidermal cell walls and root hairs, root epidermal and cortex cells undergo autolysis. As the cells are sloughed off, the endodermis is finally exposed. Bacteria and actinomycetes colonize the lysing cells. In this area of the root, secondary roots form. They push through the dying cortex and epidermal cells and often create transitory wounds that may serve as entry sites for bacterial and fungal plant pathogens.

5. ZONE OF SECONDARY THICKENING. As the young root thickens, a secondary cortex forms within the endodermis. These cells are corky and filled with suberin or polyphenolics. Little is known of the bacteriology of these cells. However, the microbial ecology of this part of the root is, perhaps, best known for mycorrhizal colonization associated with this part of the root.

C. Secondary root. The secondary root grows much as the secondary stem with annual rings of xylem formed. Likewise, old phloem layers become suberized and lignified forming first the root "bark" and then being sloughed off. The microbiology of the sloughed lignified and suberized cells is much different than the autolyzed cells of the primary root. The scondary root will not be considered further here because the primary root of crop plants is the structure most often the site of pathogenesis by phytopathogenic bacteria.

D. Physical condition of rhizosphere. The physical presence of the root influences the nearby soil in several ways: The elongating and expanding root **compresses** soil. Soil is compressed to 1.59g/cm^3 at rhizoplane whereas at 8-10mm from the root, the soil is compressed to 1.55g/cm^3. Due to compression and organic materials produced by the root, **pore sizes** in sandy loam is reduced near the root surface from 30_ m to 10_ m and **pore paths** become more convoluted. Compaction and twisted pores favor build-up of organic material already in the soil complemented by organic materials secreted or sloughed from the plant into the soil. **Mucigel**, a mixture of plant mucigels and bacterial extracellular polysaccharrides, maintains contact between plant and soil, prevents formation of a gap between the root and the soil during drought conditions favoring high transpiration rates. **Water potentials** near root surfaces is about -20 bars for mesophytic plants (most agricultural crops) and -40 for xerophytic (or desert) plants. Water stress is probably transmitted to root-associated microbes since this is an area of fluctuation of water potential and slow water movement. **Soil particle size** is reduced near roots probably by chemical action of root exudates and their bacterial degradation products.

E. Growth and distribution of microbes. The growth and distribution of microbes corresponds to the nutrient opportunities in the rhizosphere and on the rhizoplane.

1. INEQUAL OPPORTUNITY FOR NUTRIENTS. Root surfaces, the rhizoplane, as part of the rhizosphere may be most comparable to agar cultures because that surface is also two-dimensional. Bacteria are distributed on the rhizoplane in usually discrete microcolonies. Microcolonies have densities as high as 10^5 cfu/cm^2 root. Because not all bacteria in a microcolony have contact with the substrate, individual cells do not have an equal opportunitiy for exposure to the surface of the root and nutrients and products of plant metabolism. Only about 10^2 bacteria/cm^2 root are actually in contact with the root because of the geometry of the root surface and bacterial microcolonies. Bacterial quantification on root surfaces is usually expressed as cfu/cm^2. Dr. Melinda Mulesky, a graduate of PPWS under the direction of Dr. Chuck Hagedorn (CSES), developed a computer program which estimates the surface area of roots from computer scanner images.

2. AVAILABLE NUTRIENTS. Plant products affect the metabolism of root-associated microbes including phytopathogenic bacteria. **Exudates** leak passively from living cells; they include most commonly low molecular weight metabolites and inorganic ions. **Secretions** include compounds that are released as a result of active metabolic processes; this group includes enzymes and the pectins and hemicelluloses released into the root cap and the cells in the elongation zone. **Mucilage** is composed of pectins and hemicelluloses secreted by the root cap, epidermal, and root hair cells and is usually delimited by the **mucilage cuticle** or layer of poly-1,2-glycols that forms at the soil-mucilage interface. **Mucigel** is a combination of plant mucilage, exudates, secretions, their degradation products, and bacterial extracellular polysaccharaides. **Lysates** are compounds released by the autolysis of the older epidermal cells; includes sugars, amino acids, nucleotides, enzymes, growth factors, terpines, *etc.*

3. DISTRIBUTION OF BACTERIA. **Diffusion** of substances from roots stimulates microbial growth. **Motility** is also induced by nutrient concentration gradients. Effective motility is restricted to water films clinging to soil particles and is limited especially at the low water potentials encountered near the root. **Anticlinal intercellular depressions** on the surfaces of elongating roots are colonized by bacteria.

4. PROTOZOAN GRAZING. Protozoan grazing on roots may be the most important cause for reduction of bacterial numbers on the rhizoplane. Likewise nematode grazing in the rhizosphere must also reduce bacterial numbers in immediate vicinity of the root. Estimates of the number or volume of bacteria grazed are difficult to accurately determine but their impact on bacterial populations is very large.

F. Chemical environment at the root surface. Roots also affect the chemical environment of rhizosphere soil. Roots **exchange ions** with soil. Plant roots replace soil cations with H^+ and soil anions with bicarbonate (HC_3^{1-}). The sum of these replacements coincidentally lowers the **pH** in the immediate vicinity of the root. The pH near root surfaces is further lowered since $NH_4^{1+}$and NO_3^{1-} ions are concentrated. Related to ion exchange and pH reduction, **ion concentrations change**. Some ions (*e.g.*, PO_4^{2+} and K^+, cations used in microbial biosynthesis) are reduced while others (*e.g.*, Ca^{2+}, Al^{3+}, Mn^{2+}, Si^+, and Fe^{3+}) accumulate or even precipitate near the roots. Some of the accumulated ions (e.g., $Al^{3+}$and Mn^{2+}) may be toxic to microbes and/or plants. In higher pH, low Al^{3+} soils of the midwest, *Bradyrhizobium japonicum* introduced as a soybean (*Glycine max* [L.] Merr.) nitrogen fixation inoculant survives and flourishes. Usually there is no need to introduce additional inoculant to maintain nodulation efficiency. However, in sandy, low pH, high Al^{3+} soils of the southeast (typical of Tidewater and Piedmont Virginia), Al^{3+} toxcity has a role in limiting the survival of these nitrogen-fixing bacteria. Selection of adequate inoculant strains should consider their ability to resist Al^{3+} toxicity. Dr. Charles Hagedorn (CSES) housed in PPWS is an expert in the selection of inoculant strains.

II. Bacterial associations. Bacterial associations with may be non-existant, beneficial only to the bacterium, beneficial to both the bacterium and the host plant, or detrimental to the host plant.

A. NON-DISCERNABLE. Interactions among Gram-positive bacteria in non-rhizosphere soil and those in the rhizosphere are difficult to visualize since many non-rhizosphere bacteria may be dormant in rhizosphere soil and Gram-negative rhizosphere bacteria may be dormant or in low populations in non-rhizosphre soils. Among the eubacteria, it is impossible to indicate that plants are not ultimately important because the great bulk of organic material utilized by bacteria in the soil proceeds indirectly from the photosynthetic processes of eukaryotic plants. Whether the carbons fixed by photosynthesis pass throught the metabolism

of other bacteria, fungi, protozoans, mites, or animal wastes and carcasses, the origin of the fixed carbon and the biological energy to process it overwhelmingly originates with plants.

B. ASSOCIATIONS DETRIMENTAL TO PLANTS. The non-beneficial associations of bacteria with plants is most important to the subject of this course.

Ralstonia (Burkholderia or *Pseudomonas) solanacearum*--Bacterial wilt of solanaceous plants, peanuts (*Arachis hypogaea* L.) and bananas (*Musa paradisica* L.).

Clavibacter (Corynebacterium) michiganense subsp. *michiganense*--bacterial canker of solanaceous plants.

Agrobacterium tumefaciens--vectors T-DNA, the crown gall pathogen, to over 150 species of dicotyledonous plants.

Clavibacter michiganense subsp. *insidiosum*--alfalfa (*Medicago sativa* L.) wilt.

Streptomyces scabies--potato scab. In dry soils, lenticels of potato (*Solanum tuberosum* L.) tubers in the oldest nodes of the modified "stem" are especially susceptible to penetration, infection, and colonization by the scab causal agent (Adams & Lapwood, 1978).

Erwinia chrysanthemi and *E. carotovora* subspp. *carotovora* and *atroseptica*--soft rot of succulent tissues of almost all plant save conifers.

Clostridium spp.--Pectolytic clostridia cause carrot (*Daucus carota* L.) cavity spot and soft rot. Often pathogenic clostridia produce pink pigments in culture.

Pseudomonas spp., including *P. putida* and *P. fluorescens*, and some *Flavobacterium, Citrobacter, Enterobacter, Klebsiella, Achromobacter, Arthrobacter*, and *Chromobacterium* spp.--are assoicated with the deleterious rhizobacteria (DRB) phenomenon which causes crop yield losses without obvious pathology. Deformed root hairs and increased susceptibility to root diseases are associated with this disease complex.. DRB in sugar beet (*Beta vulgaris* L.) fields may comprise 18 to 20% of the bacteria isolated while plant growth-promoting rhizobacteria (PGPB) represented only 3 to 5%.

C. ASSOCIATIONS BENEFICIAL TO BACTERIA AND PLANTS. Many bacteria in the rhizosphere are stimulated by the presence of the plants. The main source of this stimulation is the availablity of complex carbohydrates near or on plants for assimilation and growth. Plants, on the other hand, often benefit from the nitrogen compound either fix or released from organic material by bacterial metabolism. For instance, *Azotobacter vinelandii*, a free-living nitrogen-fixing bacterium ultimately depends on carbon fixed by plants. While, plants growing in low nitrogen soils colonized by *A. vinlandii* benefit from the fixed nitrogen compounds. This is a beneficial association with no direct contact.

In a more intimate association, nitrogen-fixing, symbiotic bacteria contribute to the diversion of 60% of net leguminous plant's photosynthetic products to the roots of plants, *e.g.*, 500kg/ha of carbohydrates. In the field, a ratio of 1.9:1 of carbon fixed by plants (=ratio of ^{14}C fixed by nodulated plants: fixed by non-nodulated plants) appears in the rhizosphere. These figures demonstrate the importance of the symbiotic relationship to plants--that plants allow the diversion of most of photosynthetic products to the use of symbiotic bacteria and nodule growth. Interestingly, in growth chambers, this ratio changes dramatically to 0.25:1.

1. **Nitrogen fixing bacteria.** Nitrogen fixation by free-living and symbiotic or plant associated bacteria is beneficial to plants as a source of ammonia and nitrate for nitrogen metabolism.

    a. Non-symbiotic: *Azotobacter vinelandii* is a free-living nitrogen-fixing bacterium which is increased in numbers in soils containing organic material derived from plants. Recently, nitrogen-fixing pseudomonads have been isolated from roots of

plants growing in the high Canadian arctic. If they are free-living, associated with the rhizoplane or rhizosphere, or endophytes has not yet been established (Lifshitz, *et al.*, 1986).

b. Epiphytic: *Azospirillum* spp. are nitrogen-fixing, grass root-associated bacteria. *A. lipoferum* is associated with maize (*Zea mays* L.) and wheat roots (*Triticum aestivum* L.) and *A. brazilense* is associated with rice (*Oryza sativa* L.) and sugarcane (*Saccharum officinarum* L.) roots. Some studies suggest that these organism are epiphytes and some suggest that they are endophytic as well.

c. Endophytic symbiotes: Diazotrophs reduce N=N to NH_4^+ and NO_2^{2-}; they also reduce HC=CH (acetylene) to $H_3C\text{-}CH_3$ (ethylene) which may be assayed to detect nitrogenase activity.

Frankia spp. are actinomycetes that are endophytic symbiotes that fix nitrogen and nodulate many species representing the Beulaceae (alder), Rosaceae (ornamental plants), and six other families. Most of the plants are woody shrubs or small trees except the hemp-like herb *Datisca cannabina.*

Rhizobium spp. (fast-growing rhizobia) and *Bradyrhizobium* spp. (slow-growing species) are nitrogen-fixing, nodulating bacteria commonly used as inoculants for leguminous plants.

Important species and biovars:

Rhizobium leguminosarum biovars. *trifolii* nodulates clover (*Trifolium* spp.), *phaseoli* nodulates field beans (*Phaseolus vulgaris* L.), *viceae* nodulates vetch (*Vicia sativa* L.). NOTE: *R. pisi*, which nodulates pea (*Pisum sativum* L.), is no longer recognized as a separate species or biovar, but is included as *R. leguminosarum* biovar. *leguminosarum.*

Sinorhizobium. meliloti nodulates alfalfa (*Medicago sativa* L.).

Rhizobacterium loti nodulates lotus (*Nelumbo* spp.), birdsfoot trefoil (*Lotus corniculata* L.), and mimosa (*Albizia julibrissin* Durazz).

Bradyrhizobium japonicum nodulates soybean (*Glycine max* [L.] Merr), cowpea (*Vigna unguiculata* [L.] Walp), and peanut (*Arachis hypogaea* L.).

Chemotactic attraction to roots: Simple sugars attract most *Rhizobium leguminosarum* strains and biovars. Homoserine, the predominant amino acid exuded by peas, attracts pea-nodulating *R. leguminosarum* biovar. *leguminosarum* strains.

Attachment: Lectin-LPS interaction turns on infection and nodulation genes. Binding $10^{6\text{-}7}$ cfu bind/min.

LECTIN HYPOTHESIS. In the lectin hypothesis, bacterial lipopolysaccharides (LPS) bind specifically to plant lectins (glycoproteins). These interactions which are ionic, occur between the sugar moieties of both lectins and LPSs. These interactions are quite but not completely specific.

Chemical composition: Some idea of the chemical composition of the sugar moieties can be determined by hapten studies. Hapten is a generic name given to blocking reagents. In the case of specific sugar-sugar interactions such as occurs in lectin-LPS binding, single sugars resembling actual structures of the interacting molecules may bind to the lectin thus blocking the lectin binding sites. In this case subsequent added LPS will fail to bind. The hapten sugars may be used to predict lipopolysaccharide structure.

Developmental appearance: Bacterial lipopolysaccharide and the plant lectin are developmentally affeich suggests that lectin production is

developmental and responds to environmental triggers (Dazzo & Hrabak, 1981).

Evidence that lectin binding is specific. Soybean (*Glycine max* [L.] Merr) binds twenty-two of twenty-five *Bradyrhizobium japonicum* strains but, fails to bind heterologous bacteria. Immunolatex beads with LPS attached have been used to localize lectins to root surfaces. *Sinorhizobium meliloti* mutants were unable to bind agglutinin, an alfalfa (*Medicago sativa* L.) lectin, *in vivo*, they also

and *R. leguminosarum* biovar. *trifolii* containing small fragments of the *Sinorhizobium meliloti* nodulation region of *sym* plasmids(see below).

Peanut (*Arachis hypogaea* L.) rhizobia bind soybean (*Glycine max* [L.] Merr) at the bases of root hairs and peanut root hairs on the tip.

Host specificity may be transferred on plasmids by conjugation: Rhizobia contain large plasmids containing genes associated with the establishment of symbiotic relationships including host-range specifying regions and root-binding regions. These plasmids are known as *sym* plasmids. Co-transfer of *sym* plasmids from rhizobia to other rhizobia or even to *Agrobacterium tumefaciens* strains has resulted in the altered ability to bind and nodulate host plants.

Nodulation occurs in the absense of lectin: Soybeans (*Glycine max* [L.] Merr) homozygous and recessive (*le le*) express a phenotype deficient in lectin. If the hypothesis that lectin is absolutely required for attachment and nodulation is correct these plants should not be nodulated. In fact *le le* soybeans lacking soybean lectin in seeds and roots are nodulated at low frequencies by *B. japonicum*. This indicates that lectins are important but not critical in attachment and nodulation.

NODULATION. Rhizobia attach first by **lectin-LPS** binding to root surfaces. Clover (*Trifolium* spp.) root **enzymes** interact with *R. leguminosarum* biovar. *trifolii* capsular material to make binding between the bacterium and the plant more effective by possibly exposing the bacterial lipopolysaccharides more completely (Dazzo, et al., 1982). Cellulose microfibrils are involved in the second phase of attachment. Microfibrils produced by the bacterium "tie" the bacteria onto the root surface allowing multiplication at that site and resulting in "cap" or microcolony formation (Smit, et al., 1987). Root hairs deform and "curl" over the microcolony partially under the control of hac. Cellulose tubes or infection threads, penetrate through the root hair cell into the stele of the root. Rhisobacteria move, possibly by hydrostatic pressure, into a stele cell and transform into pleomorphic "bacteroids". The plant cell and its neighbors, under the influence of nodulation genes, forms a nodule by hyperplasia and hypertrophy. This phenomena is partially controlled by phytohormones, auxins and cytokinins, produced by the bacteria. The plant provides an anaerobic enviroment for nitrogenase activity required for fixing atmospheric nitrogen by over-producing oxygen-binding legehemaglobin, which colors the interior of the nodule red to reddish brown. (Hirsch et al., 1985; Long. 1985).

2. Plant Growth-promoting rhizobacteria (PGPR) including Pseudomonas putida and P. fluorescens. Several hypotheses have been advanced to explain the beneficial activity of these organisms:
   a. Plant growth hormones. If PGPR produce plant growth hormones is controversial; no direct evidence exists. In culture, many if not most bacteria produce metabolites that may have phytohormone effects on plant growth. These effects are often stimulatory.

b. Competition for ecological niches. In sterile soil or soil-less potting media, PGPR often do not provide benefit to the plant; this suggests that interactions may occur with other with other microbes. Perhaps the beneficial activity of PGPR is not directly upon the plant but as a result of biological control of DRB and other minor pathogens.
c. Colonization. Effective PGPR colonize roots aggressively and follow the root away from the spermasphere (seed zone).
d. Host specificity. PGPR may show some degree of host specificity in colonization.

3. Pathogen-antagonistic bacteria. Some bacteria, mainly fluorescent pseudomonads including P. fluorescens and P. putida, interfere with the development of pathogen-plant interactions to reduce the incidence and severity of disease. Other bacterial genera that have been effective as biological control agents include: Bacillus, Azotobacter, Agrobacterium, Clostridium, Streptomyces, and Arthrobacter. The principles and modes of action of these antagonistic interaction are not clearly understood. Antagonism may be developed in several ways:
   a. Colonization site blockage: Some argue that pathogen-antagonistic fluorescent pseudomoads may block pathogen infection sites physically.
      i. Attachment of fluorescent pseudomonads to plant surfaces may occur via water-soluble, protease and trypsin stable, protein-carbohydrate (lectins?) interactions to roots (Anderson & Jasalavich, 1979; Jasalavich & Anderson, 1981).
      ii. Pseudomonas fluorescens, a rhizobacterium, colonized roots, underground portions of stems, stolons, and progeny tubers in a lognormal distribution; the greatest populations occurred on the plant surfaces nearest the inoculated vegetative "seed" pieces (Bahme & Schroth, 1987). This bacterium reduced the severity and incidence of rhizoctonia rot on potato (Solanum tuberosum L.) tubers.
   b. Chemical responses. Antibiotics, hormones, siderophores, etc., produced by pathogen-antagonistic bacteria may affect pathogen-host interactions.
      i. Pyoverdines (pseudobactin) contains a hexapeptide bound to a fluorescent chromatophore and hydroxamate ligands, Cu^{2+}, Zn^{2+}, and Fe^{2+} reduce bacterial synthesis of pyoverdines; Mn^{2+} increases production. Pyoverdines are fluorescent when excited with ca. 400 nm light and produce fluorescent light at ca. 500 nm.
      ii. Systemic acquired resistance. At VPI&SU, evidence was developed that indicated that infection sites are not blocked but subsequent colonization of susceptible radish (Raphanus sativus L.) cortex cells was blocked by pseudomonads (Kroll et al., 1984). In this model, *Plasmoiophora brassicae*, the fungal causal agent of cabbage (*Brassica oleracea* L.) clubroot, was prevented from causing a high incidence or severe damage to a susceptible radish cultivar by a siderophore-producing pseudomonad. Since the primary colonization, inititated by zoospores, and subsequent secondary colonization by uninucleate amoeba of epidermal cells was not impaired, the blockage did not occur at initial sites of colonization. However, the numbers of binucleate amoeba found in cortex cells were significantly reduced. This reduction mirrored exactly the events which transpired in a resistant radish cultivar. Therefore the blockage of colonization within the cortex may have been related to bacterial release of small molecular weight compounds that altered the resistance of the host an induced defense mechanism. Recently it has been shown that rhizobacteria produce compounds related to the induction of systemic acquired resistance (SAR). For instance, *Pseudomonas aeruginosa* strain 7NSK2 inoculated on roots produces salicylic acid which induces systemic resistance resulting in resistance to leaf disease caused by *Botrytis cinerea* on bean (*Phaseolus vulgaris* L.) (De Meyer & Höfte, 1997). If salicylic acid produced by strain 7NSK2 or SAR is important in protecting roots from damping off caused by *Pythium splendens* in tomato (*Lycopersicum esculentum* Mill.) is not known. Similarly, the biological protection of thale cress (*Arabidopsis thaliana* [L.] Heyn.) against *Fusarium oxysporium* f.sp. *raphani* has been found to be due to activation of SAR by rhizobacteria (Van Wees *et al.*, 1997).

c. Predators. Predator actinomycetes and Gram-negative bacteria have been demonstrated in the soil. "Predator" bacteria cause populations levels of "prey" bacteria to be reduced. Gram-negative predators seem to dominate. If this phenomena is important for control of plant pathogens has yet to be demonstrated (Zeph & Casida, 1986).

Examples of biological control systems based on pathogen-antagonistic bacteria from Suslow (1982). (This section will be reviewed in greater detail in another chapter.):

Fluorescent pseudomonads control take all of wheat caused by *Gaeumanomyces gramminis* var. *tritici* (Suslow, 1982).

Arthrobacter spp. control rice rots caused by *Pythium ultimum* and *Fusarium oxysporium* f.sp. *lycopersici* (Suslow, 1982).

Arthrobacter spp. controls tomato rot caused by *Pythium ultimum, Arthrobacter* spp. and fluorescent pseudomonads controls carnation (*Dianthus caryophyllus* L.)wilt caused by *Fusarium oxysporium* f.sp. *dianthi* (Suslow, 1982).

Fluoresecent pseudomonads control flax (*Linum usitatissimum* L.) wilt casued by *Fusarium oxysporium* f.sp. *lini* (Suslow, 1982).

Fluorescent pseudomonads control *Rhizoctonia solani* and *Pythium ultimum* damping off on cotton (*Gossipium hirsutum* L.), tomato (*Lycopersicon esculentum* Mill.), field bean (*Phaseolus vulgaris* L.), and soybean (*Glycine max* [L.] Merr.) seedlings (Hagedorn, VPI&SU) Other studies, indicated that siderophores may not be the major determining factor in disease control (Hagedorn, Aceti, & Lacy, 1989). Ms Melinda Mulesky of our Department working with Dr. Charles Hagedorn, has shown that antibiotic-like substances are produced by these organisims, that root colonization is important in biological control, and that pH and soil type affect colonization of cotton roots. In other studies, these bacterium were found to control cotton rot caused by *Phymatotrichum omnivorum.*

Agrobacterium radiobacter reduces crown gall of numerous orchard and ornamental plants caused by T-DNA vectored by *Agrobacterium tumefaciens* (Lamb and Lacy, VPI&SU).

III. Classification of soil bacteria by their survival in soil. Survival in soil has been reviewed (Van Veen *et al.*, 1997). Among biotic factors, predation and competition reduce survival while root growth inhances survival. Clay minerals protect against predation. Other abiotic factors that affect survival include: water tension, organic carbon, inorganic nutrients (N, P), pH, and temperature.

A. Soil inhabitants: Indigenous organisms that persist for years without plant hosts (host may mean host susceptible to disease in some cases

Streptomyces scabies causal agent of potato (*Solanum tuberosum* L.) scab

Pseudomonas marginalis causal agent of soft rot of many hosts

Bacillus subtilis causal agent of seed rots of several plants. In Virginia Dr. Earl Grant, while a graduate student in this Department with Dr. Curt Roane, described a bacillus rot of Essex and York soybeans (*Glycine max* [L.] Merr.)

Clostridium spp. soft rot of many hosts, especially as a secondary pathogen in bacterial soft rot of potatos iniciated by *Erwinia carotovora*.

Ralstonia (Pseudomonas or Burkholderia) solanacearum bacterial wilt of solanaceous hosts and bananas

Agrobacterium tumefaciens crown gall of many dicotyledonous plants

Agrobacterium rubi crown gall of *Rhubus* spp.

Agrobacterium rhizogenes hairy root of many dicotyledonous hosts

Agrobacterium radiobacter plant-associated non-pathogenic bacterium

B. Soil invaders: depend on persistence of host tissue, do not persist without plant, disappear in days to months from soil
Clavibacter spp. causing wilts of many plants
Xanthomonas campestris pathovars. causing leafspots of many plants
Erwinia spp. causing soft rots of many plants
Pseudomonas syringae pathovars causing leaf spots of many plants

C. Reservoirs
Weed hosts harbor *Erwinia carotovora* subspp. *atroseptica* and *carotovora*

D. Factors of microbial interactions that affect bacterial survival in the soil
Bacterial yield: Assuming 24 h generation, 6-mo growing cycle, a 15 cm hectare slice, and 10^9 cfu/g, 2.3 x 10^6 kg/hectare minerals, and 2.5 X 10^{-13}g/bacterial cell, 3.9 kg/hec/day of bacteria may be produced. No estimates are available to indicate how fast or how slow bacteria may replicate during the winter in temperate areas
Nematodes harvest 800 kg of bacteria per hectare/yr
Protozoa graze on bacteria also--no estimate of harvest available
Other factors limiting bacteria population levels in soil antibiosis, bacteriocins, bacteriophage, bdellovibrio, and environmental factors including: temperature, moisture, pH, and clay adsorption.

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PHYLLOSPHERE INTERACTIONS: SHOOT AND LEAF-INHABITING BACTERIA

I. Phylloplane environment and colonization. The phyllosphere is the bacterial environment created by leaf surfaces. However, for this discussion, the phyllosphere encompasses all plant surfaces in contact with the atmosphere and is distinct from the underground portions of the plant which were discussed in the previous section.

A. Environment: The phyllosphere is a harsh environment resulting in wide fluctuations in populations of microorganisms. This fluctuation complicates the study of microbes on plant surfaces. Further, airborne and water splash depositon of microbes on plant surfaces makes it difficult to separate true residents on plant surfaces from surface contaminants. Pathologists must carefully interpret data concerning phyllosphere populations. Several reasons for the harshness of the environment exist:

1. **Nutrition:** The nutrient supply is limited. Water of guttation supplies less than 1.0 mg/ml (<0.1% wt/vol.) combined weight of dissolved amino acids, carbohydrates, and organic acids. Additional nutritional input from the plant is derived from leakage through the waxy cuticle and deterioriation of the cuticle itself.
2. **Temperature:** Temperature fluctuates hourly during the day and night since the atmosphere does not provide the insulation properties of the soil. In fall and spring and during a 24 h period, these changes may be as great at 35 C.
3. **Radiation:** Ultraviolet and infrared radiation are important on leaf surfaces. On the upper (adaxial) surface of the leaf, infrared radiation causes heating and ultraviolet radiation, at 256 nm, is bacteriocidal as well as mutagenic. Organisms may escape some effects of infared and UV radiaion by persisting on the lower (abaxial) surface of the leaf. Populations of bacteria are usually higher on abaxial surfaces.
4. **Humidity.** Water is limiting. Bacteria require free water for replication, but on the leaf surface, the relative humidity (RH) will vary greatly each day. Surprisingly, Hirano (1983) reported that *Pseudomonas syringae* pv. *syringae* and *Pantoea herbicola* continue to multiply even during times of low humidity. She suggests that hydrophilic and absorptive bacterial extracellular polysaccharides (EPS) may be important in maintaining holding water in close proximity to the cell even though free water is lacking on the leaf surface. Populations of *Xanthomonas campestris* pv. *vesicatoria* increase at high RH (>90%), fluctuated erratically at moderate RH (50-65%), and declined to nondetectable levels at low RH (10-25%). Bacteria did not survive well on tomato (*Lycopersicon esculentum* Mill.) plants sprayed with the pathogen and placed immedately under unfavorable RH conditions. However, if the plants were held for 48 h under favorable conditions before being placed in adverse conditions, surface populations declined very slowly and populations in leaf homogenates remained high (Timmer, *et al.*, 1987). Extracellular polysaccharides, such as alginate, may be important for surviving dessication. In *Pseudomonas syringae* pv. syringae, expression of some genes involved in alginate production was optional at 32 C which may correspond with the formation of an alginate capsule (Peñaloza-Vázquez *et al.*, 1997). This temperature is above the replication temperature (_ 30 C) for this organisms and may indicate that production of alginate is triggered by harsh conditions including infrared heating.
5. **Anatomy of the leaf.**

   Erectness of leaf may expose or protect bacterial populations to environmental rigors. Erect leaf blades of grasses such as maize (*Zea* maysL.) will provide less protection on their abaxical surfaces than clover (*Trifolium* spp.) leaves which are well-shaded on their abaxial surfaces.

   Leaf thickness. Thickness of a leaf will expose or protect bacteria from environmental rigors. Larger or thicker leaves provide greater insulation from temperature changes.

Surface phenomena. Very close to the leaf, humidity changes more slowly since the speed of air moving over the leaf is influenced by the adherence of the boundary layer of air to the leaf surface.

Pubescence. The relative size, number, and density of trichomes affects the thickness of the boundary layer. Hairly leaves, such as found on soybean (*Glycine max* [L.] Merr.), maintain moisture better than less hairly leaves such as found on field beans (*Phaseolus vulgaris* L.).

Cuticle. Cuticles may be thicker and less likely to leak nutrients or they may be thinner and more likely to leak. Further, they may be rough or smooth. Scaly, rough cuticles favor maintaining higher bacterial populations.

Stomata, lenticels, and hydathodes. Plant openings such as stomata (on flat leaf surfaces), lenticels (on stems), and hydathodes (at the edges of leaves) favor population increases among bacteria since both humid gases and some nutrients escape to the leaf surface via these apperatures. These openings provide access bacteria to the interior of the leaf and are therefore important in pathogenesis.

Intercellular interstices. The depressions in the cuticle at junctions of epidermal cell walls on leaf surfaces provide locations for higher bacterial populations.

Veins, veinlets, and veinules. The crevices and grooves formed between the leaf blade and these structures provide locations for higher bacterial populations.

Trichomes. Likewise, the bases of trichomes provide locations for higher bacterial populatuins. Broken trichomes release nutrients and are often colonized heavily.

B. Nature of prokaryotes on leaf surfaces. Bacteria found in the phyllosphere originate from soil, water, other plants, seeds, or they may be vectored by animals especially insects.

1. Populations of organisms are lower on plant surfaces than in the soil because of the relative harshness of this environment compared to the soil. Populations vary from 10^{2-6} per cm^2. However, the microbiota represent groups familiar from the soil: eubacteria, actinomycetes, cyanobacteria, mycelial fungi, yeasts, mites, and nematodes.

2. Classes of bacteria.

a. Casual organisms. Casual bacterial populations are composed of airbiota derived from the soil, roots, water, and other sources deposited upon the leaf. Populations of these organisms, although occasionally very high, decrease with time. They do not establish a nutritional relationship with leaves. Occasionally, some of these organism may establish a nutritional relationship with senescent plant tissue. Examples: *Bacillus* spp., *Micrococcus* spp., *Clostridium*, *Escherichia coli*, *Pseudomonas fluorescens*, *P. putida*, *Agrobacterium radiobacter*, *Erwinia carotovora etc.* Casuals from the soil are found in higher numbers on plant surfaces closer to the ground.

b. Residents. Provided that a nutritional relationship is established and populations are maintained over a lengthy period of time, organisms are classified as residents or epiphytes. Since populations of these epihytes may fluctuate greatly over time, this relationship may be difficult to establish. To compound this problem, casuals may seem to persit or even multiply since the sources for these air-deposited organism in nature may be repititious in nature. Examples:

Pantoea herbicola (ice nucleation active, rarely an invasive pathogen: brown spot soybean [Glycine max {L.} Merr.)

Erwinina amylovora (fire blight of rosaceous plants)

Xanthomonas campestris pv. campestris (black rot of cole crops)

Xanthomonas campestris--numerous other pathovars

Pseudomonas syringae pv. syringae (ice nucleation active, brown spot of beans, and pathogens of numerous other pathovars

Pseudomonas aeruginosa (facultative human pathogen--pyogenic infections of humans and animals [green pus], facultative soft rot pathogen of many plants)

Some organisms may be residents on hosts that they are not pathogenic upon. Examples:

Pseudomonas syringae pv. syringae is a resident/pathogen on bean (Phaseolus vulgaris L.), sour cherry (Prunus cerasus L.), pear (Pyrus communis L.), and tomato (Lycopersicon esculentum Mill.). It is a resident/non-pathogen on hairy vetch (Vicia villosa Roth) and weed grasses.

Pseudomonas aeruginosa is reported to be weakly pathogenic on chrysanthemums (Chrysanthemum morifolium Ramat.) and able to multiply or persist for considerable periods in or on various plants. Since this organism is an opportunistic pathogen of humans, especially burn patients and others with damaged or depressed immune systems (acquired immune difficiency syndrome--AIDS), flowers should not be received by certain classes of patients at hospitals (Cho, et al., 1974).

C. Attachment to leaves. Pseudomonas syringae pv. lachrymans,causal agent of angular leafspot of cucumbers (Cucumus sativus L.), adheres more tightly to its host compared to non-host plants. On host plant leaves inoculated by dipping in suspension of the pathogen, 8 to 48% of the colony forming units (cfu) are removed by gently washing. However, 60-89% cfu are removed from non-host cultivars of cucumbers.

D. Penetration into leaves and stems.

1. Cutinases. As a general principle; prokaryotes are usually believed to lack the ability to force their way into host plants. Penetration by these pathogens is usually effected through natural openings or wounds. However, this principle of "non-invasiveness" is inaccurate because of the following exceptions:

   Streptomyces scabies, causal agent of potato (Solanum tuberosum L.) scab, produces cutinase which allows fungal-like penetration of tuber epidermal layers of cells.

   Cutinase-producing pseudomonads cohabiting with nitrogen-fixing coryneform bacteria in the phyllosphere of mung beans (Vigna radiata [L.] R. Wilczek). In that phyllosphere, Pseudomonas putida provides the shared the carbon source for both organisms by cutinase degradation of the leaf surface while the coryneform shared fixed nitrogen with the pseudomonad (Sebastian, et al., 1987).

2. Stomates. Stomates, organs for gas exchange on plant leaves, form openings available for bacterial pentration. A leaf may have 50 to 300 stomata/mm2. Stomates are most often located on abaxial (lower) surfaces of leaves. Maize (Zea mays L.), has stomates on both sides of leaves. Open stomatal openings average 4 X 26 symbol 109 \f "Symbol"m or 104 symbol 109 \f "Symbol"m2. They are smaller when closed, but continue to form a path for bacterial pentration.

3. Substomatal chambers. The void immediately inside a leaf from the stomatal opening provide sites for replication for Pseudomonas syringae pvs. glycinea and phaseolicola.

4. Lenticels. Lenticels are structures on the surface of stems (and tubers) which allow exchange of gases from internal plant structures with the atmosphere. They may also allow entry of pathogenic bacteria. Lenticels penetrate the periderm (= phellum or suberized cork cells) and expose the phelloderm (cortex) to gaseous exchange. Suberin interferes with pectate lyase activity (Hankin & Zucker, Ann. Bot. 34:1047-1062, 1970) of soft rot pathogens. The phellogen is the meristematic tissue which produces the filling cells that block the opening of lenticels. During episodes of high humidity the phellogen ruptures allowing the entry of pathogens such as *Erwinia carotovora* subsp. *carotovora*

5. **Nectaries.**

   Nectarthodes are the glands which produce secretion of sugar and water.

   Nectaries are the location of the openings of nectarhodes and are usually fournd near the bases of the pistil and sepals. Nectaries of pears (*Pyrus communis* L.) more accessible than apple (*Malus sylvestris* Mill.) to *Erwinia amylovora*

6. **Hydathodes.** Are openings on the edges of leaves through which waters of guttation escape usually early in the morning or when humidity is extremely high. *Xanthomonas campestris* pv. *campestris*, causal agent of black rot of crucifers commonly enters cabbage (*Brassica oleracea* var. *capitata* L.) plants in this manner causing a distinctive "V" shaped black rot lesion at the edges of the leaf.

7. Abscission scars. A periderm forms at the abscission layer, petiole cells are destroyed by cellulase, the leaf falls, and, finally, wound gum fills the leaf traces, cells. Several pathogens enter the plant through abscision regions:

a. Leaves. Several pathogens enter via vessels of the leaf traces:

Pseudomonas syringae pv. *savastanoi*, causal agent of olive (*Olea europaea* L.) and oleander (*Nerium oleander* L.) knot

Pseudomonas syringae pv. *morsprunnorum*, causal agent of cherry (*Prunus cerasus* L. and *P. avium* [L.] L.) canker

Xanthomonas campestris pv. *pruni*, bacterial spot of stone fruit especially peacy (*Prunus persica* [L.] Batsch).

b. Petioles. *Erwinia carotovora* subsp. *carotovora* enters tomato (*Lycopersicon esculentum* Mill.) fruit via the petiole vascular system especially when fruit is picked green, placed in a cold wash whereby the gases within the fruit contract causing a partial vacuum in the vessels and pulling infested water into the plant. Penetration is also aided by hydrostatic pressure resulting from immersion of the fruit (Bartz, 1982).

8. Trichomes. Trichomes are divided into two kinds; glandular and foliar. Glandular trichomes often contained compounds which are repellant or antagonistic to insects and/or pathogens. Foliar trichomes often prevent wetting of plant surfaces (this is especially true of soybean leaves). However some pathogens utillize trichomes, especially foliar ones, as a site for survival or plant entry including:

Corynebacterium michiganese pv. *michiganens*e multiplies in broken trichomes and may enter the plant via that route.

Pseudomonas syringae pv. *tomato* survives in trichomes during dry periods

Pseudomonas syringae pv. *lachrymans* survives on cucumber in a similar manner.

9. Secondary movement: Movement from the point of entry or penetration is important in establishing pathogenesis. Application of *Xanthomonas campestris* pv. *pruni* to peach (*Prunus persica* [L.] Batsch) by spraying into intercellular spaces of non-wounded leaf surfaces resulted in spring cankers in twigs (Du Pleiss, 1987). Scanning electron microscopy (SEM) indicated that *Pseudomonas syringae* pv. *morsprunorum* applied to sour cherry (*Prunus cerasus* L.) by spraying probably gained entry through stomata and spread intercellulary from the mesophyll through the parenchyma of the bundle sheath into the vascular system of a minor vein. Once a vein had been entered, migration occurs to the leaf blade and petiole (Roos & Hattingh, 1987). Likewise, *Pseudomonas syringae* pv. *syringae* introduced into plum (*Prunus domestica* L.) shoots systemically moves into leaves and shoots via the xylem (Roos & Hattingh, 1987).

II. Interactions in the phylloplane.

A. Interactions among prokaryotes.

1. Parasitism. Parasitism occurs among bacteria in the phylosphere.

Bdellovibrio, a bacterial predator, attachs other bacteria including plant pathogens.

2. Nutrient competition.

Pantoea herbicola (acid tolerant) utilizes nectar and produces acid from nitrogen sources in pear (*Pyrus communis* L.) blossoms faster than does *Erwinia amylovora* (acid intolerant) thus depriving the pathogen of nutrients and providing an it with an unsatisfactory environment.

3. Antibiotic production. Chemical antagonism provides bacteria with a competitive advantage for colonization space and nutrients on the leaf surface.

7% of 358 epiphytes produce antibiotics active against *Pseudomonas syringae* pv. *glycinea.*

Pseudomonas fluorescens produces antibiotics active against fungi and *Pseudomonas syringae* pv. *phaseolicola*. This antibiotic is translocatable

All strains of *Pseudomonas syringae* pv. *syringae* produce bacteriocins with a wide spectrum of activity

Pseudomonas syringae pv. *phaseolicola* produces a few bacteriocins with narrow spectra

Pantoea herbicola produces several bacteriocins active against *Erwinia amylovora*

4. Stimulation of the host's defenses. Non-compatible phytopathogenic bacteria or their products may induce systemic acquired resistance in plants.

Pseudomonas syringae pv. *tabaci* and *Erwinia amylovora* stimulate tobacco (*Nicotiana tabacum* L.) defenses so that super-colonization by other pathogens is reduced. Heat killed cells also work.

Likewise, the defenses of apple (*Malus sylvestris* Mill.) are induce by *Pantoea herbicola* and *Pseudomonas syringae* pv. *tabaci*. Heat killed cells also work.

III. Interactions among prokaryotes and fungi: Hyphasphere concept: like the phylloshere, bacteria may inhabit the hyphasphere of fungi establishing a nutritional association. In the phyllosphere and rhizoshere/rhizoplane, many bacteria seem to be associated with fungi. The basis for this association is that fungi, like all other living organisms, excrete outside there cells compounds which may be used as nutrients by bacteria. Carbohydrates probably are most important in respect to bacterial colonization. This is ths source of stubborn bacterial contamination of fungal culture collections. There is also evidence that phycomycetes, such as *Pythium* spp.,assist the spread of soft rot and leaf spot organisms.

A. Parasitism. Bacteria may be parasites and/or pathogens of fungi.

Ustilago zeae spores lyzed by bacteria

Erwinia uredovora lyses uredospores of cereal rusts. In PPWS, experiments by Dr. John Skelly (later head of the Department of Plant Pathology at Pennsylvania State University) on the effects of air pollution on bean (*Phaseolus vulgaris* L.) rust, lesions numbers were difficult to determine. On examination, it was observed that spores suspended in water no stained with vital stains (Congo red) and were collapsed (lyzed) and were ineffective as inoculum. Why?

Bacillus spp. destroys spores of *Puccinia recondita*

Bacillus pumilus destroys spores of *Helminthosporium sativum*

Pseudomonas fluorescens reduces the germination of *Dreschlera dictyoides* on grasses (*Lolium* spp.).

Bacteria lyze the germtubes of *Colletotrichum gloeosporides.*

B. Nutrient competition: "Soil fungsitasis".

The germination of *Botytis cinerea, Phoma beta*, and *Cladosporium herbarum* are prevented when bacteria scavenge the nutrients required for germination from the leaf surfaces.

Nutrient competition inhibits elongation of *Colletotrichum* germ tubes.

Some fungi are stimulated by the nutrient competition, *e.g., Uromyces vicia-fabae.*

C. Antibiotic production

Bacillus spp. produce antibiotic activity against *Botrytis cinerea*, *Nectria galligena,* and *Rhizoctonia solani*

Pseudomonas spp. inhibit *Botrytis cinerea, Dreschlera maydis, Rhizoctonia*, and *Pythium ultimum*.

Siderophores (pyroverdines similar to pseudobactin) aids germination by *Colletotrichum musae* by scavenging iron. Lesion sizes and numbers are increased by the presence of bacteria.

Chelating agents may change the reaction of plants to change from resistant to susceptible for *Colletotrichum lindemuthianum*

D. Mychorrhizal associations. Fluorescent pseudomonads enhance the formation of ecto- and endo-mycorrhizal associations. In experiments by Dr. John Skelly in this department, mycohrrhizal associations failed in steamed potting mix to which only white

pine (*Pinus strobus* L.) seelings (also germinated in steamed potting mix) and mycorrhizal fungi had been added. Why?

IV. Ice nucleation activity (Lindow, 1982)

A. Ice formation: at low temperature (-40 C) homogeneous ice nucleation, the random ordering of water molecules into ice lattices, is most important. At warmer temperatures, heterogenous ice nucleation is most important. Silver iodide nucleates at less than -8 C, while most organic and inorganic materials such as dust particles nucleate at temperatures less than -10 to -15 C. Warm temperature ice nucleation catalyzed by certain bacteria may occur at temperatures as warm as -2 to -5 C.

B. Discovery. Northern corn (maize; *Zea mays* L.) blight (*Helminthosporium turcicum*) inoculum from infested leaves which had been dried and ground, caused blocks of maize to frost at relatively warm temperatures..

C. Ecological advantage. Populations of ice nucleating bacteria increase rapidly during the warmer daytime periods following warm temperature frost events probably inresponse to nutrients released from ice damaged cells.

D. Control. Controls for warm temperature frost damage (WTFD) utilize standard methods for controlling bacterial plant pathogens and limiting frost damage:

Controls for pathogenic bacteria	**Controls for frost damage**
copper-containing formulations including cupric hydroxide and Bordeaux mix	smudgepots
antagonistic bacteria	water spraying
antibiotics such as streptomycin and oxytetracycline	moving air
pH extremes	
cationic detergents (unlike anionic stickers and spreaders used commonly in agriculture)	

E. Frost tolerant plants.

Intercellular ice. Ice is limited to intercellular spaces instead of being damaged by the formation of intracellular ice which causes membrane breakage.

Slow cooling. Frost tolerance is also attributed to slower rates of cooling which causes a removal of intracellular water to freeze in equilibrium with the intercellular ice

F. Insect freezing. Insects feeding on plants colonized by epiphytic ice nucleation active (INA) bacteria are often killed by warm temperature frosts.

G. INA bacteria in the atmosphere. INA bacteria are very important in ice nucleation events leading to precipitation including rain and snow.

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FASTIDIOUS ENDOPHYTES

I. NATURE AND IMPORTANCE. Endophytes. Endophytes are plant-associated prokaryotes that form nutritional associations with their host plant within its tissues. Phytopathogenic prokaryotes are a subset of these organisms which cause recognizable symptoms of disease. Strictly defined, all phytopathogenic prokaryotes are endophytes; however, this section is devoted to the examination of nutritionally fastidious prokaryotes including phytoplasmas, *Spiroplasma* spp., fastidious xylem- or phloem-limited bacteria (FXLB or FPLB), and *Clavibacter xyli*. These organism, except *C. xyli*, are vectored by insects and depend upon their insect hosts to penetrate the plant's anatomical defensive barriers and place them into the host's xylem or phloem.

Fastidious endophytes. Most non-fastidious endophytic prokaryotes may be cultured on simple agar media containing chemically-defined inorganic or simple organic compounds. They have some portion of their disease cycle separate from the host plant and insect vector--often existing as epiphytes on the surface of plants. The common denominator for fastidious prokaryotes is that they are restricted to vascular habitats in plants or are located within the insect lumen or hemolymph-bathed organs. Their growth requirements, when known, include highly complex molecules and substrates. Among these complex growth requirements are gamma-globulin-free horse serum, fetal bovine serum, and hemin-chloride. Most fastidious prokaryotes have not been cultured. It could very well be that fastidious, insect-vectored prokaryotes, in their completely parasitic life style, have simplified their genomes and, consequently, their metabolic capabilities. They have lost the ability to synthesisze several essential compounds, including some amino acids, and now satisfy those reqirements for life by utilizing complex materials.

Non-fastidious endophytes. The endophytic pathogenic stages of non-fastidious prokaryotes will be discussed in later sections dealing with the principles of plant damage in pathogenesis. Those sections include the toxin-producing pathogens (*i.e., Pseudomonas syringae* pv. *phaseolicola*), enzyme-producing pathogens (*i,e., Erwinia carotovora*), tumor-inducing pathogens (*i.e., Pseudomonas syringae* pv. *savastanoi*), and the wilt-inducing pathogens (*i.e., Clavibacter michiganense* subsp. *michiganense*).

History and naming fastidious endophytic prokaryotes. In the past, because mycologically-oriented pathologists failed to culture fungi from or observe them in tissues colonized by fastidious endophytic prokaryotes, their symptoms were attributed to abiotic conditions (*i.e.*, drought for marginal necroses of forest trees) or other biotic causal agents (*e.g.*, plant viruses).

> <u>European period in Ameican applied mycology</u>. In the 1900's through the 1960's, American pathologists were so strongly influenced by the European mycologists who founded modern plant pathology. It is no accident that many if not most American pathologists of that period could proudly traced their training "genealogies" back to those great mycologists. Americans even copied their non-scientific prejudices, rejecting perhaps out of some ideal of "ethnic purity" the idea that bacteria could be plant pathogens. European and Ameican pathologists maintain this prejudice even today. For instance, in his textbook "Bacterial Plant Pathology: Cell and Molcular Aspects", David Sigee (1993) states that "fungi are generally more important that bacteira as plant pathogens". What about warm temperature frost damage which was estmated to cause $1.5 billion in damage in 1982? Like their European antecedents, American pathologists seemed willing to overlook that their own countryman, Erwin F. Smith who, in a sensational series of controversial scientific confrontations with European plant pathologists, established conclusively that bacteria were plant pathogens through carefully controlled scientific experiments.

Two examples of how anti-bacterial prejudice dominated our thinking consider Anaheim disease of grape (*Vitis vinifera*) and X-disease of peach (*Prunus persica*). Anaheim disease was associated by an American pathologist in the last decade of the 19th century with non-culturable bacteria which could be forced (using pliers) from the petioles of grape leaves with symptoms. Despite that published observation, those bacteria were ignored without benefit of comment in the literature as the causal agent and a probable viral causal agent was assumed until 1973. For the second example, in the 1930's Ernie Stoddard, an American pathologist at the Connecticut Agricultural Experiment Station in New Haven, found that symptoms of peach X disease (a yellows disease) could be remitted using newly discovered sulfanilamide drugs. These drugs are effective against pathogenic bacteria in mammalian disease. His work, clearly indicating a prokaryotic involvement with a second yellows disease, was ignored in the arrogance of the mycological-virological orientation of plant pathology of the times.

Forest pathology and endophytic bacteria. Until recently, most forest pathologists recognized that prokaryotes cause important diseases of domestic trees (Peach X-disease, fire blight, almond scorch, *etc.*) rejected the idea that prokaryotes caused important diseases among forest trees. Those persons did not reckoned with the fact that elm yellows, caused by a phytoplasma, may well cause the extinction of the American elm (*Ulmus americana*) if Dutch elm disease does not. Further, ash yellows affects millions of ash trees in re-growth forests in the northeastern and midwestern United States. Finally, xylem-limited bacteria, similar to *Xylella fastidiosa*, are now believed to be important pathogens of oaks (*Quercus* spp.) and sycamores (*Platanus* spp.) causing scorch symptoms. In Virginia, this pathogen probably is the cause of yellowing and margin necrosis of such disparate plants as Virginia creeper and indigenous oak and maple (*Acer* spp.) species.

Japanese period of the history of fastdious prokaryotes. In 1971, Japanese researchers observed that non-culturable organisms resembling mycoplasmas (cell wall-less animal parasites and pathogens) were associated with yellows disease of plants in transmission electron microscopy (TEM) micrographs of phloem vessels. Up until this time Ameican plant pathologists had explained these structures either as "artifacts of tissue preparation" or "viral inclusion bodies". However, it was demonstrated that these "mycoplasma-like ogranisms" (MLOs), now known as phytoplasmas, could be transmitted from plant to plant by grafting or the parasitic plant dodder (*Cuscuta* spp.). Upon transmittance, their establishment and colonization within the phloem was associated with the development of yellows symptoms. Further, remission of yellows symptoms as well as disappearance of the phytoplasmas could be obtained using the same strategy developed over 30 years earlier by the Americian Stoddard, using anti-prokaryotic antibiotics including tetracyclines. In the early 1970's, Dr. Gary Hooper, then at Michigan State University and later Chairperson of our Department (1980-84) and Vice Provost at VPI&SU (1984-90), was one of the most prolific American pathologists in the rediscovery of the prokaryotic nature of the causal agents of yellows diseases as an electron microscopist at Michigan State. He employed the simple expedient of re-examining by TEM embedded sections of tissues from many different yellows-diseased plants noting the lack of viruses and the incidence of the theretofore overlooked phytoplasmas.

American period. American pathologists quickly accepted the Japanese rediscovery of the prokaryotic nature of the yellows pathogens and went on to make many if not the major contributions to the field. In 1970, the causal agent of citrus stubborn (a yellows disease) was cultured and subsequently named *Spiroplasma citri*. This organism resembles phytoplasmas in TEM sections of phloem vessels, but in vigorously growing young cultures were associated with spiral bacteria-like organisms motile by a spring-like flection of their essentially cell wall-less cells. Spiroplasmas, believed to be related in a general manner to

Phytoplasmas, are known to cause many plant diseases, are found as epiphytes in the nectaries of some plants (tulip poplar--*Liriodendron tulipifera*), and some morphologically-similar organisms cause disease in animals.

In 1973, the causal agent of leaf scorch of almond (*Prunus amygdalus*)and Anaheim disease were found to be caused by a single endophytic, fastidious, and xylem vessel-limited bacterium with a "rippled" Gram-negative cell wall. The outward resemblence of its cell wall to those of bacteria of the genus *Rickettsia* (often associated in mammals with tick-vectored pathogens) earned these scorch pathogens the general name "rickettsia-like organisms" (RLOs). Since culture of the plant pathogens on complex media has allowed molecular comparisons, it has been established that these organisms are not related to *Rickettsia* spp. Therefore the applelation, RLOs, is incorrect. A general term for these organisms is "fastidious xylem-limited bacteria" or FXLBs for acronyms lovers everywhere.

Recent terminology. In 1994, the genus *Phytoplasma* was accepted by the American Phytopathological Society to represent those non-culturable, cell wall-less mycoplasma-like prokaryotes assoicated with yellows diseases. As molecular taxonomy and cultural methods continue to improve, this term may prove either to be a benefit or one more inaccurate and confusing name.

Evolution of fastidious prokaryotes. Some people theorize that the fastidious nature may reflect long association with the host. That disease caused by fastidious prokaryotes often is of a chronic nature (progressing slowly) seems to have affected the development of this hypothesis. The hypothesis is that after long periods of co-evolution and accomodations with their hosts these organisms have lost the ability to cause acute disease and have abandoned, presumably to save biological energy, the ability to synthesize simple and complex nutritional requirements but depend instead upon their host to provide these nutrients. Plant pathologists often forget that evolution to accomodate the association with the plant is also necessary. This group of pathogens is very special. They are evolved and specialized to exist successfully in two different hosts--plants and insects. Each association is the product of long and successful evolution. Survival and colonization in the insect vector replaces the epiphytic, resident phase of non-fastidious epiphytic bacteria.

General information about fastidious endophytes. The etiological role of bacteria and fungi which were easily cultured was established early in the history of plant pathology. The role of these fastidious endophytes was not easily elucidated and these diseases were often passed off as virus-induced, even though no specific evidence indicating their presence was found. In 1967, the discoveries that mycoplasmalike bodies occurred in sieve elements of yellows-diseased plants and that treatment with the antibacterial antibiotic tetracycline, but not penicillin, caused symptom remission and the disappearance of these bodies, established the concept that these diseases may be caused by prokaryotes. Because the nature of these pathogens has been recognized rather recently and because they have been, and often continue to be, difficult to work with, very little is known about the disease processes they induce in plants, about mechanisms controlling their pathogenicity, or even about their taxonomic positions and relationships. The mechanisms by which fastidious endophytes move through vascular tissues is unknown. The rate is probably influenced by the pathogen itself, the host, the amount of introduced inoculum, and even the time of year at which inoculation occurs. These organisms have no known resting stage or protective structure to carry them through periods of adverse temperatures or conditions.

II. HABITATS: THE XYLEM AND PHLOEM. Xylem. The xylem distributes water throughout a plant using non-living conducting tubes, the vessel elements and tracheids. Vessel elements are stacked end-to-end to form long tubes several centimeters to several meters long. Adjacent vessels are connected to membrane-lined pits through which water must flow to pass

laterally from vessel to vessel. Transpiration from the leaves pulls water upward against gravity, resulting in a tension on the water columns in the vessels--usually less than atmospheric pressure, often -5 to -10 atm xylem pressure. The wilting point of most plants occurs at -12 to -15 atm xylem tension. At the permanent wilting point, xylem vessels embolize; developing water vapor or air bubbles that block vessels effectively so that they are no longer able to conduct water. The xylem sap environment contains less than 1.0 mg/ml dry weight of nutrients and has a low osmotic potential of about 0, a water potential of -30 bars. The nutrients consist of simple sugars, amino acids, and organic acids. The paucity of nutrients is misleading; this is not a nutrient-poor environment since prokaryotic cells living in that environment are bathed in a constant flow of xylem sap.

Phloem. The phloem is composed of living cells, the sieve tube elements, which are stacked end-to-end to form long conduits through which photosynthetic products are transported throughout the plant. There are sieve plates containing pores at the ends of the sieve tube elements. The phloem sap is a highly concentrated organic soup. The phloem sap environment, in sharp contrast to the nutrient poor xylem sap, contains 15 to 30% dry weight of solid materials, mainly sucrose, and has a high osmotic potential of -21.7 bars and a turgor pressure ranging up to 30 atm. The pressure is so high that organisms inhabiting the phloem do not require cell walls. The phloems cells communicate via sieve plates at each end of the cell that allow direct cytoplasm-cytoplasm connections. The diameter of the pores in these cells is on the order of few _m and restricts the movement of prokaryotes to some extent.

III. EVOLUTION OF INSECT VECTORS FOR PHYTOPATHOGENIC PROKARYOTES. Most vascular tissue-inhabiting organisms also have alternate insect hosts that serve as vectors. Very little is known about the internal habitat in the vectors. The phloem-inhabiting phytoplasmas multiply systemically within their vectors and can pass through the insect's salivary glands to inoculate plants. Apparently, the saliva lubricating the insect's mouth parts contaminates phloem sap. The xylem-inhabiting,, Gram-negative bacteria accumulate in the insect's foregut where they appear to multiply. They may be "regurgitated" into the mouth parts to become available for plant contamination during insect feeding. In contrast, the Gram-positive, xylem-inhabiting ratoon stunting bacterium, *Clavibacter xyli*, is mechanically transmitted and does not seem to require or have an insect vector. This may be the result of long association with sugarcane (*Saccharum officinarum*) culture which requires mechanical cutting of nodes of the plant for vegetative propagation. Logically enough, xylem-feeding insects transmit xylem-limited bacteria and phloem-limited organisms are vectored by phloem-feeders. Considering the diversity of fastidious endophytic prokaryotes and their vectors, certainly the relationships among these organisms developed separately many times during evolutionary history. The section below outlines in general how these relationships may have developed.

A. Casual attachment.

Casual attachment of the pathogen to the exterior of the vector; no nutritional relationship:

Erwinia amylovora, causal agent of fireblight of roseascous plants is vectored by various flies, bees, and aphids.

Erwinia carotovora , the soft rot pathogen of many plants, is vectored by many insects including:

Drosophila melanogaster, the fruit fly.

Presence of the bacterium in the lumen of the insect, often the bacterium is important in the development and maturation of the insect larvae:

Erwinia carotovora , the soft rot pathogen of many plants, is vectored by many insects including:

Hylemya antigua, the onion (*Allium cepa*) maggot, which requires bacterium for maturation of young

Macronoctua onusta, the iris (*Iris* spp.) borer requires bacterium for maturation of young

Cactoblastis cactorum, the prickly pear (*Opuntia* spp.) borer, requires the bacterium for nutritional assistance of its proteases and maturation of its young

Hylema platura, the seed corn maggot, transmitts the black leg pathogen to potato (*Solanum tuberosum*) on infested eggs at oviposition and, as a normal inhabitant of the insect gut, provides the host with nutrients from modified plant materials

Pseudomonas syringae pv. *savastanoi* olive (*Olea europaea*) knot pathogen

Dacus oleae, the olive fly, requires bacterial proteases for nutrition

B. Overwinter survival. Insect required for overwinter survival of the pathogen; exterior attachment and no-nutritional relationship.

Erwinia tracheiphilia, the cucurbit wilt pathogen, is vectored by *Acalymma vittata*, the striped cucumber beetle (formerly *Diabrotica vittata*) and *Diabrotica undecimpunctata* the spotted cucumber beetle. It over winters on the beetle.

Erwinia stewartii the causal agent of Stewart' wilt is vectored by the corn flea beetle, *Chaetocnema pulicularia*.

C. Multiplication in vector. Pathogen multiplies in the vector, no part of its life cyle external to plant or insect hosts; nutrionally dependent on the plant and insect.

1. Phytoplasmas. These agents are extremely small, possess no cell wall, inhabit the sieve tubes of plants with yellows diseases, are transmitted by phloem-feeding leafhoppers, and require sterols for growth. Phytoplasmas are associated with the yellows diseases (**Table 1**). Symptoms may include: yellowing, chlorosis or bronzing of foliage, stunting (shortening of internodes, reduction of leaf size), proliferation of axillary buds often resulting in a witches'-broom effect, virescence (greening), proliferation of secondary roots, abnormal fruit and seeds, and sterile flowers. Important examples are aster yellows, coconut lethal yellowing, stolbur, elm yellows (phloem necrosis), *Paulownia* witches'-broom, pear decline, tomato big bud, and peach X. The yellows diseases, in general, respond to tetracycline antibiotics, but not to penicillin. Phytoplasmas have a variable cellular morphology (pleomorphic) ranging from spherical to elongated to filamentous, with diameters averaging 0.3 to 0.8 _m. Small rounded and large globular bodies have been reported predominately in late season or advanced pathological stage while branched filamentous forms have often been reported in early season or in early stages of disease. Since these are thin-section electron microscopy studies, shapes may be mistaken. Cells contain DNA and ribosomes, are limited by a single unit membrane, and have no membraneous inclusions. Phytoplasmas appear to be transmitted by leafhoppers, grafting, and parasitic dodder (*Dodder cuscuta*). Direct proof of pathogenicity is lacking. They are often found in the mature sieve elements of the phloem where their distribution is uneven. The early stage symptom development suggest an impairment of phloem function or a plant growth regulator imbalance or both. The blockage of sieve pores by callose deposits and/or their occlusion by phytoplasmas might impair phloem transport in colonized plants. The phytoplasma might produce toxic substances which may contribute to phloem necrosis, but no compelling evidence for this exists. Electron microscopy sections present evidence that phytoplasmas may move from one phloem sieve tube to the next by moving through the pores in phloem sieve plates (Hartmann *et al.*, 1971).

Table 1. Spiroplasma and phytoplasmas pathogens and some of their important vectors.

Disease	Pathogen	Vector
		Leafhoppers
Citrus stubborn	*Spiroplasma citri*	*Circulifer tenellus*
Corn stunt	*Spiroplasma maydis*	*Dalbus maidiis*
X-disease of peaches	X-disease phytoplasma	*Scaphytopius acutus*
		Paraphelepsis irroratus,
		Colladonus montanus
Aster yellows	Aster yellows phytoplasma	*Macrosteles fasifrons*
		Psylilids
Pear decline	Pear decline phytoplasma	*Psylla pyricola*

2. Spiroplasmas have a characteristic helical morphology, are often culturable, and cause stubborn or little leaf disease of citrus and brassicaceous plants, brittle root of horseradish, corn stunt disease, and diseases in cherry (*Prunus cerasus*) , peach (*P. persica*), pear (*Pyrus communis*), and vinca (*Vinca rosea*). Citrus stubborn disease symptoms include smaller, acorn-shaped fruit, fruit may taste bitter, trees stunted, and chlorotic leaves. Apparently, phytopathogenic spiroplasmas, although limited to phloem tissue, are distributed systemically throughout all organs in infected plants. This distribution can be uneven, however. Major symptoms caused on plants by spiroplasmas include stunting, chlorosis and yellowing, reduced fruit size, reduction of leaf and flower size, necrosis, and wilting. Spiroplasmas have been reported to possess plasmids. Hypotheses for mechanisms of pathogenesis include: blockage of phloem sieve tubes, translocatable toxins, phytotoxic lactic acid production, and/or interference with normal plant hormone balance.

Spiroplasma spp. is epiphytic in flowers of the powder puff plant (*Calliandra haematocephala*). This observation is important since this organism and other spiroplasmas epiphytic on tulip trees (*Liriodendron tulipifera*) are the first phytoplasma known to occupy habitats outside of plant phloem and insect hemolymph (McCoy *et al.*, 1982).

2. Fastidious phloem-limited bacteria (FPLB). The Gram-negative, phloem-inhabiting bacteria have not been cultured *in vitro*, but in electron micrographs they were found to be bounded by a dual membrane, with a rippled outer layer. They are small, ca. 0.3 x 1.3 _ m, rigid, rod-shaped, nonmotile bacteria sensitive to both tetracycline and penicillin. These agents are associated with citrus greening and clover club leaf (**Table 2**). Symptoms are characteristic of the yellows-type diseases and may include: stunting, yellowing of young leaves, leaf curling and twisting, uneven expansion of leaves, virescence of flower petals, witches'-broom, premature flowering and fruit drop, and often premature death of the entire plant. They can be transmitted by leafhoppers, dodder, and grafting. They have been found primarily in mature sieve elements, irregularly distributed among the vascular bundles.

Table 2. Fastidious phloem-limited bacteria (FPLB) and their vectors.

Disease	Pathogen	Vector
		Leafhoppers
Clover club leaf	Clover club leaf pathogen	*Agalliopsis novella*
Citrus greening	Citrus green pathogen	*Psylla* sp. not specified

3. Fastidious xylem-limited bacteria (FXLB). The fastidious xylem-inhabiting pathogens are all short, nonmotile, rod-shaped bacteria (0.2-0.5 x 1.0-4.0_ m). The sharpshooter-borne xylem bacteria have a Gram-negative-type, rippled cell wall. The mechanically transmitted sugarcane ratoon stunting disease bacterium, *Clavibacter xylei,* has a smooth, Gram-positive-type wall. In the past, these were referred to as

"rickettsialike". Most of these bacteria have now been cultured "*in vitro*" and taxonomic characterizations indicate no relationship to the rickettsia. Symptoms associated with the Gram-negative, xylem-limited bacterial caused diseases are stunting, wilting, foliar burning or decline (**Table 3**). The diseases include Pierce's disease of grapevine, phony disease of peach, periwinkle, elm leaf scorch, Sumatra clove wilt, and others. The Pierce's disease causal agent, *Xylella fastidiosa*, also causes alfalfa dwarf disease, almond leaf scorch, and a disease in Virginia creeper. It appears that plum leaf scald disease is caused by the phony disease of peach bacterium. All known vectors of these agents are xylem-feeding homoptera which transmit the bacteria persistently with no incubation period. Apparently the bacteria are regurgitated from the insect's salivary syringe into the xylem upon feeding. The bacterial cell wall has a dual membrane with the wrinkled outer wall typical of Gram-negative bacteria. They are small, 0.3 x 1-3_m. Polarly oriented fibrils or fimbriae are often visible and the bacteria are usually embedded within a matrix in individual vessel elements. Culturing generally requires an adsorbing agent in most media, *e.g.* bovine serum albumin, soluble starch, or activated charcoal, to remove growth-inhibiting products; supplemental iron and specific carbon sources. They are relatively slow growing, needing a week or more to produce colonies 0.5-1.0 mm in diameter on agar.

Disruptions in xylem function due to embolisms in the tracheids and occlusion of tracheary elements by the bacterium or tyloses have been implicated as contributors to disease symptoms. The symptoms do not suggest a major role for changes in plant hormone balance in disease with the xylem-limited bacteria.

Table 3. Fastidious xylem-limited bacteria (FXLB) and their vectors.

Disease	Pathogen	Vector
		Sharpshooter Leafhoppers
Pierce's disease	*Xyllela fastidiosa*	*Draeculacephla minerva. Graphocelphala atropunctata, Oncometopia nigricans, Homalidisca coagulata,* and others
		None
Ratoon stunt	*Clavibacter xyli*	Mechanically transmitted

IV. VECTOR TRANSMISSION AS SEQUENCE OF EVENTS. Co-evolution of fastidious prokaryotic plant pathogens with their plant host is complicated exponentially by their necessary co-evolution with their insect vectors. Further, the co-evolution of the insect vectors with their plant hosts adds yet a further dimension to this picture. Mathematically, if the coevolution of a prokaryote and its host may be represented by the formula U^V, co-evolution of the pathogen with its insect vector may be represented by W^X and the co-evolution of the insect with its plant host would be Y^Z. The combined equation might be more complex than $(U^V W^X Y^Z)^{VXY}$. We cannot hope to understand in the near future the whole host-pathogen-vector-host interaction, but we may glimpse some of the process. The sequence of events in the colonization of insect vectors and the methods for transmission of fastidious prokaryotic plant pathogens may recaptiulate co-evolution of the pathogens with their vectors **(Fig. 1)**.

Acquisition of pathogen	Latency (growth in the host)	Inoculation	Example
I. No vector relationship	None	**Mechanical transmission**	*Clavibacter xyli*
II. External attachment	**A. Multiplication not required**	**Detachment**	*Erwinia amylovora* (Non-fastidious bacterium)
	B. Multiplication required		
III. Ingestion	Attachment to the foregut ↓ Attachment to the midgut ↓ **C.. Penetration** through mid gut cells ↓ **D. Circulation** with the hemolymph throughout body cavity ↓ **E. Salivary glands** colonization	**Egestion**	*Xyllela fastidiosa* (FXLB)
		Injection with saliva	*Spiroplasma citri phytoplasmas*, Clover club pathogen (FPLB)
IV. Vertical transmission (*via* egg)	**F. Ovary colonization** (Clover club pathogen [FPLB])		

Fig. 1. Inportant steps in the evolution of vector-phytopathogenic prokaryote interactions. This scheme has been modified greatly from the one presented by Purcell (1982).

V. COLONIZATION OF INSECT VECTORS

A. Xylem-limited bacteria colonization of leafhoppers. Purcell *et al.* (1979) consistently isolated the Pierce's disease agent, *Xylella fastidiosa*, from ts leafhopper vector, *Graphocelphala atropunctata* and demonstrated by light- and scanning electron-microscopy that the bacteria were attached to the floor of the cibarium and apodemal groove of the diaphragm. Nymphs of *G. atropunctata* lose the ability to transmit the bacterium after molting. Brlansky *et al.* (1983) studied the sharpshooters, *Oncometopia nigricans* and *Homalidisca coagulata* which are vectors of several plant pathogenic xylem-limited bacteria including: Pierce's disease bacterium (*Xylella fastidiosa*), Phony peach bacterium, and periwinkle wilt bacterium. They found that bacteria colonized the cibarium, precibarium, and the apodemal groove of the diaphragm. Bacteria in both insect species were attached in a polar fashion to the walls of the cibarium and precibarium by means of extracellular material and possibly fimbraelike structures. Dividing bacteria were observed.

B. Phytoplasmas and spiroplasmas colonization of leafhoppers. Histological evidence indicates that phytoplasmas invade the gut wall after being ingested by leafhoppers. They circulate through the hemolymph, colonize other tissues including the salivary glands and are excreted into plants with salivary fluids during feeding (Rosenberger, 1982). The organims may or may not affect the health of their insect vectors as well as

the health of heir plant hosts. No apparent affect on the vector. Aster yellows colonized leafhoppers live just as long as non-colonized leafhoppers (Littau and Maramorosch, 1960), but other phytoplasmas reduced the life span and reproductive potential of their insect hosts. *Colladonus montanus* colonized by the agent of Western X-disease was reduced in mean lifespan from 55 to 38 days and 30% of the colonized females were sterile while an additional 30% were reduced in fecundity (Jensen, 1971). The cytopathological effects of the Western X-phytoplasma on its vector include: symptoms in the salivary, neural, adipose, and alimentary tracts. In some cases, the salivary glands are grossly enlarged (Whitcomb *et al.*, 1968).

VI. DETECTION OF FASTIDIOUS PROKARYOTES. Fastidious prokaryotes are difficult to detect in plant tissue and the symptoms they cause are often confused with symptoms of viral-incited diseases or herbicide damage. Considering the difficulty in culturing the organisms and the confusing symptoms, it is not surprising that the true identity of these agents was not discovered until the 1970's. The following list of methods has been used to identify fastidious prokaryotes:

A. Electron microscopy. The first phytoplasmas and fastidious xylem- or phloem-limited bacteria were observed by transmission electron microscopy. Dr. Gary R. Hooper, Department Head of PPWS, VPI&SU from (1980-84), Vice-Provost for Research and Graduate Studies at VPI&SU (1985-91) and now acting Vice President for Research Brigham Young University was one of the pioneers in the description of phytoplasmas by this method (Jones *et al.*, 1974).

B. Antibiotic treatment. Phytoplasmas and fastidious vascular-limited bacteria, unlike viruses or fungi, are susceptible to anti-bacterial antibiotics (Lacy, 1986; McIntyre, *et al.*, 1979). Treatment with oxytetracycline seems to be effective for remitting symptoms caused by phytoplasma-incited disease without detrimentally affecting fruit flavor (Hankin *et al.*, 1979).

C. Transmission by grafting. Transmission of disease symptoms by grafting coupled with evidence for phytoplasmas by transmission electron microscopy or symptom remission following antibiotic treatment differentiates phytoplasma colonization from virus-incited problems (McIntyre *et al.*, 1979). Grafts may be accomplished by the phloem to phloem connections established by *Dodder cuscuta*, a parasitic plant, or by grafting indicator scions on disease root stock. The indicators demonstrate diagnostic symptoms is they are colonized by the pathogen from the rootstock.

D. Demonstration of phytoplasma by microscopy. Fluorescence microscopy of phytoplasmas-colonized plant tissue using the DNA-specific fluorochrome 4'-6-diamidino-2-phenylindole (DAPI) is useful for presumptive diagnoses of disease caused by phytoplasmas (Douglas, 1986; Hiruki & da Rocha, 1986). Acridine orange direct count methods have been used for vascular-limited prokaryotes recovered from plant tissues (Davis, 1986).

E. Serologic detection. Antibodies to fastidious organisms have been difficult to obtain since non-culturable prokaryotes may not be purified from tissue as easily as viruses. Immunofluorescence microscopy using anti-rabbit goat immunoglobulins conjugated with fluorescein isothiocyanate may be effective for detecting rabbit antibody-phytoplasma antigen complexes (da Rocha, *et al.*, 1986). Simple immunodifusion (Ouchterlony) tests may also be used to detect phytoplasmas (Sinha, 1983). Fluorescent anitbody techniques have been developed for direct counts of *Clavibacter xyli* subsp. *xyli*, the sugarcane ratoon stunt pathogen, on polycarbonate filters and glass slides (Davis, 1985).

F. DNA hybridization probes. DNA cloned from non-culturable phytoplasmas has been used to develop probes to detect the presence of Western X-disease phytoplasma in plants and insect vectors (Kirkpatrick *et al.*, 1987).

G. Polymerase chain reaction. Oligonucleotide primers from unique DNAs of fastidious prokaryotes may be utilized as sensitive probes. Amplification of phytoplasma DNA

sequences allows rapid, if expensive identification. The chief problem with this procedure is obtaining the unique DNA sequences to use as probes.

H. Separation of phytoplasmas, spiroplasmas, and fastidious vascular-limited bacteria from plant tissues. Basic to the development of serologic and molecular techniques for detecting these organisms are methods for mass isolation of the pathogens from plant tissue. Enzyme treatment of plant tissue (Lee & Davis, 1983) and centrifugal recovery of vacuum-infiltrated water from plant tissues (Gillaspie, 1987) have been used sucessfully.

VII. OTHER DISEASES CAUSED BY FASTIDIOUS PROKARYOTES.

Several hundred plants are known to be affected by diseases caused by fastidious prokaryotes. There is no reason to believe that all plants may be affected by these pathogens. The aster yellows phytoplasma has except for the soft rot pathogen, *Erwinia carotovora*, and crown gall pathogen, T-DNA vectored by *Agrobacterium tumefaciens*, has the widest host range of any phytopathogenic prokaryote. The host range of the aster yellows phytoplasma may be as great as the wide-host range fungal pathogens of plants, *(e.g., Pythium ultimum)* but its range has not been studied as intensively because it is currently non-culturable. **Table 4** lists some interesting example of disease caused by fastidious prokaryotes.

Table 4. Some plant diseases caused by fastidious prokaryotes

Disease	Pathogen	Reference
Cantharanthus roseus yellows	MLO	Hiruki & da Rocha, 1986
Brittle root of horseradish (*Armoracia rusticana*), wild mustard (*Brassica kaber*), and shepherd's purse (*Capsella bursa-pastoris*)	*Spiroplasma citri*	O'Hayer, et al., 1984
bermuda grass (*Cynodon* spp.) stunt	*Clavibacter xyli* subsp. *cynodontis*	Davis & Augustin, 1984
Virescence of horseradish	phytoplasma plus *Spiroplasma citri*	Eastman *et al.*, 1984
Machismo disease of soybean (*Glycine max*)	machismo phytoplasma	Fletcher *et al.*, 1984
Dying of bentgrass (*Agrostris palustris*) cv. Toronto creeping strain C-15	XLFB (probably *Clavibacter* spp.)	Roberts *et al.*, 1982
Ash decline (*Fraxinus* spp.)	ash decline phytoplasma	Sinclair, 1987
Orange disease of rice (*Oryza sativa*)	orange phytoplasma	Hibino *et al.*, 1987
Red maple scorch (*Acer rubrum*)	FXLB	Sherald *et al.*, 1987
Heath myrtle (*Baekea virgata*) yellows	phytoplasma	Hiruki, 1986
Little leaf disease of *Brugmansia candida*, a flowering bush	phytoplasma	Hiruki, 1986
Sycamore (*Platanus occidentalis*) leaf scorch	FXLB	Sherald *et al.*, 1983
Blueberry (*Vaccinium pallidum*) stunt	MLO vectored by *Scaphytopius magdalensis*	Dale & Fletcher, 1987

VII. CULTURE OF FASTIDIOUS PROKARYOTES. Originally, all fastidious prokaryotes were non-culturable. Beginning with *Spiroplasma citri* and *Xylella fastidiosa*, heretofore non-culturable organsims became culturable (reviewed in Chen *et al.*, 1982). However, the media were complex and contained items that are not defined chemically such as _-globulin horse serum and fetal bovine serum. This may be changing, because a chemically defined medium has been developed for *Spiroplasma mirum*, the suckling mouse cataract agent. This medium is by no means simple since it contains 80 compounds (Hackett *et al.*, 1987).

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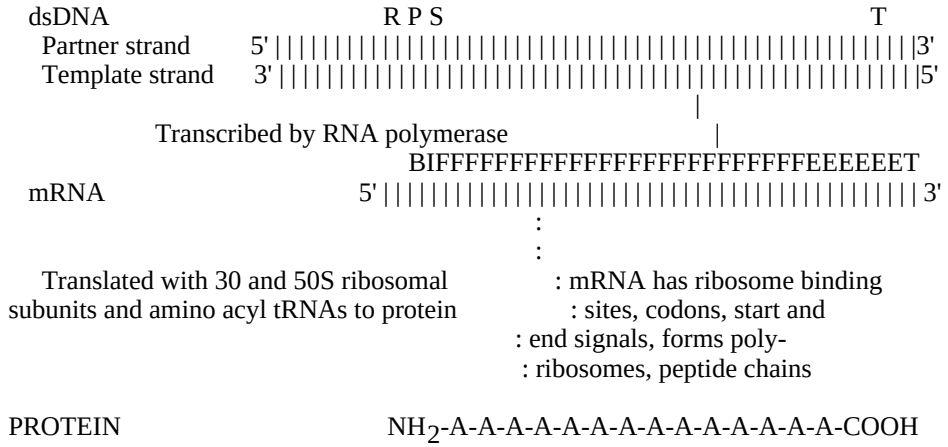
PLANT DAMAGE: ENZYMES AND TOXINS

I. Enzymes. Enzymes are catalytic proteins. Cell degrading enzymes (CDEs) produced by phytopathogenic bacteria reduce plant cell components to compounds useful for pathogen nutrition. Some of these CDEs are important in the development of pathogenesis as well as nutrition. Most bacteria have some or all of the classes of enzymes we list here as CDEs; however, few bacteria are pathogens of plants.

A. Enzymes are polypeptides coded for in the genetic material. The follow ing diagram reviews the Central Dogma for the origin of polypeptides:



B. Genes encode protein structure. To understand the production of enzymes, the structure of genes and function of genes must also be understood.

1. Promoter region (~60 bp) is an *cis*-acting site upstream of the open reading frame involved in binding RNA polymerase to initiate transcription. It consists of:

The Pribnow box (P) ($\mathbf{T}_{89}\mathbf{A}_{89}\mathbf{T}_{50}\mathbf{A}_{65}\mathbf{A}_{65}\mathbf{T}_{100}$) is located about -10 bp upstream from the transcription start site. This AT-rich region melts dsDNA into ssDNA for RNA synthesis from the template strand.

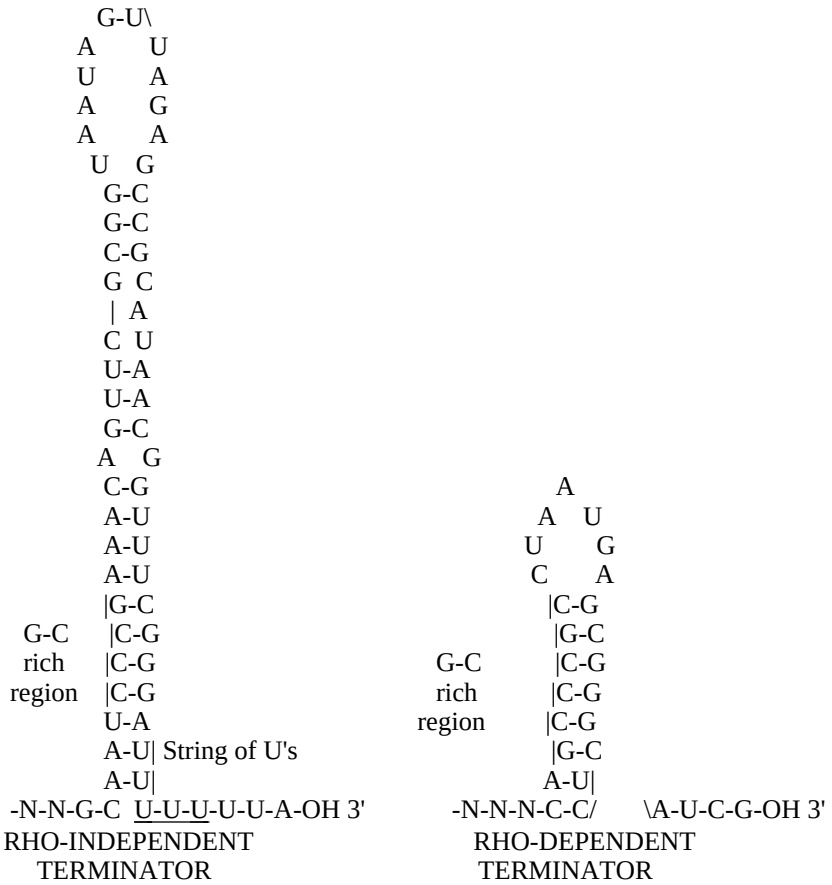
The recognition region (R) ($\mathbf{T}_{88}\mathbf{T}_{83}\mathbf{G}_{81}\mathbf{A}_{61}\mathbf{C}_{69}\mathbf{A}_{52}$) is located about -35bp upstream from the Pribnow box. This is the recognition sequence for RNA polymerase binding.

The sequences intervening between the -10 and -35 bp sites may be important in fitting the geometry of attached RNA polymerase. Alternatively, they may not be important at all since experiments show that the -10 and -35 bp sites have most of the contact points with RNA polymerase.

Start site (S) for transcription corresponds to the first nucleotide incorporated into the transcript by RNA polymerase. In bacteria, this nucleotide retains its original 5' triphosphate. The start point is usually a purine in the template (sense) trand; however, it may be either of two adjacent pairs or, occasionally, any one of several adjacent positions.

2. Termination site (T)**.** During transcription, palindromic termination sites form near the 3' end of the RNA and are required in prokaryotes to terminate RNA transcription. Two types of termination occur: Rho dependent and rho-independent. With rho-independent termination, at the hairpin lood (palindromic secondary structure) RNA, DNA, and RNA polymerase dissociates from each other at a string of easily melted U residues (see figure below).

In rho-dependent termination, requires in addtion to a hairpin loop the rho factor, a protein of about 55 kd that is active as a hexamer, which attaches to mRNA at a specific site (*rut*)about 35 bp prior to the actual termination point. The rho factor associates with the nascent mRNA moves along it behind RNA polymerase until the polymerase slows as the palindromic terminator forms. Rho associates with the polymerase releasing it from the DNA and mRNA. Rho is released from the free polymerse.



3. Ribosome binding site (B)**.** Binding assays have identified protected sequences 35-40 bp in length including a sequence possibly involved in binding the 50S ribosomal subunit to DNA. The binding sequences show little conserved sequences except to a region close to the 3' end of the 16S ribosomal RNA which contains the ...**UCCUCC**.... complementary to the Shine-Delgaro bacterial DNA sequence ...**AGGAGG**....

4. Initiation codon (I)**.** The initiation codon represents the first amino acid, N-formyl methionine, at the N terminus of the polypeptide.

5. Open reading frame (F)**.** The open reading frame consists of a series of tri-nucleotide codons which are translated into specific amino acids in the lengthening polypeptide. See the chapter on Genetics and Evolution of Prokaryotic Phytopathogens for details on the genetic code.

6. Termination codons (E)**.** Three codons, UAA, UAG, AND UGA serve as punctuation codons and are not translated into amino acids.

B. Location of enzymes. Enzymes may be extracellular and secreted out of the bacterium into its environment, they may be intracellular and maintained in the cytoplasm of the bacterium, they may be periplasmic and maintained outside the cytoplasmic membrane, but within the outer membrane (in Gram negative bacteria) or within the cell wall (in Gram positive bacteria). Finally, they may be membrane-bound and inserted via hydrophobic areas within the cytoplasmic membrane.

C. Protein secretion. Secreted proteins have special structures at the N-terminius.

One-step secretion. Proteins secreted by one step into the periplasm or through Bayer's junctions to the extracellular environment have a signal peptide. These proteins are translated on the cytoplasmic membrane. The signal hydrophobic peptide, about 20 amino acid residues, attaches to a membrane-bound protein, crosses the membrane, and `pulls' the hydrophilic polypeptide behind it. Once across the membrane, the signal peptide is cleaved by the signal peptidase and the process protein is released.

Two-step secretion. Other proteins secreted across first the cytoplasmic and then the outer membrane, have two methods of secretion: In the first, the a signal peptide allows the first membrane to be crossed and then an hydrophilic pro-peptide, which may be quite large (5 to 8 kd), forms a temporary pore in the outer membrane through which the polypeptide is pulled into the exterior environment. The propeptide cleaves itself to free the protein outside the cell. In the second method, the protein is secreted across the cytoplasmic membrane using the signal peptide method and then two periplasmic helper proteins facilitate the movement

of the protein across the outer membrane. Variation of these methods are known and secretion by other methods is possible.

D. Specificity of enzymes. Degradative enzymes may cleave polymers such as protein, carbohydrates, or nucleic acids, at random points within the chain in an *endo*- manner or they may nibble away terminal monomers in an *exo*- manner.

E. Cleavage methods. Most degradative enzymes cleave in one of two manners, they add water in a hydrolytic manner and are called hydrolases or they remove water in a *trans*-eliminative manner and are called lyases.

F. The plant cell. sources of nutrients in the plant cell and types of degrdative enzymes produced by phytopathogens to obtain those nutrients.

Plant cell sturcture	Nutrient	Degradative enzyme
Cuticle		
Cutin	**Fatty acid peroxides**	**Cutinase**
Suberin		
Suberin	**Fatty acid polyesters**	**Suberin esterase**
Cell wall		
Pectic substances	**Galacturonans**	
	Non-methylated	**Pectate lyase**
		Oligogalacturonase
	Methylated	**Pectin methylesterase**
		Pectin lyase
		Polygalacturonase
Cellulose	**Glucose monomer**	**Cellulases**
Native cellulose cross-links		C_1 cellulase
Native cellulose main strand		C_2 cellulase
Soluble cellulose to cellibiose		C_x cellulase
Cellibiose to glucose		β-glucanase
Hemicellulose	**β-1,4-linked xylans**	**Xylanases**
Proteins	**Polypeptides**	**Proteases, proteinases**
Cytoplasmic membrane (and other organelle membranes)	Complex structure	
Proteins	**Polypeptides**	**Proteases, proteinases**
Phospholipids	**Phosopholipids**	**Phospholipase**
Phosphatidyl compounds	**Phospholipids**	**Phosphatidase**
DNA	**3-*deoxy* polynucleotides**	**Deoxyribonucleases** (DNases)
RNA	**Ribopolynucleotides**	**Ribonucleases** (RNases)

G. Induction of enzymes. Some enzymes are produced constituitively or at a constant rate; others are inducible and/or repressible. In other words, their expression or lack of expression is affected by the presence or absence of coumpounds in the environment. For example, in *Erwinia carotovora*, the presence of cellulose and anaerobic conditions induce the production of cellulase. The best studied inducible and repressible enzyme in phytopathogenic prokaryotes is *endo*-pectate lyase in *E. carotovora*. This enzyme is repressed by the presence of simple sugars such as glucose but induced in the presence of sodium polypectate.

During the incubation of *E. carotovora* with combined glucose and pectate, two exponential growth phases occur as the bacteria first consume glucose, the preferred substrate, then pectate, the more slowly utilized substrate. This **diauxie curve** is typical of inducible enzymes.

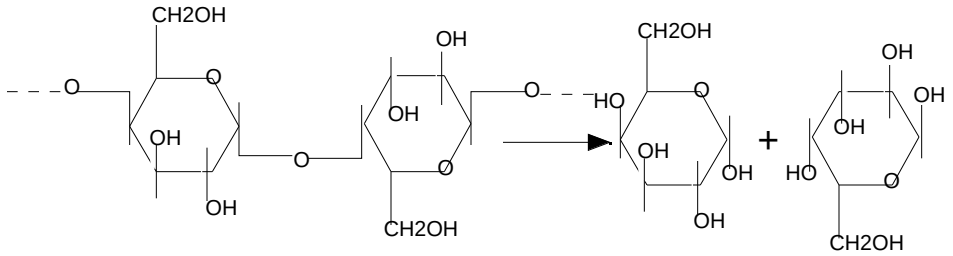
Catabolite repression (such as repression caused by glucose) likely is caused by lack of induction of genes requiring activation of transcription due to low levels of cytoplasmic cAMP (cyclic adenosine monophosphate). When the level of glucose is reduced in the intracellular pool due to utilization in bacterial metabolism, cAMP levels rise in the cell. cAMP binds to CRP (cAMP receptor protein) and causing its confromation to change and allowing binding of cAMP-CRP to a DNA binding site very near the RNA polymerase binding site) inducing transcription of the gene for pectate lyase.

H. Enzyme size. Enzyme size may be important in pathogenesis. For instance, the major extracellular *endo*-pectate lyase from *E. carotovora* is about 40 kDa, however, it is so tightly folded that it co-migrates with molecules as small as 31 kDa. Most of the degradative enzymes described as important in pathogenesis seem to be about this size; perhaps they may diffuse into the lattice of the plant cell wall. It may be that once the initial or primary enzyme has affected a plant cell wall, then other larger degradative enzymes may diffuse into the loosened fabric of the cell wall to further degrade the cell.

I. Model for soft rot. Coordination of enzymes. The picture that emerges is that a coordinated battery of enzymes may be required for pathogenesis of plants by enzyme-producing bacteria. This is the picture that arises with *E. carotovora;* both extracellular polygalacturonase and extracellular *endo*-pectate lyase are required for pathogenesis (Roberts et al., 1986b).

J. Enzymes in pathogenesis. The roles of enzymes in pathogenesis are best known from studies with soft-rot erwiniae reviewed in Collmer & Keen (1987) and Kotoujansky (1987).

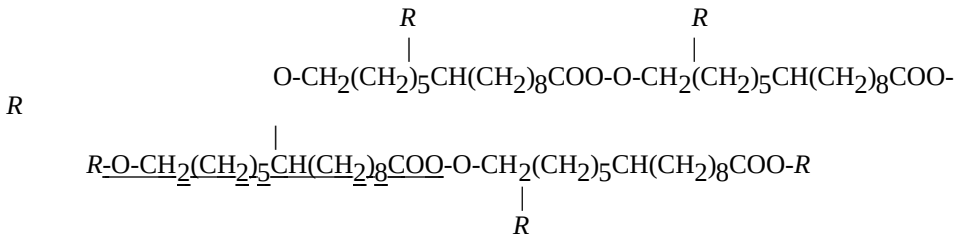
Cellulases. Cellulases or (endoglucanases) have been reported from several pathogens including *Erwinia carotovora* (Roberts, *et al.*, 1986) and *Ralstonia (Pseudomonas or Burkholderia) solanacearum* (Kelman & Cowling, 1965). Roberts, *et al*. (1988) demonstrated by gene replacement using a disarmed endoglucanase gene that the mutant strain was significantly less aggressive on tomato than the wildtype and produced 200-fold less endoglucanase. A merodiploid constructed with a plasmid containing the wildtype endoglucanase gene was more aggressive than the mutant. The mutant was pathogenic but delayed in symptom development indicating that more than one factor was responsible for pathogenesis. Breakdown of crystalline cellulose requires the concerted activity of three or four enzymes; C_1 cellulase cleaves cross-linkages among cellulose fibrils, C_2 cellulase breaks primary cellulose polymers in an *endo* manner, C_x cellulase (endo-_-1,4 glucanase) cleaves soluble cellulose into cellobiose (disaccharides molecules), and cellobiase (_-glucosidase or β-glucanase) which degrades cellobiose to glucose.



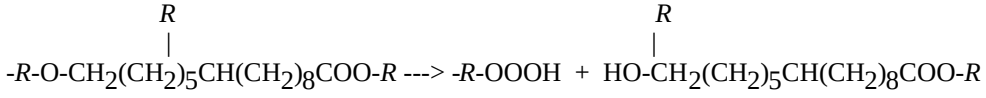
CELLULOSE (_-1,4-linked glucose)

Cutinases. Cutinolytic activity was detected in leaves of either susceptible or resistant tomato cultivars within 48h after inoculation with *Pseudomonas syringae* pv. tomato. The activity decreased markedly at later stages of disease development. The enzyme involved appeared to be constituitive and were enhanced only slightly in the presence of substrate. The cutinolytic activity appeared to be bacterial in origin. Cutinases may be involved in the primary stages of disease development in tomato cultivars susceptible to bacterial speck (Bashan *et al.*, 1985).

Streptomyces scabies has a 26 kd protein with cutinolytic activity. The necessity of this enzyme in pathogenicity has not been demonstrated; however, the shallow penetration of the pathogen under the epidermis of tubers would suggest that may have a role in pathogenesis. (Reviewed in McQueen & Schottel, 1987)

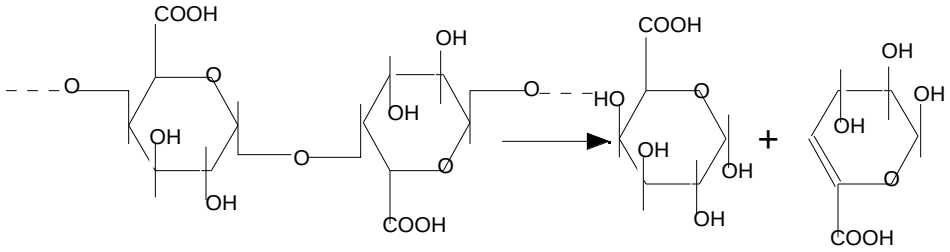


CUTIN STRUCTURE (with 10,16-dihydroxyhexadecanoic acid monomer underlined; *R* indicates linkages to other cutin moieties including 19,16-dihydroxyhexadecanoic acid and 9,10,18-trihydroxyoctadecanoic acid)



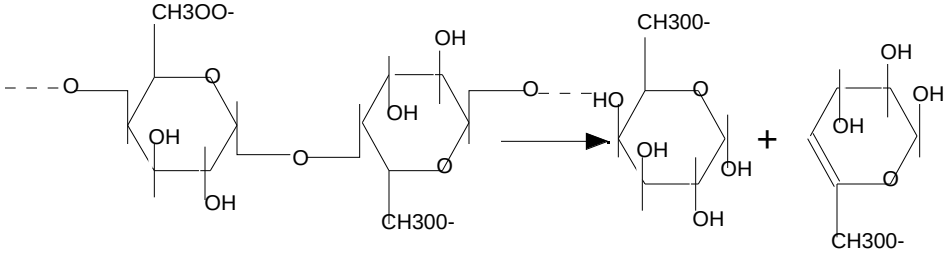
CUTINASE (hydrolyzes ester bonds)

Pectate lyase. Pectate lyase digests pectic acid (or its pectate salts) but not methylated pectin. (Pectin has the same molecular structure except that the carboxyl groups are methylated). This is the chief enzyme responsible for bacterial soft rot symptoms. Roberts *et al.* (1986) cloned and described the major extracellular *endo*-acting pectate lyase from *Erwinia carotovora* subsp. *atroseptica* and found that it had a pH optima of about 8.5, required Ca^{2+}, had a pI of about 9.5, and a molecular weight of 32 kD. Allen (1987) found that the pectate lyase of *E. carotovora* subsp. *atroseptica* was strongly homologous by DNA:DNA hybridization to the subsp. *carotovora* enzyme but that neither had detectable homology to *Erwinia chrysanthemi* pectate lyases by DNA:DNA homology. Roberts *et al.* (1986) reported that under extremely harsh conditions, that subsp. *carotovora* pectate lyase produced by recombinant DNA-containing *Escherichia coli* would not rot tuber tissue unless polygalacturonase was also present.



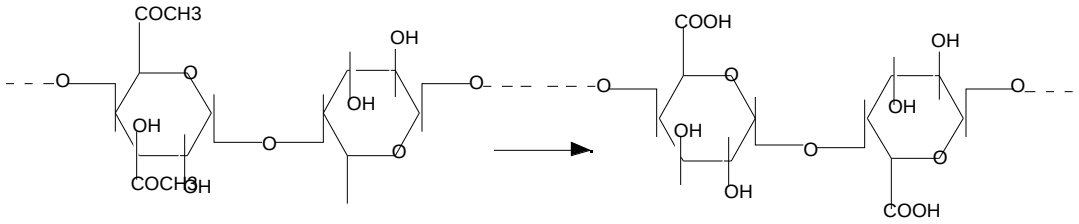
Pectic acid (_-1,4-linked glucuronic acid)

Pectin lyase. Pectin lyase cleaves pectin, the methylated form of pectic acid, but not the non-methylated pectic acid. A 32 kD pectin lyase has been isolated and characterized from *Pseudomonas fluorescens* isolated from soft-rotted potato. The enzyme had a pI of 9.4 and the protein acited as a cross-reacting antigen with a pectate lyase (PLb) produced by *Erwinia chrysanthemi* (Schlemmer, *et al.*, 1987).



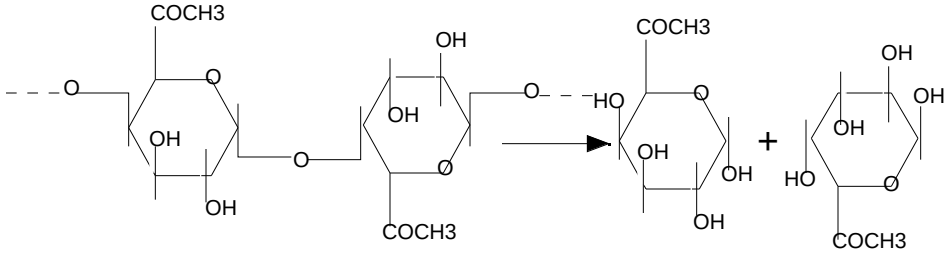
PECTIN (methylated _-1,4-linked glucuronic acid)

Pectin methylesterase. Pectin methylesterase de-methylates pectin producing pectic materials. Demethylation is required before pectate lyase may digest pectin. Likewise, the action of pectin methylesterase removes pectin as a substrate for pectin lyase by onverting it to pectic acid. Pectin methylesterase has been reported from soft rotting xanthomonads (Liao & Wells, 1987) and *Ralstonia solanacearum* (lman & Cowling, 1965).



(methylated _-1,4-linked glucuronic acid) (_-1,4-linked glucuronic acid)

Polygalacturonase. Polygalacturonase has the same substrate specificity as pectate lyase; however, this enzyme has a more acidic pH optimum (5.5) and does not require metallic cofactors. This enzyme is produced by *Erwinia carotovora* subspp. but not by *Erwinia chyrsanthemi*. Roberts *et al.* (1986) discovered that *E. carotovora* genes for pectate lyase and polygalacturonase are both required to rot tuber tissue when cloned into *Escherichia coli*.



PECTIN (methylated _-1,4-linked glucuronic acid) GLUCURONIC ACID

Protease. Mount and Tseng, (1974) found that a protease from *Erwinia carotovora* subsp. *carotovora* strain EC14 lyzed cucumber protoplasts. A protease was cloned by Allen *et al*. (1986) from EC14 and a protease-deficient mutant was shown to be slightly but significantly impaired in the ability to rot potato tubers (F.D. Smith, Ph.D. Dissertation, U.Mass, 1988). The pI of this protease (Prt2) is about 4.7. A site-specific mutant for a second protease (Prt1) was also slightly (20 to 30 %) reduced in maceration ability (Kyöstiö *et al.*, J. Bacteriol. 173: 6537-6546, 1991).

Kelman (personal communication, 1989) reported that proteases from *Erwinia carotovora* subsp. *carotovora* hydrolyze gelatin, azocasein, and extensins (hydroxyproline-rich glycoproteins), but not membrane proteins, or cytoplasmic proteins.

Erwinia chrysanthemi produces three antigenically and structurally distinct proteases; the genes are clustered on a 40-kb DNA fragment. The proteins are, respectively, 50, 53, and 55 kD in mass, and a low-molecular weight, heat-stable, essentially intracellular protease inhibitor which is subcloned with proteases B and C on an 8.5 kb DNA fragment, binds all three proteases (Wandersman, *et al.*, 1987).

Wang & Kelman (1982) had reported that a strain of *Pseudomonas fluorescens* rotted potatos but did not produce pectate lyase but did produce protease. Their hypothesis was that protease was responsible for rotting; however, their assays would not detect the activity of pectin lyase. Schlemmer *et al.* (1987) reported that this strain produced pectin lyase.

Suberin esterase. A 38 kd protein isolated from *Streptomyces scabies* was found to degrade suberin. The enzyme was isolated from two pathogenic strains from diverse geographic origins, but not from to non- pathogenic strains. The enzyme required zinc for activity, had optimal activity at pH 8, was stable up to 60C, and had an apparent Km of 125uM *p*-nitrophenyl butyrate (McQueen & Schottel, 1987).

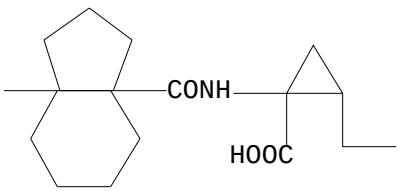
II. TOXINS. (Reviewed in Durbin, 1982) The definition of toxin is controverSial. Toxins cause damage to plant cells and tissues; agreement is good on this point. However, some authors do not include high molecular weight compounds since their action may be physical rather than chemical, most do not include plant growth promoting substances (plant hormones) since they are constituents of healthy plants that have been recognized separately.

A. In this lecture we will evade the question of semantics and definitions by refering to all compounds with toxic affects on plant cells.

B. We will also, for the sake of time, evade the central question of if these compounds are actually active in pathogenesis. This is an exceptionally difficult point to prove since to be active in pathogenesis one must confirm that the compound is present during pathogenesis in the proper concentration, and causes the symptoms attributed to it.

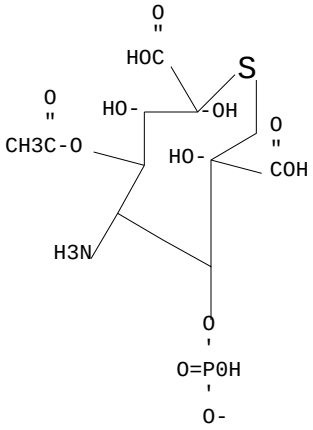
C. Finally, a point must be made for the fact that toxins do not make an organism a pathogen. Toxins merely modify the extent of pathogenesis. For instance, wild fire and haloblight mutants that no longer produce toxins are still pathogenic--they no longer increase the amount of injury by producing toxins. Examples:

Coronatine. Produced by *Pseudomonas syringae* pv. atropurpurea, a pathogen of oats and *Pseudomonas syringae* pv. glycinea. The toxin causes chlorosis and streaking in oats.

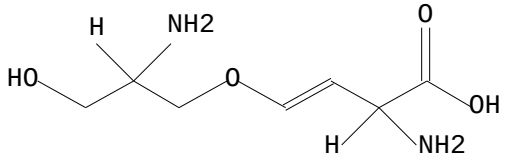


Syringomycin. Produced by *Pseudomonas syringae* pv. syringae. A complex cyclic peptide of that affects the permeability and organization of mitochondrial and nuclear membranes. Causes necrosis and limited chlorosis often surrounding lesions. Self protection of pathogen from the toxin. The toxin is destroyed in extracellular culture supernatants as the pH rises or complexed with other macromolecules to be less damaging (Durbin, 1988; Iacobellis, *et al*., 1987).

Tagetitoxin. Produced by *Pseudomonas syringae* pv. tagetis is an unknown compound that affects chloroplast thylaloid membranes. Affected plants may turn white especially near growing apices. Often affects marigolds and sunflowers. Specifically inhibits chloroplast RNA polymerase (Durbin, 1988). Self protection. Possibly the toxin does not enter the pathogen's cells.



Rhizobitoxine. Produced by *Bradyrhizobium japonicum* especially under conditions of high nitrate soil fertilization causes chlorosis and necrosis of the apices of soybeans.

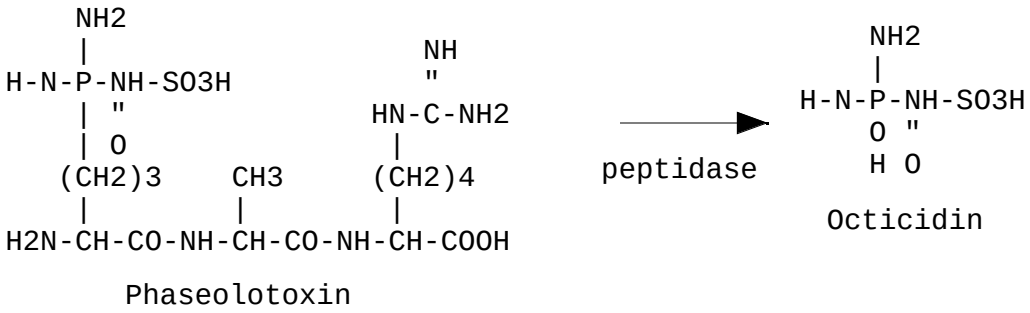


Inhibits _-cystathionase in the transsulfuration pathway for production of the amino acid homocysteine, inhibits ethylene production, and blocks the s-adenosyl methionine (SAM) binding site on aminocyclopropane carboxcylic acid (ACC) synthetase, the enzyme forming ethylene.

Bacterization of soybean seeds or roots with *Bradyrhizobium japonicum* reduced significantly charcoal rot disease caused by *Macrophomina phaseolina*. Rhizobitoxine was detected in the roots and was antifungal. This may provide a useful function for the toxin (Chakraborty & Purkayastha, 1984).

Phaseolotoxin. A tripeptide produced by *Pseudomonas syringae* pv. phaseolicola, causes the haloblight symptom on field beans. Phaseolotoxin is cleaved *in planta* to

the even more toxic compound Psorn. Pathogens that no longer produce phaseolotoxin remain pathogenic causing simple leafspots. Phaseolotoxin production occurs at 16-20 C but not at 28 C.



Phaseolotoxin

Psorn inhibits ornithine carbamoyltransferase (OCTase) an ornithine cycle enzyme that converts ornithine into citrulline. Ornithine therefore accumulates in the tissues and arginine and cutrulline biosynthesis is blocked. However, ornithine does not produce chlorosis nor does ammonia production. Since carbamoyl phosphate increases and stimulates pyrimidine synthesis, increased pyrimidines were also investigated and found not to cause chlorosis. Perhaps the lack of citrulline in thyllakoid membranes or the lack of some metabolic product of citrulline cause the chlorosis and disorganization of the chloroplasts.

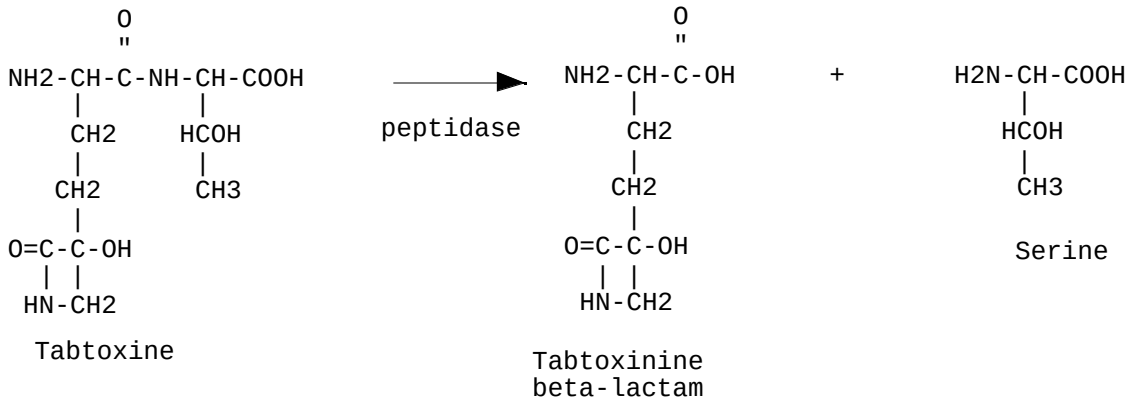
Phaseolotoxin is transported into plants by illicit transport via oligo-peptide permeases (Durbin, 1988).

Peet *et al.*, 1986 recovered a 28Kb *Kpn*I fragment that contains five different *Eco*RI fragments mutagenized with Tn*5* that no longer produced phaseolotoxin (Tox$^-$). Evidently, at least five genes are involved in toxin production.

Gnanamanickam *et al.*, 1983 presented evidence that some strains of *Pseudomonas syringae* pv. glycinea may also produce phaseolotoxin. This may no be surprising since pathovars phaseolicola and glycinea overlap in host ranges on lima beans (Schroth, *et al.*, 1971).

Self protection. The effects of phaseolotxin are partially avoided since the pathogen has a resistant OCTase. This resistance is only partial and other mechanisms, such as lack of uptake must also be operative.

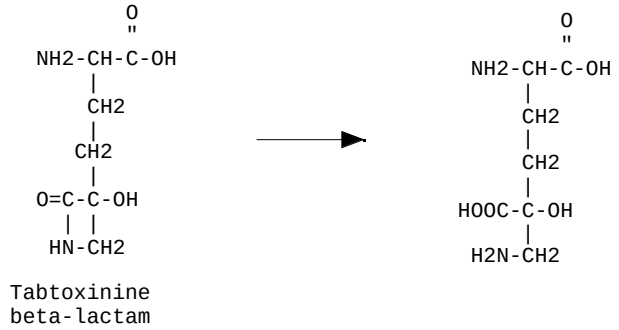
Tabtoxin. Produced by *Pseudomonas syringae* pv. tabaci causes wildfire of tobacco. The effects of the toxin are demonstrated by large yellow halos surrounding lesions.



In plants, tabtoxin inhibits ribulose 1,5-bisphosphate carboxylase-oxygenase (RuBPCase). Tabtoxin is transported into the plant by illicit transport via di- and oligo-peptide permeases. Tabtoxin is once in the plant cell is hydrolyzed to tabtoxinine _-lactam by Zn^{2+}-containing amino peptidases. The hydrolytic active product, tabtoxinine _-lactam inhibits irreversibly glutamine synthetase causing ammonia to accumulate and cause chlorosis. The conversion of tabtoxin to tabtoxinine _-lactam may also be initiated in the periplasm of the bacterium by bacterial peptidases. This potentially my cause problems with glutamine synthetase in the bacterium.

Although the pathogen inhibits glutamine synthetase in the plant host, it retains significant glutamine synthetase activity itself. Knight *et al.*, 1986) found that once the conversion from tabtoxin to tabtoxinine _-lactam is initiated in the bacterium, the bacterial glutamine synthetase becomes adenylated. This adenylation of the enzyme, especially in the presence of effectors such as AMP, alanine, glycine, histidine, and serine, significantly protected the enzyme from inhibition by tabtoxinine _-lactam. The non-adenylated enzyme is quickly inhibited by the toxin.

The extent of protection afforded by the adenylated glutamine synthetase was, howvever, not sufficient to protect completely against the toxic effects of tabtoxinine-_-lactam. In 1987, Knight, *et al*. reported that a second self-protection mechanism was operative. Detoxification of toxic tabtoxinine-_-lactam to non-toxic tabtoxinine occured by opening the lactam ring of the toxin as shown below:



The pathogen also lacks the ability to take up tabtoxine-_-lactam. Methionine, glutamine, and methionine sulfoxide (MSO) competitively inhibit uptake via permeases (Durbin, 1988).

Amylovorin. Amylovorin is probably an artifact rather than a toxin. It was believed to be high-molecular weight, incompletely described polysaccharide with nitrogen-containing moieties that is apparently toxic to plant tissue. It is produced by *Erwinia amylovora*, the fire blight causal agent on pear, apples, and other roseaceous plants.

Watersoaking EPS. In leaf spotting diseases caused by pseudomonads and xanthomonads, the bacteria produce a high-molecular weight extracellular polysaccarides found in the intercellular spaces of the plants that seems to function in maintaining the water-soaked condition of the plants and prevent bacterial cell-plant cell contact that may trigger resistant responses.

Unknown toxins. Mitchell *et al*. (1983) reported that strains of *Pseudomonas syringae* pv. tomato produced a diverse group of toxins. One was a carboxcylic acid but distinct from coronatine.

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MECHANISMS OF PLANT DAMAGE: WILT- AND TUMOR- INDUCING COMPOUNDS

I. WILT-INDUCING COMPOUNDS. Non-fastidious bacteria that colonize xylem vessels of angiosperms are a heterogeneous group. Examples of these organisms include *Erwinia amylovora*, causing fireblight of roseaceous plants; *Erwinia stewartii*, causing Stewart's wilt of corn; *Clavibacter michiganense* subsp. *michiganese*, causing tomato canker (this bacterium was once incorrectly believed to colonize phloem seive tubes rather than xylem vessels); *Clavibacter michiganense* subsp. *insidiosum*, causing bacterial wilt of alfalfa; *Burkholderia solanacearum*, causing Granville wilt of tobacco and wilts of other solanaceous plants and bananas; and *Xanthomonas campestris* pv. campestris, causing blackrot of crucifers. The methods by which some of the fastidious,xylem-limited bacteria, such as *Xylella fastidiosa*, the Pierce's disease causal agent, are probably identical to the group of non-fastidious wilt pathogens; however, they have not been studied as completely.

A. Xylem anatomy (Reviewed in Esau, 1965).

Xylem cells. Xylem cells, when mature are acytoplasmic tubes with open ends or perforated end plates.

Xylem parenchyma. Xylem parenchyma cells are living cells that occur alongside xylem cells.

Vessels. Vessels are xylem cells are arranged end-to-end and may form open vessels as longs as several millimeters to as much as 30 cm in elm trees.

Xylem sap. Xylem sap contains less than 1 mg/ml of solids by dry weight. These include simple sugars, organic acids, and amino acids.

Pits. Lateral flow of xylem sap occurs via bordered pits (0.5 _m diameter) that line the wall of xylem cells. These pits are composed of primary wall cellulose with large open spaces between the fibrils. They may be decorated in various ways; border pits have thickened tori in the center. In alfalfa resistant to alfalfa wilt (caused by *Clavibacter michiganes***e** subsp. *insidiosum*), pits in the stems pass molecules up to 5 x 10^6 MW; in the petioles, only molecules smaller than 2 x 10^6 MW pass.

Primary and secondary walls. Xylem interior walls are composed of cellulose and are secondary walls in cell formation. They are often decorated with lignified raised spirals. The exterior walls are the primary cell walls composed mainly of cellulose with some pectinic materials. Cellulases produced by pathogens may release xylem cell wall components that may occlude perforated plates and pits.

Tyloses. Tyloses, invaginations through pits of cellulose walls from adjacent xylem parenchyma cells, have been observed in damaged vessels. Controversy! Do tyloses form fast enough to account for resistant reactions, especially to fungal pathogens--some say yes; Dr. E.L. Stromberg, PPWS, says no.

Wilting tests. Polyethylene glycols (carbowaxs) of various molecular weights were tested against tomato cuttings (Hodgson et al. 1949) and found that higher molecular weight molecules (>8,000 MW) induced blockage of perforated plates and caused

wilting of stems, while smaller molecular weight polymers induced wilting of petioles, leaves, and leaf edges.

Callose. Callose, _-1,3-linked glucose, has been identified in xylem vessels affected by fungi. It is possible that callases (_-1,3 glucanases) may release these polymers into the xylem sap stream and they are deposited on pits and end plates thus occluding flow.

Emboli. Damage to xylem vessels causes occlusions (or emboli) to form that block the vessels and cause them to be dysfunctional. In mechanical damage, emboli may be formed by air bubbles. This is why florists cut flowers under water to prevent interruption of the capillary column of xylem sap.

B. Chemistry of bacterial extracellular polysaccharides (EPS). For a more complete review, refer to the chapter on Bacterial Cytochemistry and Anatomy.

Fire Blight EPS. Erwinia amylovora produces amylovorin, 98% galactose and 0.375% protein, and "ooze" is 80% carbohydrate, 20% bacteria (Phytopathology 29:142-156, 1939; Science 183:1081-1082, 1974)

Black Rot EPS. *Xanthomonas campestris* pv. campestris produces xanthan gum, MW 10^6, D-glucose, D-mannose, D-glucuronic acid as main structural units along with some pyruvate (J. Polymer Sci. 5:519, 1961).

Ring Rot EPS. *Clavibacter michiganense* subsp. *sepedonicum* produces a high molecular weight molecules of glycopeptide (MW > 200,000)

Alfalfa Wilt EPS. *Clavibacter michiganense* subsp. *insidiosum* produces wilting polysaccharides in a regulated manner that have been classified into three components may (Van Alfen, *et al.*, 1987a&b). All three components reduce transpiration in alfalfa cutting when introduced through the stem:

Component I. A very high molecular weight (>5 x 10^6 MDa) macromolecular aggregate of non-covalently-bound complex of nine polypetides and component II. The polypeptides range size from 13 to 76 KDa. This component is unable to pass through leaf traces or pit membranes in alfalfa stems.

Component II. A polysaccharide, 5 x 10^6 MDa, has a residue ratio of 2 fucose: 1 galactose: 1 glucose. This molecule passes through stem pit membranes but not those in leaf traces.

Component III: The smallest molecule 22 KDa, has a residue ratio of 3 galactose: 1 rhamnose: 1 fucose. This molecule passes both pit membranes and leaf traces and accumulates in the leaf.

C. How are vessels blocked?

Polysaccharides. Bacterial EPS or plant cell degradation products may accumulate at perforation plates and on pits and occlude them.

Toxins. Toxins may change the rate of transpiration.

Emboli. Bacterial penetration causes emboli.

II. TUMORIGENESIS. Tumor-inducing bacteria include *Agrobacterium tumefaciens*, causing crown gall of many plants; *Rhizobium* and *Bradyrhizobium* spp., causing nitrogen-fixing nodules on legume roots; *Frankia* spp., causing nitrogen-fixing nodules on alder roots; *Pseudomonas syringae* pv. savastanoi, causing olive or oleander knot (Surico, *et al.*, 1984); *Phyllobacterium myrsinacearum* causes nitrogen-fixing leaf nodules on Rubiaceae and Myrsinaceae (represented by berry-bearing trees or shrubs such as *Ardisia crispia* cultivated as ornamentals in pots--without nodules, plants do not development normally and may die); and *Nocardia vaccini*, causing galls on blueberries. Central to this gall-inducing pathogenesis are the synthesis of plant growth regulators including auxins and cytokinins; *Rhodococcus fascians*, although it causes fasciation (proliferation of lateral shoots), belongs in this group since cytokinins are involved. Likewise, *Agrobacterium rhizogenes*, which causes hairy root, proliferates roots on many plants since auxins are involved. As we will see, *A. rhizogenes* may be a natural "rooty" mutant of *A. tumefaciens* (Akiyoshi, *et al.*, 1983). Most likely the "witches broom"-causing MLOs also belong in this diverse group; however, no growth regulators have been yet associated with these pathogens.

A. Auxin synthesis. In *Pseudomonas syringae* pv. savastanoi and *Agrobacterium tumefaciens* auxins are produced by a two-step synthesis from tryptophan (Liu *et al.*, 1982, Comai & Kosuge, 1980; Schroder, 1987; Thomashow *et al.*, 1985). Auxin conjugates with aspartic acid have been discovered in rhizobia and may participate in nodulation.

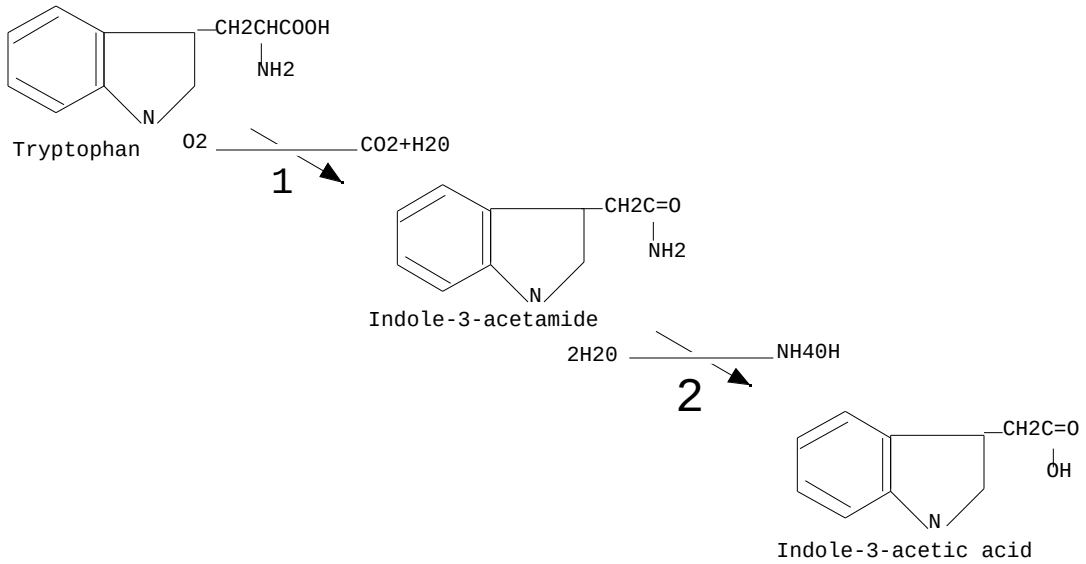

Figure 1. Tryptophan-2-monooxygnease (1) and indoleacetamide hydrolase (2) convert tryptophan to indole-3-acetic acid (auxin) in bacteria.

Genetics of auxin biosynthesis. In oleander isolates of *Pseudomonas syringae* pv. savanastanoi, the genes encoding tryptophan monooxygenase *(iaaM*), indoleacetamide hydrolase (*iaaH*), and indoleacetic acid-lysine synthetase (*iaaL*) on plasmids (pIAA) that range in size from 53 to 92 Kb. In some strains, however, these

genes are chromosomally-borne. Loci for *iaaM* and *iaaH* are closely assoicated in an operon but *iaaL* is located some distance away on the same plasmid. Indole acetic acid-lysine synthetase is produced by oleander strains and conjugates lysine or a lysine-derived moiety on to indole acetic acid to produce indole acetic acid-lysine; this enzyme is not found in olive strains in which *iaaM* and *iaaH* are found closely associated on the chromosome rather than on pIAA.

Monooxygenase. Tryptophan monooxygnease is coded for by *iaaM* and indoleacetamide hydrolase is coded for by *iaaH* in *Pseudomonas syringae* pv. savastanoi and the genes occur in an operon. In bacteria, genes in an operon are transcribed one one RNA moleculae to produce a polystronic mRNA message. The porteins are translated separately from the polycistronic message. The *iaa* operon is constituitively expressed. Tryptophan monooxygenase is a FAD-linked, 62 KD protein inhibited competitively by 7 _M indoleacetamide or 200 _uM indole acetic acid. The locus for this gene, *iaaM*, has been sequenced and shows DNA homology with the *tms1* locus of TDNA in crown gall pathogenesis.

Hydrolase. Indoleacetamide hydrolase production is regulated with *iaaM* since insertions in *iaaM* have a polar effect on expression of *iaaH*. This indicates that *iaaM* and *iaaH* are co-transcribed and the *iaaH* promoter is distal to *iaaM.* The nucleotide sequence of *iaaH* shows homology with the sequences of *tms2* locus in crown gall TDNA.

Auxin conjugates with amino acids. Indole acetic acid-lysine synthetase, encoded by *iaaL*, requires ATP and influences the intracelullar pool of indole acetic acid by forming conjugates with dibasic amino acids such as acetyl-indole-acetic acid lysine:

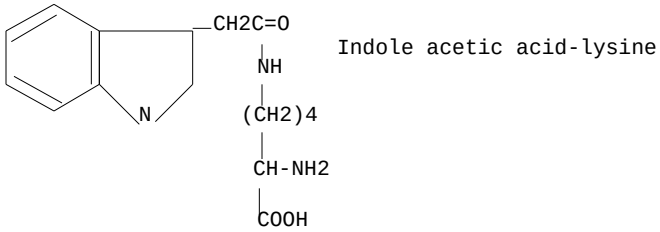

Figure 2. Indole acetic acid lysine is produced by the condensation of lysine and indole acetic acid catalyzed by indole acetic acid lysine synthetase.

Plant biosynthetic pathways. Evidently, the tryptophan monooxygenase-indoleacetamide hydrolase pathway is a unique bacterial synthesis of auxin. In plants and other bacteria, several other pathway intermediates occur between tryptophan and indole-3-acetic acid:

tryptamine--->indole-3-acetaldehyde--->indole-3-pyruvate--->

indole-3-acetaldehyde--->N-hydroxytryptophan-->

indole-3-acetaldoxime-->indole-3-acetonitrile

Genome location location. In *Pseudomonas syringae* pv. savastanoi oleander isolates, plasmid-borne genes encode the enzymes that catalyze the formation of indole acetic acid from tryptophan.

Other auxin-producing phytopathogenic prokaryotes. Erwinia herbicola has been implicated in russetting of pear fruit. Previously, russetting of pear fruit was thought to incited by cold temperatures or excess moisture early in the growing season. In fact, Steven Lindow found that russeting was related to colonization of lenticel on the fruit bacteria producing indole acetic acid in large numbers during early season wet weatherPresumably, indole acetic acid induces formation of corky cells below and around the lenticels (Anonymous, 1996).

B. Cytokinin synthesis. Agrobacteria and rhodococci produce cytokinins of both the isopentenyladenine and the *trans*-zeatin types. No evidence is available concerning rhizobia and bradyrhizobia.

Cytokinins and oleander knot. *Pseudomonas syringae* pv. savastanoi produces up to 10 _g/ml of the cytokinins isopentyl adenine, trans-zeatin, dihydrozeatin, and methyl-zeatin. In both olive and oleander strains, genes for cytokinin production are located on a plasmid, usually distinct from the one bearing genes for indoleacetic acid production. The patterns of cytokinin production varies from indoleacetic acid production; only after indoleacetic acid production reaches its peak does cytokinin production begin. The principle indigenous cytokinin of tobacco crown gall tissue is zeatin riboside 5'-monophosphate (Scott & Horgan, 1984).

Isopentyl transferase. The genetic locus, *ipt*, encoding isopentyl transferase (cytokinin biosynthetic function) in *Pseudomonas syringae* pv. savastanoi was found to reside on 42 to 84 KB pCYT plasmids in both oleander and olive strains (Morris, 1986; Roberto & Kosuge, 1987). Strains cured of pCYT produce attenuated galls. Homology (50%) occurs between the *ipt* locus and the *tzs* locus of the pTi *vir* region and *tmr* locus of TDNA in the crown gall pathogenesis system (Powell & Morris, 1986).

Regulation of isopentyl transferase. The *ipt* locus evidently is controlled in some way by the products of the *iaa* operon since cytokinin production does not begin until indole acetic acid production has reached a peak.

Biosynthesis of cytokinins. Cytokinin synthesis in bacteria (Akiyoshi, *et al.*, 1987, Letham and Palni, 1983). Less information is available concerning cytokinins. One possible pathway to isopentyladenine and zeatin is described below.

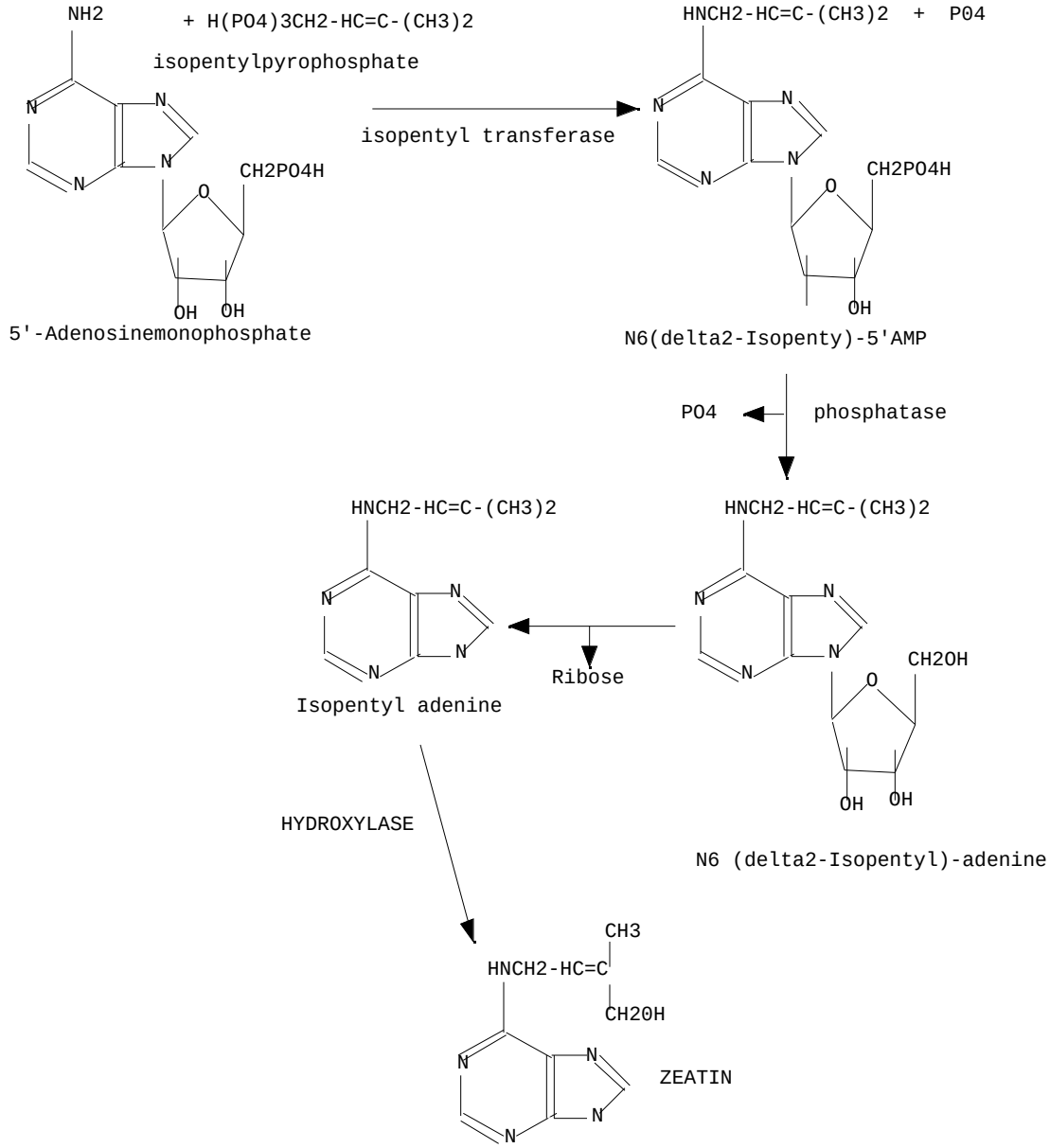

Figure 3. Cytokinin biosynthesis in phytopathogenic bacteria.

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PLANT DAMAGE: MOLECULAR BIOLOGY OF CROWN GALL

Crown gall and hairy root, diseases long associated with soil-inhabiting agrobacteria, are actually caused by pathogenic DNAs. These DNAs are inserted into and replicate with the plant genome thus satisfying the requirement for continuous pathogen presence and replication within the diseased organism. Since neither agrobacteria nor their associated plasmids persist within diseased tissues, they are not pathogens. The pathogenic DNAs reach the susceptible hosts bonded covalently with their primary vectors, plasmids, which in turn are located within secondary vectors, the agrobacteria. Obviously, the molecular biology and disease cycles of these pathogenic DNAs are complex. They are dealt with here with phytopathogenic prokaryotes since most plant pathologists, microbiologists, and molecular biologists consider agrobacteria to be the pathogens and the concept of pathogenic DNAs has not been generally considered, to the author's knowledge, outside of VPI&SU. However, the mechanisms whereby DNA may be moved from a plasmid in the cytoplasm of a bacterium across two bacteria membranes, moved across a plant cell wall, moved across a plant plasmalemma, moved through the cytoplasm of a plant cell, moved through a double plant nuclear membrane, inserted precisely in a plant chromosome, and expressed in a plant cell are of great interest. Obviously, the genetic and evolutionary chasm between prokaryotes and eukaryotes are bridged easily by the pathogenic DNAs. Thus, these `simple' plasmids, DNAs, and bacteria were engineering plants long before their more 'sophisticated' human counterparts were using rude stone tools in Oldavi Gorge.

I. Is *Agrobacterium tumefaciens* a pathogen or a vector?

A. The search for the tumor inducing principle (TIP). Tumor-like disorganized callus tissue was formed when normal plant tissues were cultured *in vitro* on media containing the phytohormones, auxin and cytokinin. However, crown gall tumors differed from callus in that explants continued to grow on artificial media without added phytohormones. Tumor tissue cultured in vitro for a long period of time is also interesting because it is almost always impossible to isolate agrobacteria from the tissue. This clearly violates the principle of disease for constant association of the putative pathogen with its host.

Chromosomal DNA. Because agrobacteria were rare or absent even in tumor tissue derived from diseased plants, pathologists considered other vehicles for conveying the tumor inducing principle to the host. Bacterial chromosomal DNA was considered in the late 1940's and early 1950's as a possible suspect for the tumor inducing principal. This concept was inspired by the results pioneering work of Griffin (1928), in England, who showed that genetic transformation of bacteria (*Streptococcus pneumoniae*) was possilble. His observations set off the controversy which was to clearly delineated nucleic acids (DNA or RNA) rtather than proteins as the genetic material. Avery, MacLeod, and McCarty,(1954) clearly demostrated that DNA along with transforming ability was destroyed by deoxyribonuclease. Others argued that this research did not exclude the

possibility of contaimination of DNA with protein, the actual genetic mateiral, or contaiminatio of the deoxribonuclease with proteinase. It remained for Fraenkel-Conrat and Singer (1957) to show, using transcapsidation of tobacco mosaic virus (TMV) strains that the phenotype was associated with the nucleic acid (RNA in this case) rather than protein protein coat.

Work with crown gall did not go so smoothly. Braun (1949) used purified agrobacterium DNA to inoculate carot disks. In a very small number of these, he recovered tissue that would replicate on articifical media without the addition of phytohorones. He published these observations in the journal, *Science*. Other workers were unable to confirm his observations. This plus the fact that he failed to use uninoculated controls forced him to retract his article. It could be convincingly argued that agrobacteria contaminating the surface of carot roots could have escaped disinfestation, been swept by the blade cutting the disks into the cut surface of the disk, and attach to the wounded tissues.

Many researchers repeated Dr. Braun's experiments to no avail. As an undergraduate, Dr. E.L. Stromberg (PPWS, VPI&SU) was assigned such a project at the University of California, Riverside under the direction of Dr. D.E. Munnecke without successful result.

Bacteriophage. Reasoning that the TIP might be a rare fraction of the DNA assoicated with agrobacteria, several reserachers isolated phage DNA and unsuccesfully tried to transform plant tissues by transformation using bacteriophage DNA as the transforming DNA.

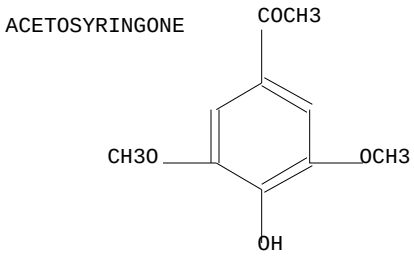
Plasmids. Kerr (1971) in Australia observed that mixtures of tumorigenic and non-tumorigenic agrobacteria on cut plant surfaces allowed transfer of TIP to non-tumorigenic agrobacteria. He did not understand the basis for this transfer but considered that conjugal plasmids may be involved.

Schilperoot (1972) discovered that agrobacteria which had lost their tumorigenic capability also lost a very large plasmid (pTi) from their cytoplasm providing support for Kerr's hypothesis.

TDNA. Nestor and Chilton s hybridized plasmid DNA to plant gall DNA and found a slight, repeatable but possibly non-significant hybridization with the whole plasmid. However, when they hybridized restriction fragments of pTi with the gall DNA, they discovered significant hybriization with a small part of the plasmid. This was the first evidence that the pathogenic DNA was inserted and that that insert consisted of a discrete subsection of the whole pTi plasmid designated TDNA (transferred or tumor DNA).

B. Tumor formation process.

Motility. Motile agrobacteria are more effective in causing tumorigenesis. The bacteria respond positively to plant wound-derived compounds such as acetosyringone in a chemotactic manner. Oher compounds that attact agrobacteria include sinapinic acid and syringic acid.



Attachment.

Site. Agrobacteria attach to the plant wound surfaces.

Receptors. Binding to receptors on cell wall--reversible.

Pectin. Agrobacteria bind to pectin a material chiefly found in the middle lamellae and interwoven with cellulose in cell walls. Ionic bonds between the bacterial lipopolysaccharides and plant pectic materials account for the primary biniding.

Cellulose fibrils. Cellulose fibril formation is induced by contact with the plant cell. Agrobacteria bind by are bound more firmly by cellulose fibrils exuded by the bacterium. These fibrils may be related to the cellulose "infection" tubes formed by rhizobia and bradyrhizobia.

Expression of *vir* genes.

TDNA processing into ssTDNA.

Transfer of ssDNA into plant cell. Takes 24 h of co-cultivation; may be stopped by antibacterial antibiotics.

Genomic insertion. Integration of TDNA into the plant genome.

Expression of TDNA genes.

B. Structure of plasmid pTi.

Size. 200-400kbp.

TDNA. Tumor DNA zone (TDNA) 14-23 KB. In nopaline pTi plasmids the TDNA is a contiguous linear DNA fragment; in octopine pTi and pRi, two segments of TDNA are separated by 2-16 KB of non-transferred DNA.

Borders. Render directional specificity for TDNA transfer.

Left border (B_L). The left border is more variable and less important that the right border (J. Molec. Appl. Genet. 1: 361-370, 1982).

```
1         5         10        15        20        25
T T G C C T G A T T T C G A T T T C G A G T G C A
    ^           ^ ^
```

Arrowheads (^) indicate sites of cleavage to form ssTDNA

Right border (B_R). Concensus sequence of a border repeat. Concensus includes nopaline pTi, octopine pTi, and pRi:

```
1         5         10        15        20        25
  (C)                 (G)
T G Pu  C A G G A T A T A T N N NN N T G T A A N N
  ^
```

Arrowhead (^) indicate site of cleavage to form ssTDNA

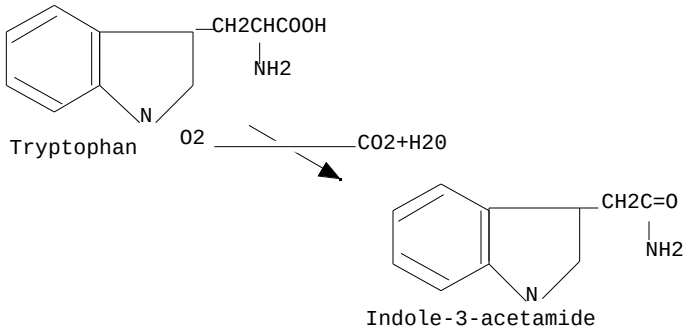
NNNNN region may be important in species specificity

Overdrive region. This region is located within or just out side B_R and increases the efficiency of plant cell transformation with TDNA.

Oncogenicity region. Teminology for human tumor development have become integrated into the lexicon of crown gall. The oncogenicity region (*onc)* is the term applied by some to the region of the TDNA producing phytohormones involved in tumorigensis or even the whole TDNA region to imply that it is the region responsible for tumorigenesis. Others believe that this pseudo-medical terminology may be confusing and rely on terms more closely indicating the funciton of genes with in the TDNA.

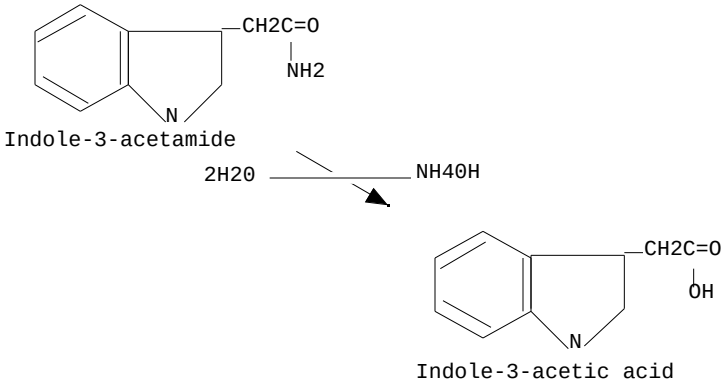
Auxin synthesis genes.

Tryptophan monooxygenase (*tms1*) coding region.



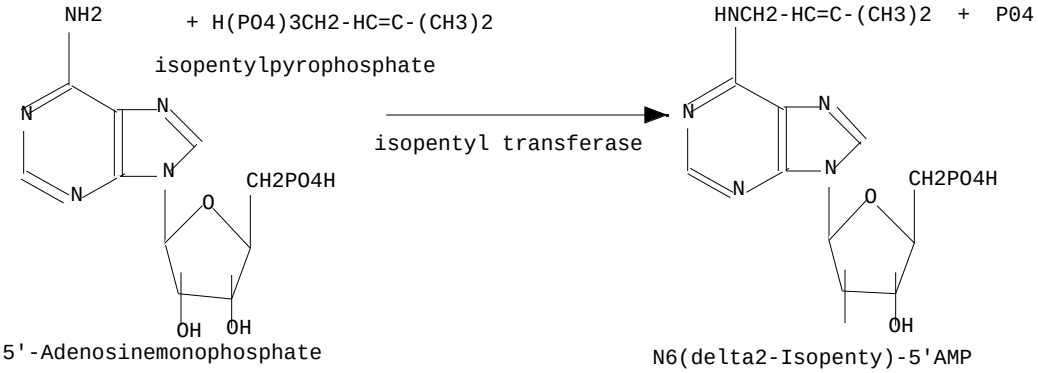
Tryptophan monooxygnease converts tryptophan to indole acetamide.

Indole-3-acetamide hydrolase (*tms2*) coding region.

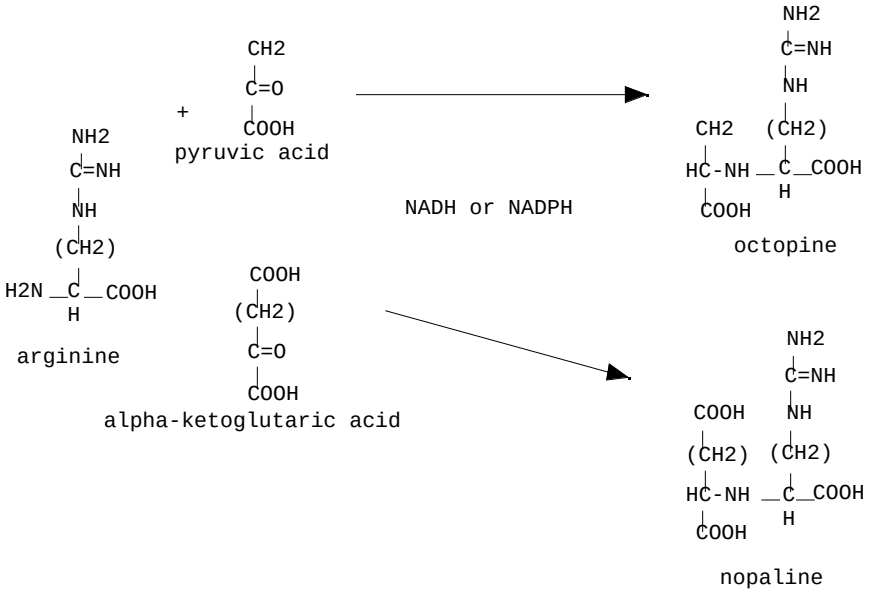


Indoleacetamide hydrolase converts indole acetamide to indole-3-acetic acid (auxin).

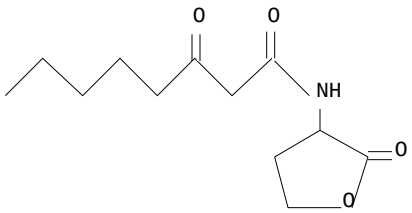
Cytokinin synthesis gene (*tmr*) isopentyltransferase coding region. This region is present in agrobacteria associated with crown gall (tumors; *A. tumefaciens*) and absent in agrobacteria associated with hairy root proliferations (*Agrobacterium rhizogenes*).



Opine synthesis gene Octopine (*ocs*) or nopaline (*nos*) synthetase coding regions are found in most TDNA. Opine synthetases catalyze unique amino acids almost exclusively associated with crown gall in nature. Opines, such as nopaline and octopine, provide nitrogen and carbon sources for the nutrition of agrobacteria. The opine link forms the basis for the opine hypothesis of symbiosis which ties the bacterium, plasmid, and TDNA together.



Opines. Opines are signals of plant proximity which induce conjugal transfer among bacteria. In this manner, pTi induces its own transfer among agrobacteria. Transfer among bacteria allows the plasmid to move into new niches in the environment. Opines in turn induce N-acyl-octanol-L-homosrine which is a common bacterial inducer of genes related to conjugal transfer of plasmids [transfer (*tra*) and mobilization (*mob*) genes] as well as a consensus signal for other bacterial responses to bacterial density. (Zhang et al., 1993; Piper et al., 1993)



N-beta-oxo-acyl-amides of L-homoserine: hexanol (shown), octanol, and decanol side chains occur

Tumor size regulating genes (*tml1* and *tml2*). These loci regulate the size of tumors.

Opine export gene. Position and code not known. This gene allows opines to escape plant cells. Alternatively, the action of auxins and cytokinins on the plant cell membranes may cause them to be permeable to opines.

Eukaryotic promotors. In the TDNA, eukaryotic rather than prokaryotic promoter regions front each gene (*tms1*, *tms2*, *tmr*, and *ocs*) that is expressed in the plant. Other eukaryotic signals are present in the TDNA region including polyadenylation signals recognized by the plant but not the bacterium. However, there is some indication that prokaryotic genes may be found in the *ocs* locus. This may suggest nested prokaryotic genes exist within the genes expressed *in planta*. Perhaps 'nested' genes exist that are expressed only in the bacterium.

Virulence (*vir*) region. This 35Kb region encodes host range specificity among eight loci (*virA*, *virB*, *VirC*, *virD*, *virE*, *virG*, *tzs* and *pin*) producing about 20 polypeptides. These genes are inducible by plant products. For instance, *pin*, a locus controled by *virA*, is induced by acetosyringone, a phenolic compound often associated with plant wounds.

***virA* region.** The product, VirA, of this gene acts as a receptor, or an environment sensor, for the plant inducer molecule, acetosyringone (3',5'-dimethyoxy-4'-hydroxy-acetophenone) and its relatives (*e.g.*, _ -hydroxyacetosyringone). This is a typical receptor molecule, a composed of four regions:

Hydrophobic transmembrane region. Between the transmembrane regions is a region located in the periplasm that binds with ChevE and increases the sensitivity of the bound VirA to acetyosyringone. Upon complexing with acetosyringone, the protein undergoes a configuration change which is analogous to a signal to the other end of the protein.

Trasducing region. A second region transduces the signal from from the hydrophobic membrane spanning region to the third region.

Histidine kinase. Region three is a kinase with autophosphorylation activity such that upon receiving the "signal" from region one via

region two phosphorylates residue 474, a histidine residue in the presence of ATP.

Region 4. Has amino acid sequence similarity to part of VirG and may act to enhance VirA-VirG interactions. However, deletion of this region apparently does not affect the interaction.

Activity. The kinase phosphorylates a second protein--VirG. The phosphorylation of VirG activates that protein and activated VirG binds DNA upstream from several *vir* loci at *vir* boxes. Through the action of VirG, the remaining genes in other *vir* regions are activated. For induction of the *vir* regions the optimal concentration of acetosyringone is 200-500 _M.

***virB* region.** Mutants in this region lose tumorigenic capacity. One to six complementation groups have been reported in this region with one to three transcripts produced. The VirB proteins form the channel in the bacterial membrane for export of the T-DNA-protein aggregate to plant cells.

***virC* region.** This region encodes a single transcript of 1.5 KB that produces two polypeptides, 25-26 KDa (VirC1) and 22-23 KDa (VirC2). Transposon insertions in either *virC1* or *virC2* cause identical attenuations in tumorigenicity. Affects the host range for tumorigenesis. VirC1 and VirC2 produce proteins that complex with the overdrive region of the DNA just outside the right border of the TDNA.

***virD* region.** Mutations in this 5 KB region completely eliminate tumorigenicity. At least four open reading frames (ORF) exist in this region. The protein product of *virD1*, VirD1 (16 KDa), associates with the product of *virD2*, VirD2 (48 KDa), at the restiction site on the right border of the TDNA. The complexing of VirD1 with VirD2 allows the two proteins to act as a site specific endonuclease which nicks the border sequences of TDNA asymmetrically one one strand only. The other ORFs in this region may have roles in TDNA transfer. The VirD2 protein functions with the other VirD proteins in separating the single-stranded (ss) TDNA region. VirD2 protects the 5' end of the ssDNA from exonuclease activity (Ward & Barnes, 1988).

***virE* region.** Mutations in this 2 KB region attenuate tumorigenicity and may be involved in host specificity. Encodes an ssTDNA-binding protein (VirE2, 68 KDa) that may functions to protect ssTDNA from degradation by plant cell nucleases. Two proteins are produced, 7 and 68 KDa produced from the loci *virE1* and *virE2*, respectively.

***virG* region.** Regulatory function. VirG, phosphorylated by VirA kinase is activated and bindw with the *vir* box in front of genes in the other *vir* regions.

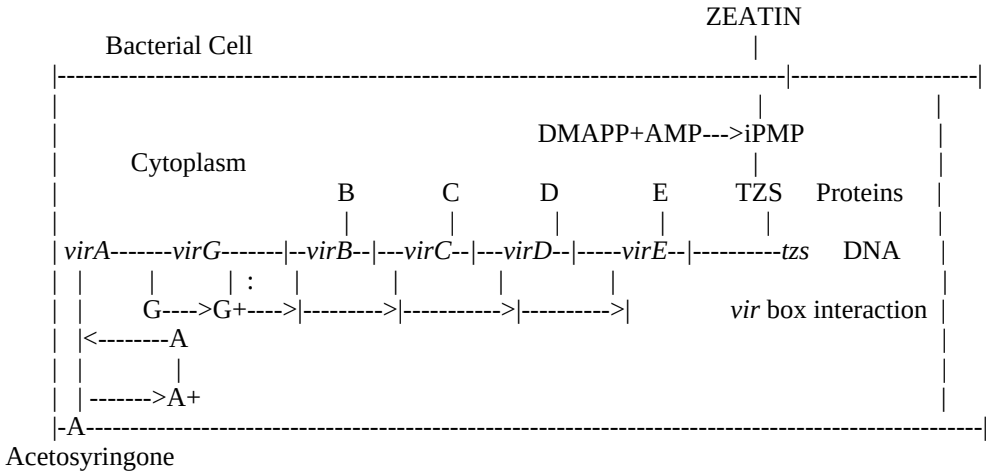
T T C A C T T G T A A C *vir* box I
A A C G A T T G A G A A *vir* box II
T A A A A T T G A A A T *vir* box III
t a c a a T T G a a A n consensus *vir* box

***tzs* locus.** In nopaline synthesizing pTi plasmids, this locus encodes a protein very similar to isopentyltransferase for the synthesis of *trans*-zeatin, another cytokinin. Increased greening at inoculation sites, regeneration of vegetatively produced plants, and greater tumorigenic ability have been suggested for this locus. This locus is found only in nopaline strains, not in agropine or octopine strains.
***pinF* region.** This is region also control ed by *virG*. *pinF* is not a virulence gene.

Directions for transcription of vir regions on pTi.

.....tzs pinA virA virB virG virC virD virE TDNA region.....
---> -----? ----> ----> ---> <--- ----> --->

Cascade regulation (Morris, 1988).



Acetosyringone interacts with product of *virA* which phosphorylates the product of *virG* which, in turn, induces *virB, virC, virD, virE*, *pinF* (not shown), and *tzs*. The product of *tzs* catalytically changes isopentylpyrophosphate (DMAPP) and adeninosinemonophosphate (AMP) into the precursor (iPMP) for zeatin.

Transfer of T-DNA into plants. The products VirB, VirC, VirD, and VirE are involved in the transfer of TDNA into the plant cell. Transfer

occurs using essentially the same machinery that allows transfer of plasmids from one bacterium (donor) to another (recipient). One area of controversy is the state of the DNA transferred. In plasmid transfer a rolling model of DNA synthesis occurs with a very short region of single-stranded (ssDNA) protected by single-stranded DNA binding proteins at the replication fork. The DNA transferred to the recipient cell is double-stranded (dsDNA). The dsDNA may circularize and form a new plasmid in the cytoplasm of the recipient. Alternatively, the dsDNA may, by double cross over phenomena, move into the recipient bacterium's DNA. In T-DNA transfer if the transfer is made with ssDNA or dsDNA into the cytoplasm of the plant is controversial. It may be that T-DNAs differin this mechanism. However, apparently dsDNA is aquired by the genome of the host plant by genetic mechanism that apparently involves the borders of T-DNA. It may be that the transit from the cytoplasmic membrane of the host through nuclear pores is aided by cytoskeletal components of plants. Some Vir proteins may act as chaparonins to guide the DNA into the nucleus.

Opine catabolism and transfer region. Transfer function (*tra* and *mob* loci) and opine (opine permease) uptake and catabolism genes (*occ*) are grouped together but apart from the *vir* and TDNA regions on pTi.

Origin region. Origin of plasmid replication (*ori*) and plasmid incompatibility functions *inc*) genes are grouped together.

Other plasmids involved. A transposon mutant deficient in cellulose fibril synthesis (*cel*) for attachment was located on a large cryptic plasmid that most *A. tumefaciens* strains have in addition to pTi.

Chromosomal determinants of pathogenicity. Bacterial and plasmid genes add to the symbiosis with TDNA to provide for crown gall tumorigenesis.

Attachment. Methylated pectin reduces attachment. Suggests lipopolysaccharide (LPS)-pectate attachement necessary. Living cells required, but protein synthesis is not required. Spheroplasts do not bind but whole cells do; therefore the attachment site in on the bacterial cell wall--presumably the outer membrane portion. LPS is probably involved, but the *chvA* and *chvB* loci (_-1,2-glucan synthesis) is also involved and up to three outer membrane proteins (33,34, and 38 KDa) may also be involved. These proteins are mediated by *att* loci.

LPS composition. Plasmid pSa changes LPS composition and reduces binding.

Cellulose fibrils. After primary attachment, cellulose fibrils are produced which bind cells and developing colonies to the cell surface.

Chromosomal loci involved in attachment.

cel. Mutants in this locus do not synthesize cellulose fibrils. These mutants still attach to cells and form tumors, but attachment is easily

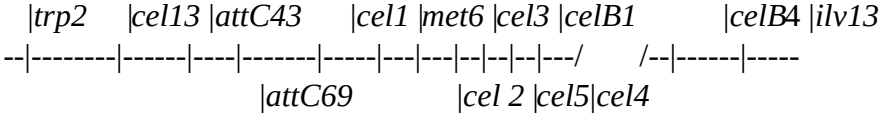
reversible. Transposon mutants inserted into six different-sized *Eco*RI fragments indicating six possible loci. A seventh transposon inserted into a large cryptic plasmid most *A. tumefaciens* strains have. Three additional transposon mutants cause overproduction of cellulose fibrils (Robertson et al., 1988).

att. Mutants in this locus appear to synthesize normal extracellular polysaccharides but lack one or more cell surface proteins, fail to grow on certain selective media and do not form tumors.

***chvA* and *chvB*.** Tn5 mutagenesis indicates a 12 kb region on the chromosme. Mutations in two transcriptional units, *chvA* and *chvB*, result in the inability to attach. Evidently, *chvA* mediates export of a small (17-20 glucose residues), cyclic β-1,2-glucan which is produced by a protein mediated by *chvB*. Prior to export, a 235 KDa protein-glucan complex is located on the inner membrane of the cell wall. These mutants may be tumorigenic at high osmotic pressure--since _ -1,2-glucans are periplasmic in both rhizobia and agrobacteria, and are involve in osmotic buffering, this may be their role.

exoC. Mutants in this locus are nonmotile, grow poorly on some media, and do not produce cyclic β-1,2-glucan or high MW succinoglycan. Rhizobia mutants of *exoC* synthesize altered lipopolysaccharides--which is of interest in agrobacteria since *exoC* mutants are 2- to 10-fold more deficient in attachment than *chvA* or *chvB* mutants.

pscA. Mutants at this locus are deficient in the production of cellulose fibrils and the four major species of exopolysaccharides. *pscA* maps at a different locus than either *att* or *chv*.



Bacterial chromosomal loci associated with agrobacterial attachment to plant cells.

pTi functions in rhizobacteria. Moving pTi into rhizobacteria. causes them to produce galls; moving rhizobium pSym plasmids into agrobacterium allows development of ineffective nodules.

Speculation on the origin of pTi. Pseudomonads and agrobacteria share homology in auxin synthesis genes but not cytokinin synthesis genes. Plasmids may be derived from bacteriophages.

II. pTi AS A VECTOR FOR ENGINEERING PLANTS

A. Dicot host range.

B. Monocot introductions.

C. Disarming pTi..

D. Replacing pTi genes with agronomically desirable genes.

E. Problems--non-specificity of insertion.

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PREFORMED AND ACQUIRED RESISTANCE

RESISTANCE: PREFORMED BARRIERS AND SYSTEMIC ACQUIRED RESISTANCE

DEFINITIONS. The word "virulence" is used several ways in plant pathology literature; the following list includes several usages for this one word: **Virulence:** 1. synonym of aggressiveness; 2. antonym of avirulence; 3. genetic ability of a pathogen race to overcome genetically-determined host resistance to cause disease; 4. relative ability of a pathogen of a given genotype to cause damage on a specific host with a given genotype under defined environmental conditions (Shaner *et al.*, 1992).

In this section we will use virulence to mean the ability of pathogens to overcome host resistance (especially, usages 1, and 3). Virulence is used in confusing manners in the litterature. Examples of usages:

> Usage 1: A virulent pathogen causes more damage than a less-virulent pathogen on a susceptible host.
>
> Usage 3: A compatible pathogen causes disease on a particular cultivar of a plant species; an incompatible pathogen does not cause disease on that cultivar, but is capable of causing disease on some other cultivar of that species. This usage for virulence involves gene responses in both host and pathogen—or gene-for-gene interactions.

A pathogen on its susceptible host cultivar comprises a **compatible interaction** and disease will develop provided that environmental conditions permit. Conversely, an pathogen on a resistant or non-susceptible host cultivar yields an **incompatible interaction**. This suggests that virulence is superimposed over basic compatibility or the ability to cause disease.

DEVELOPMENT OF BASIC COMPATIBILITY. Relationships among prokaryotes and plants are as old as the plants themselves. Eukaryotes evolved in and competed for biological space and nutrients in an environment already colonized by prokaryotes. In fact, mitochondria and chloroplasts are most likely derived from degenerate prokaryotes that formed the early symbioses within an archebacterium. Today this symbiosis is the basis for the group of organisms known as eukayotes. Certainly, for survival, early plants developed methods for preventing unwanted colonization by prokaryotes. Therefore, the interactions we study today evolved over many eons and we should expect them to be complex as well as subtle. These interactions consist of stepwise accumulations of genetic changes. Schematically we may view these changes schematically in Fig. 1.

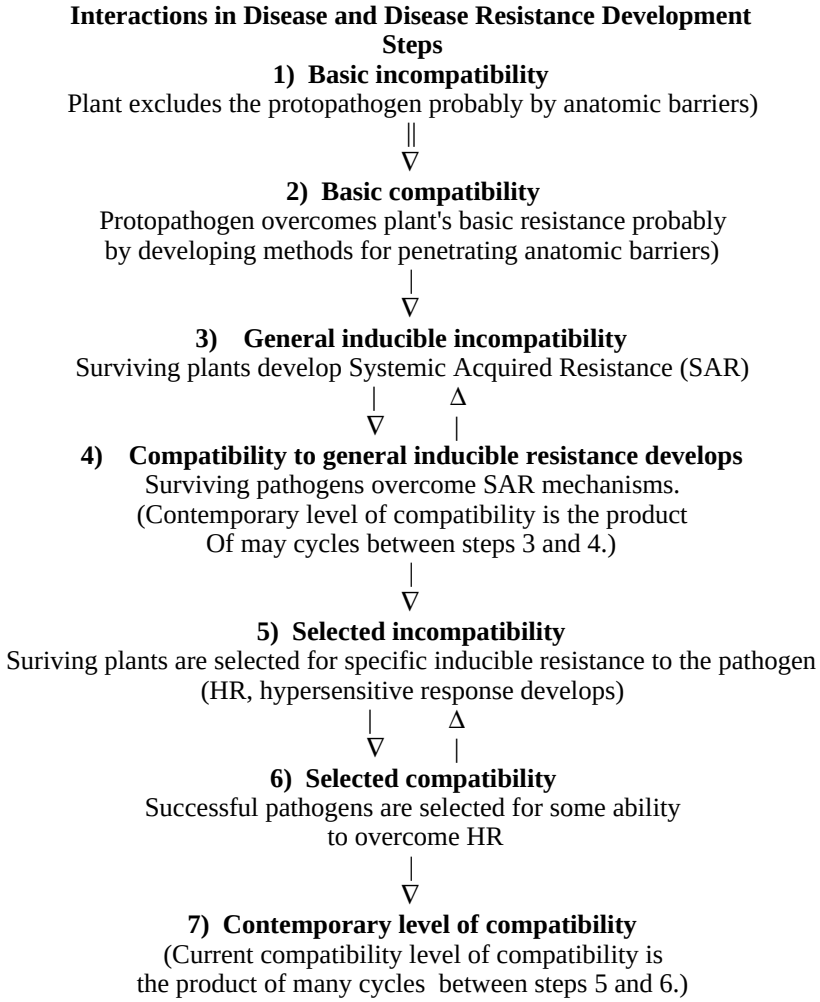


Figure 1. Schematic representation of the basic and selective compatibility and incompatibility. Phytopathogen overcome basic resistance to cause disease in plants. Plants respond by developing general inducible resistance (SAR, systemic acquired resistance). Pathogens respond by developing specific methods to overcome SAR. Plants respond by developing specific gene-for-gene inducible resistance responses (HR, hypersensitive response). Pathogens respond and develop specific methods for evading induction of HR.

I. Preformed barriers. PREFORMED RESISTANCE. Plants remain attractive ecological niches; they are under-exploited nutrient sources practically free of competition from microorganisms. The barriers to basic compatibility are strong since only about 120 of 1800 named species of bacteria cause plant disease. Perhaps, preformed resistance, or passive plant defense to entry and colonization, resembles ancient defenses of plants to prokaryotes. These defenses include the cuticle, epidermis, plant cell walls, turgor and hydrostatic pressure within vascular elements, special anatomic features of natural plant openings, and inhibitory chemicals. These defense mechanisms have broad activity and also provide barriers against the entry of pathogens other than prokaryotes.

Several phytopathogenic prokaryotes appear to be able to form compatible relationships with many plants despite preformed resistance mechanisms. These pathogens may have retained the ancient ability to avoid or overcome preformed resistance. This group includes the soft-rot bacterium *Erwinia carotovora*, whose host range encompasses almost every fleshy or succulent plant tissue; the crown gall vector organism, *Agrobacterium tumefaciens* colonized by pTi, a plasmid-containing pathogenic TDNA which causes tumors on more than 180 plant species; and the aster yellows causal agent, a phloem-limited, phytoplasma, which affects over 120 different species.

Examples of anatomical preformed resistance are the cuticular decorations, size, and frequency of distribution of stomatal pores that reduce entry of plant pathogenic prokaryotes into plant tissues. Chemical preformed resistances include compounds such as lignin that restrict the catalytic activity of cell-wall degrading enzymes, toxic compounds that are present in concentrations great enough to prevent prokaryotic replication, and cleavage of various non-toxic glycosides into aglycones toxic to pathogens (reviewed in Lacy *et al.*, 1979). Pathogens may avoid preformed resistance mechanisms by several methods. They may use enzymes to degrade barriers to penetration such as cutinase produced by *Streptomyces scabies*, avoid hydroquinones by reducing them or limiting their production, or develop resistance to inhibitory chemicals.

A. Physical barriers. Many of the concepts presented here have been discussed separately in other sections of the lecture. Review especially the natural openings discussed for plant colonization in the phyllosphere and the pseudowounds discussed in conjunction with that section and the section on vascular colonization by non-fastidious prokaryotes.

1. Epidermis. The epidermis is composed of the cuticle, waxy layer formed by polymers of hydroxy and epoxy fatty acids. This layer is water resistant, has few sources for bacterial nutrition and is relatively thick. Plant cuticles are difficult to degraded enzymatically (most bacterial cutinases are of low activity levels), contribute an overall negative electrostatic charge to plants that may repulse bacterial deposition from aerosols, limit bacterial cohesion to plant surfaces, are not readily wetted, reduce diffusions of water soluble nutrients from within the plant, and often contain antimicrobial compounds, such as catechol, dissolved in the waxes. Cell walls beneath the cuticle are glued into a coherent tissue by a gel matrix composed of neutral polysaccharides and pectic substances. Within this matrix, are found epidermal cells with tough cell walls composed primarily of cellulose but with hemicellulose, pectic materials, and proteins intermixed (review cell wall discussion from enzymatic degradation section).

2. Bacterial entry. Bacterial enter plants most often through breeches in the physical barriers that are either natural, caused by plant development, or created by opportunities provided by wind-driven rain, abrasion wounding, insect and animal damage, or anthropomorphic aid and assistance through cultural contacts.

a. Natural openings. Natural openings such as stomata, hydathodes and lenticels provide areas of increased moisture or relative humidity that may be more heavily colonized by bacteria such that they are present when conditions may allow for penetration by bacterial motility.

b. Pseudowounds. During the development of plants wounds developed by the growth of either lateral or adventitious roots, abscission of leaves, or the breaking of root hairs during the elongation of roots among abrasive mineral particles may provide sites for bacterial entry.

c. Adaptations to prevent entry. Plants have developed methods to prevent damage and possible entry of plant pathogens including prokaryotes by making plant surfaces less appealing for colonization.

i. Glands/terpenoids. Modified trichomes form gland cells containing antimicrobial terpenoids.

ii. Root tip. The root tip is protected by rapidly dividing cells in the root cap. Their lubricating ability proceeds from the ease with which they are sloughed off and the softeness of the pectic gel they are contained in. these cells are sacrificed to protect the actual root tip from damage from abrasive mineral particles or attachment and/or penetration by pathogens.

iii. Ectomycorrhizal/ physical/antibacterial coumpounds. Plants may also develop protective symbioses. Epiphytic microbial populations in the rhizosphere and phyllosphere often have protective properties which resist through microbial competition and/or antagonism (antimicrobial compounds and antibiotics) colonization by the resisdent phases of phytopathogenic bacteria. More elaborate symbioses, such as ecto- and endo-mycorrhizal associations may provide additional protection of the plant from pathogens.

B. Chemical protection of internal tissues.

1. Definition. Antimicrobial preformed chemicals which protect plants from pathogen colonization must, by definition, be prexisting in the plant in a form not damaging to the plant itself, occur at a concentration effective against the target pathogen, and be either in its active form or be able to be readily released in an antive antimicrobial form.

2. Homoserine. In resistant pea (*Pisum sativum* L.) cultivars, the antimicrobial and rare amino acid homoseringe is in concentrations which are inhibitory to the pathogen *Pseudomonas syringae* pv. pisi. In this case, homoserine is not toxi to the plant and is available in plant tissues in its active form.

3. Glycosylation. Glycosylation is the process of detoxifying toxic compounds within the cytoplasm of plants by the addition of sugar moieties to the toxin so that plant damage does not occur. Glucosidases, enzymes often stored in the vacuoles of plants, and thus separated by compartmentalization from glycosylated and neutralized toxins in the cytoplasm, are capable of deglycosylating or removing the sugar moieties. Thus, in pathogen damaged cells, mixing of vacuolar substances with the cytoplasm results in the formation of the aglycone

(de-glycosylated) toxin by enzyme action. The aglycone toxin is available to provide antimicrobial activity against the pathogen. Many examples of this type of glycosylated preformed antibmicrobial compounds exist.

a. Chlorogenic acid. In potato (*Solanum tuberosum*) an antimicrobial terpenoid, chlorogenic acid is toxic to the potato scab pathogen (*Streptomyces scabies*) and the plant unless it is glycosylated.

b. Juglone and arbutin. Walnut (*Juglans regia*) and pear (*Pyrus communis*) contain non-toxic glycosides of juglone and arbutin, respectively, that may be deglycosylated to form potent antimicrobials. Arbutin and juglone are hydroquinones.

c. Cyanogenic compounds. Over 1000 plant species produce cyanide (CN)-containing compounds. Cyanide is very efficient inhibitor of the electron transport system effective at 0.1mM. Isothiocyanic acids (R-C=N=S-H) or mustard oils are common and in high concetrations in the cruciferae. Isothiocyanic acids may be glycosylated and made non-toxic in the cytoplasm through the thio-bond (R-N=C=S-glucose). Myrosinase, an enzyme compartmentalized in the vacuole, is cable of releasing the glucose to form toxic mustard oil (R-N=C=S-H).

d. Benzooxazolones. In maize (*Zea mays* L.), *g*lycosylated *d*ihydroxy*m*ethoxy*b*enz*ox**a**z*inone (GDMBOA) may be deglygosylated by glycodisdases to remove glucose yielding the toxic aglycone *d*ihydroxy*m*ethoxy*b*enz*ox**a**z*inone (DIMBOA) which is unstable and rapidly decomposes into a second toxic compound, *m*ethoxy*b*enz*ox**a**z*olinone (MBOA). Maize lines high in GDMBOA tend to be more resistant to bacterial stalk rot caused by *Erwinia chrysanthemi* although other factors are important in soft rot resistance (Lacy *et al.*, 1979).

4. Other mechanisms. Oher biochemical mechanisms may induce the release or formation of antimicrobial compounds from preformed defensive compounds.

a. Hydrolysis. By a different mechanism, other cyanide-containing non-toxic molecules may become toxic. For instance, the hydrolysis of non-toxic cyanic acids (R-C=N) directly yields hydrogen cyanide (HCN) and the hydroxide form of the compound(s) (R-OH).

b. Thioesters. Thioester bonds (R-S-R') form toxic compounds in plants. In onion (*Allium cepa* L.), non-toxic alliin is converted to toxic allicin (leak oil) by this process.

c. Hydroquiniones. Hydroquinones are formed from phenols by oxidation with either peroxidases or polyphenol oxidases. Oxidase negative bacteria such as *Pseudomonas syringae* pathovars seem to avoid damage by hydroquinones in plant leaves whereas oxidase positive pathogens such as *Pseudomonas fluorescens* are damaged. It is believed that the oxidase positive bacteria induce through their own oxidase the formation of damaging hydroquinones.

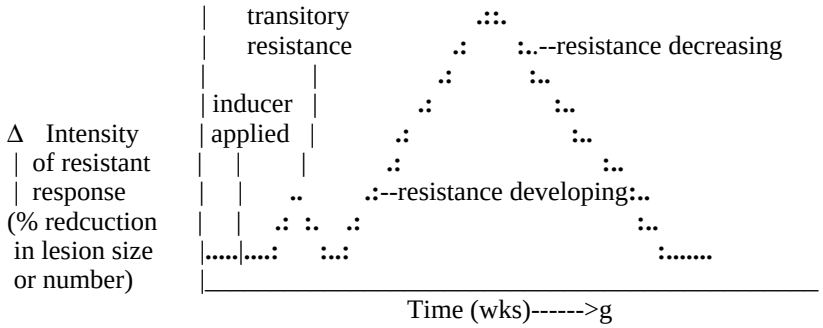
5. Watersoaking.--EPS-cleaving enzymes.

6. Saprophytic barrier.--Acid rain

II. Systemic acquired resistance. (Note: Systemic acquired resistance is called several names including induced resistance. Since induced general resistance may be confused with induced specific resistance, *s*ystemic *a*cquired *r*esistance (or SAR) is the preferred name).

SYSTEMIC ACQUIRED RESISTANCE. Development of active resistance mechanisms probably was a co-evolutionary response by the plant host to circumvention of preformed or passive defenses by successful pathogens. Systemic acquired resistance is a general phenomenon induced by treatment of plants with living, killed, or subcellular components of microorganisms or certain abiotic substances. The plant responds by becoming more resistant to subsequent challenges by diverse disease-causng agents. This light- and time-dependent resistance develops within a few hours, peaks in several days, and persists for up to a few weeks.

A. Elements of the system.



B. Inducers.

1. Bacteria as inducers. Mixed inoculations of plants with virulent and non-virulent bacterial cells may result in protection.

a. Co-inoculation with virulent and avirulent *Ralstonia solancearum* (this may be controversial since avirulent strains also induce hypersensitivity).

b. Pre-inoculation of *Pyrus* with incompatible *Pseudomonas syringae* pv. tabaci or non-pathogenic mutants of *Erwinia amylovora* induces protection against pathogenic *Erwinia amylovora*.

c. Other phenomena may mimic induced resistance in early stages, *i.e.*, blockage of attachment sites in wounds by *Agrobacterium radiobacter* reduces attachment by *Agrobacterium tumefaciens*; pre-inoculation of pear (*Pyrus communis* L.) blossoms with *Erwinia herbicola* protects agains *Erwinia amylovora.*

2. Bacterial components as inducers.

a. Heat killed-bacteria cells. heat-killed *Agrobacterium tumefaciens* protects against the living pathogen.

b. Cell-free sonicates. Sonicates of pathogenic or non-pathogenic mutants of *Erwinia amylovora* protect agains the pathogenic living pathogen.

c. Cellular components. DNA but not RNA from *Erwinia amylovora* protects against the living virulent pathogen.

3. Non-specific inducers.

a. Rubbing with carborundum, rubbing with cotton swabs, or injecting with water: Protects leaves of tobacco (*Nicotiana tabacum* L.) against the hypersensitive reaction caused by inoculation with *Pseudomonas syringae* pv. pisi.

b. Acetylsalicylic and polyacrylic acids. Protect against some viral diseases. Raskin *et al*. (1991) have showed that endogenous levels of acetylsalicylic acid become elevated during the development of systemic acquired resistance. Addition of acetylsalicylic acid to mimic these levels induced resistance. They believe that acetylsalicylic acid is a systemic signal as well as inducer of systemic acquired resistance.

C. What is systemic acquired resistance?

1. mRNAs build up for pathogenesis-related proteins: these include chitinases, lysozymes, and endoglucanases. Chitinases and endoglucanases have catalytic activities that directly may affect cell walls of ascomycetous and oomycetous fungi respectively. Chitinases often have lysozyme activity as well allowing direct affects upon bacterial cell walls.
2. Inconsistently, protein bands have been detected.
3. Systemic acquired resistance is phloem-translocated.
4. Systemic acquired resistance diverts energy away from growth and fruit filling.

D. Can systemic acquired resistance be used in the field to prevent disease?

III. RESISTANCE: SPECIFIC INDUCED RESISTANCE

Previously, we have been dealing with preformed resistance and systemic acquired resistance--basic incompatibility and general incompatibility. Now we will deal with specific incompatibility. As the name implies, the host must recognize the pathogen specifically in this type of resistance to trigger its defenses. Therefore, a brief review of plant recognition of the bacterium is in order at this point.

DEVELOPMENT OF VIRULENCE. Once a pathogenic relationship is established, coevolution occurs. This consists of a series of genetic responses by one organism in the relationship to the other organism. These adjustments include the development of resistance for the host and virulence to overcome host resistance for the pathogen. In this situation, a major advantage for one interactant may mean extinction for the other interactant. The successful co-evolutionary interactions or diseases we study today have survived because the interactants have established dynamic genetic equilibria. At this point, the genetic adjustments of the virulent pathogen minimize the resistant responses of the host while maximizing its nutritional gains without endangering the survival of its host species.

Systems in which co-evolution has occurred typically involve specialization of both pathogens and hosts. This specialization includes the development of races of the pathogen and resistant plant lines or cultivars within the susceptible plant species. Parallel gene-for-gene relationships between resistance in the host and virulence or avirulence in the pathogenic prokaryote occur.

Examples of systems in which pathogenic races of prokaryotes and specific resistance to those races are known among cultivars of the susceptible species include the *Pseudomonas syringae* pvs. phaseolicola, causal agent of haloblight of bean (*Phaseolus vulgari* L.), tomato, causal agent of tomato (*Lycopersicon esculentum* Mill.) spot, and glycinea, causal agent of soybean (*Glycine max* [L.] Merr.) blight, and *Xanthomonas campestris* pv. malvacearum, causal agent of angular leafspot of cotton (*Gossipium hirsutum* L.). In addition, *Ralstonia solanacearum*, causal agent of Granville wilt of solanaceous crops including tobacco (*Nicotiana tabacum* L.) and bananas (*Musa paradisica* L.) and *Erwinia amylovora*, causal agent of fire blight on roseaceous perenials including pear (*Pyrus communis* L.) and apple (*Malus sylvestris* Mill.) cause the hypersensitive reaction typical of gene-for-gene pathogen-host interactions.

RECOGNITION MECHANISMS. Recognition of a pathogen and a plant results from the identification of a chemical signal from the pathogen by the host.

Early concepts in recognition (reviewed in Keen and Holliday, 1982). Lectins, glycosylated proteins on the surface of plants have been known to be involved in the recognition of plants by nitrogen-fixing bacteria. ***Rhizobium*** and *Bradyrhizobium* attach to specific legume containing certain lectins. The **lectin hypothesis** suggests that specific lipopolysaccharides (LPS) on the outer membrane of bacteria interact in an ionic manner with lectins on plants. Experimentally, these interactions may be studied using **haptens** or interfering compounds. Specific sugars (such as N-acetyl-D-glucosamine, D-galactose, 2-deoxyglucose, *etc*.) will interfere with lectin/LPS interactions. The sugars chosen must be similar to those of the lectin and LPS which interact ionically to hold the two molecules together. (Review the lectin hypothesis in the lecture on the Rhizosphere.)

Contemporary concept in recognition The lectin hypothesis did not explain hypersensitive reactions adequately. The concept of very specific **receptor proteins** triggering a multiplying cascade of signals inducing many genes in the resistant response fit better the observed phenomena. It is an especially elegant solution to the idea that the inducers (elicitors) of the hypersensitive response appear to be in very small concentrations. Receptor proteins span the cytoplasmic membrane. The receptor site is exposed outside the cytoplasmic membrane. These receptors exactly “fit” the elicitor molecules produced by the incompatible pathogen. Once an elicitor has docked with a receptor, the receptor molecule undergoes a configurational change. The part of the receptor molecule inserted in the cytoplasm becomes active as affector of other protein molecules in a catalytic manner—thus amplifying the signal of the original elicitor. The

signal is transported as a cascade of protein interactions utimately acting as protein inducers of specific genes important in the hypersensitive response.

HYPERSENSITIVITY. Combinations to remember.

Combinations	Disease Develops	Hypersensitive Reaction
Non-compatible host species and non-pathogen	-	-
Compatible species and compatible pathogen	+	-
Resistant cultivar of compatible host species and incompatible pathogen	-	+
Resistant cultivar of compatible host species and compatible pathogen	+	-

Compared to the generalized *s*ystemic *a*cquired *r*esistance (SAR) response, the hypersensitive response is a more specific active plant resistance response induced by a small number of living cells of avirulent pathogens in contact with plant cells. Virulent pathogens and non-pathogens or saprophytic prokaryotes do not induce this response. This response is time- but not light-dependent and occurs more rapidly than induced resistance. The hypersensitive reaction consists of four stages:

Hypersensitivity is an universal plant reaction to fungi, viruses, and bacteria. However, it was discovered much later in reactions with bacteria than fungi due to the generally smaller size of the necrotic lesions resulting from the response to bacteria. When observed, these responses were often believed to be symptoms of disease rather than symptoms of a resistant response. Examples of these mistakes which have found their way into the literature as "diseases" include:

Necrotic spots on leaves of stone fruits, includeing peach (*Prunus persica* [L.} Batsch) caused by resistant responses to *Pseudomonas syringae* pv. syringae.

Bleached cereal leaves during cool, moist periods may be due resistance to *Pseudomonas syringae* pv. syringae

Black streak of sugar beet (*Beta vulgaris* L.) may be a resistanct response to *Pseudomonas syringae* pv. apatata.

A. Induction period. An induction period (1.5-5 hr) or the minimum time required to irreversibly induce the response. This response requires:

1. Protein synthesis. Evidence for protein synthesis in the hypersensitive reaction includes:

Antibiotics. Treatment with prokaryotic protein synthesis-inhibiting antibiotics indicates that the avirulent pathogen produces a peptide that is recognized by the host.

Temperature. Incubation at non-permissive temperatures also blocks the recognition period.

Proteases. Proteases prevent the hypersensitive reaction.

Amino acids. Histidine- and arginine-requiring mutants do not induce hypersensitive reactions unless these amino acids are supplied.

DNA replication. Nalidixic, a DNA synthesis-inhibiting antibiotic, retarded bacterial cell division, but not the hypersensitive response.

RNA synthesis. Rifampin, a prokarotic specific RNA synthesis-inhibiting antibiotic, has not to my knowledge been tested. One could predict that the hypersensitive reaction might be affected especially if genes induced by the plant-microbe interaction require the production of mRNAs. If these genes are constitutive, the reaction may occur but at a reduced rate since synthesis or transcription of new mRNA molecules would be inhibited.

2. Gene-for-gene.

Specificity. Races of the pathogen and cultivars of the susceptible host species are separated by specific but parallel genetic resistance at the single gene level.

Capsules/EPS. Mutants of virulent pathogens may be selected that elicit hypersensitive rather than compatible responses. Acapsular mutants of *Ralstonia solanacearum* and *Erwinia amylovora* elicit hypersensitive reactions; wildtypes of these pathogens with normal extracellular polysaccharides do not elicit the hypersensitive reaction.

3. Cell-cell contact.

Contact. The hypersensitive response may be eliminated by preventing cell-to-cell contact.

Incompatible pathogens suspended in agarose do not elicit the hypersensitive reaction. This may indicate that the recognition compound may be cell-bound.

Compatible pathogens produce water-soaking extracellular polysaccharides that may protect them from contact with plant cell walls and subsequent recognition.

Binding. Incompatible pathogens and saprophytes are both bound to plant cells. This seems to indicate that the saprophytes lack the molecules that elicit the hypersensitive response.

Lectin hypothesis. Lectin-lipopolysaccharide interactions have been postulated. (Review the concept and chemistry of the lectin hypothesis--see the lectures on the Rhizosphere and Cytochemistry and Anatomy.); however, these interactions lack the specificity shown in the hypersensitive reaction.

Hypersensitive and pathogenicity (*hrp*) region. Staskaweiz and Panopolous at the University of California at Berkeley were among the first investigators to describe a large genetic region that seems to code for both the hypersensitive response and pathogenicity on plants. Mutants in this region either are not able to colonize plants or no longer elicit a hypersentive response.

4. **Living cells.** Living plant and bacterial cells are required.

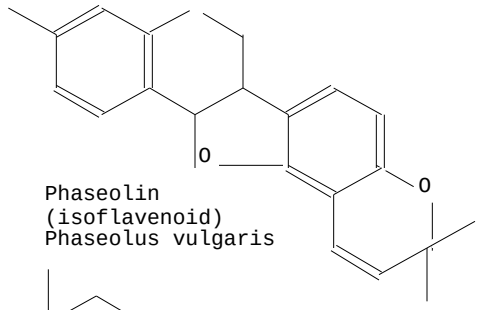
Inoculum concentration.

Concentration does not affect induction of the hypersensitive response.

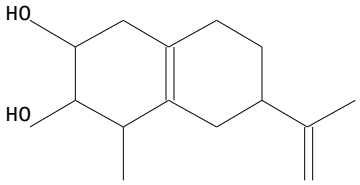
Inoculation of tobacco with 5 X 10^6 of *Pseudomonas syringae* pv. pisi, causal agent of pea (*Pisum sativum*) blight, cause visible hypersensitive response.

Only one cell of *Pseudomonas syringae* pv. morsprunnorum (1μm^3), causal agent of cherry (*Prunnus avium*) leafspot, was required to kill one tobacco cell (50,000 μm^3) and 50 incompatible *Pseudomonas syringae* pv. tabaci, causal agent of tobacco wildfire, cells killed one tobacco cell. These studies were accomplished using selectively staining cells in suspension or whole plants.

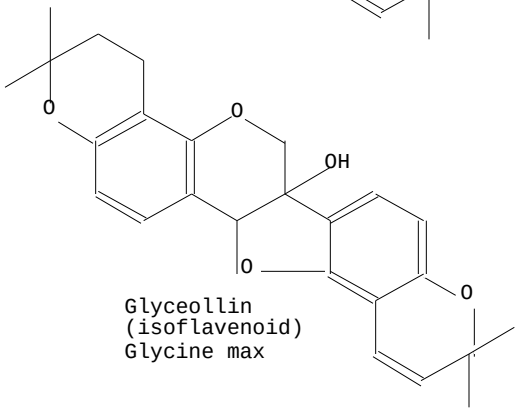
5. **Phytoalexins.** 100 to 400 µg/ml required for inhibition of bacterial growth.



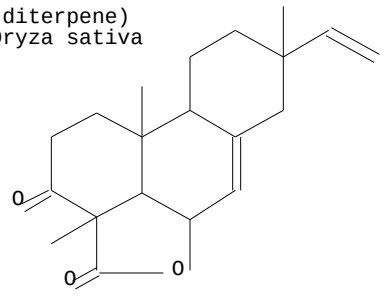
Phaseolin
(isoflavenoid)
Phaseolus vulgaris



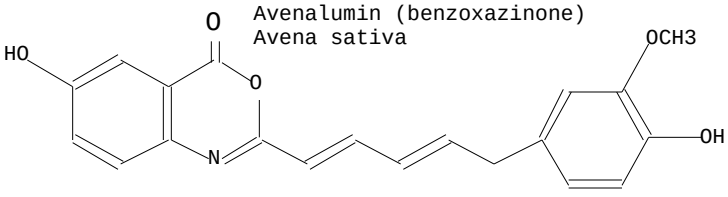
Rishitin (sesquiterpene)
Solanum tuberosum



Glyceollin
(isoflavenoid)
Glycine max



Momilactone A
(diterpene)
Oryza sativa

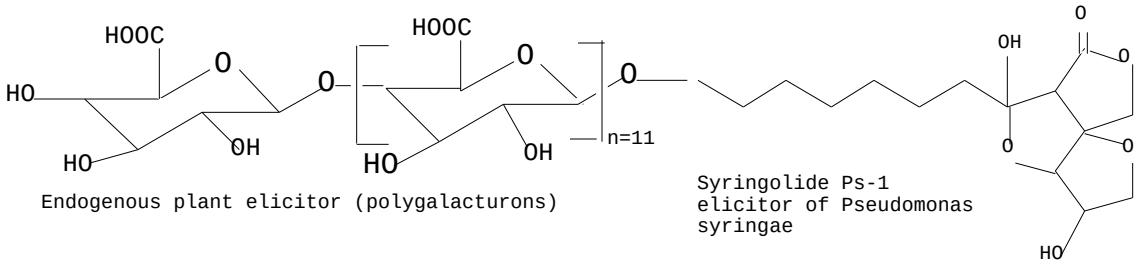


Avenalumin (benzoxazinone)
Avena sativa

Temperature. In incompatible interactions between *Pseudomonas syringae* pv. glycinea and resistant soybean cultivars, phytoalexins are produced at 22 but not 31 C. Plants incubated at 31 C had compatible reaction, at 22 C incompatible reactions

Inhibition of synthesis. The herbicide glyphosate, which inhibits the conversion of shikimate to chorismate (phenylalanine synthesis) in higher plants, inhibits phytoalexin accumulation, but not the hypersensitive reaction. Bacterial populations were two-fold higher in glyphosate-treated leaves than in non-treated leaves. However, when leaves were fed phenylalanine or tyrosine to circumvent the glyphosate blockage, further bacterial replication was not observed.

Avirulence (*avr*) genes and their products. Genes related to the production of elictors encoded by *avr* genes seem to produce a variety of products. Some elicitors are degradative products of cell walls produced by the activity of cell wall-degrading enzymes (*e.g.*, pectic degradation fraction of fungal or host cell walls shown below; mainly important in resistance to fungi, Keen *et al.*, 1996), low molecular weight products of secondary metabolism (*e.g.*, syringolides; Keen *et al.*, 1996; Yucel *et al.*, 1994), or high molecular weight proteins (Fensulau *et al.*, 1992; Pirhonen *et al.*, 1996).



Phytoalexin production, then, does not require living cells. Some of these fractions are produced by the activity of pectolytic enzymes. Although pectate lyase produced by *Erwinia rubrifaciens* was implicated in hypersensitive reactions, Azad and Kado (1983) believe that it does not have a central role.

6. Toxins. Is hypersensitivity induced by bacterial toxins? Gardner and Kado (1976) reported that pectate lyase produced by *Erwinia rubrifaciens* induces the hypersensitive resoponse. Azad and Cado (1984), obtained transposon mutants of *Erwinia rubrifaciens* that were unable to elicit the hypersensitivity response; however, these mutants produced high levels of pectate lyase. They concluded that more than pectate lyase is involved in the hypersensitive response elicited by *Erwinia rubrifaciens* in tobacco.

Sequeira, hypothesized that a highly unstable toxin exists that damages host membranes only when released in close proximity to the plant cell wall. However, Klement (1977) flushed intercellular fluids from a previously inoculated portion of a leaf into an adjacent non-inoculated potion did not observe the presence of compounds capable of inducing the hypersensitive response. Flushing may have diluted the elicitor to non--detectable levels.

Secretion proteins in animal pathogens. Fenselau *et al.* (1993) described determinants of pathogenicity that are related to proteins involved in secretion in animal pathogens. Genes for this protein secretion sytem are preserved in the hypersensitive response and pathogenicity (*hrp*) region of many plant pathogens including xanthomonads, pseudomonads, and erwinias. Pirhonen *et al.* (1996) developed a heterologous sytem in *Escherichia coli* to express *avr* genes from *Pseudomonas syringae* pv. syrinage strain Pss61. The *hrp* cluster from the pseudomonad was transferred on a plasmid into *Escherichia coli*. These investigators demonstrated that *avrB* from *P. syringae* pv. glycinea expressed from a triple *lacUV* promoter on a second plasmid was expressed and induced the hypersensitive response in soybean cultivars expressing the resistance gene *Rpg1* and in thale cress (*Arabidopsis thaliana* [L.] Heynh.) expressing *RPM1*. Inactivation of the energy transducing system (presumably ATPase) or outer membrane components of the *hrp*-sytems blocked expression of *avrB.*

Harpin. Allan Collmer and Steve Beer's group at Cornell described a protein, harpin, coded by *hrpN* in *Erwinia amylovora*, which allowed *Escherichia coli* engineered with this gene to elicit a hypersensitive-like reaction from tobacco (Wei *et al.,* 1992). Pirhonen *et al.* (1996) found that deletions abolishing harpin had little effect on expression of *avrB* expessed from a *Escherichia coli* containing the *hrp* region of *Pseudomonas syringae* pv. syringae. Surprisingly, harpin and a *hrp* regions were also discovered in *Erwinia chrysanthemi*, a soft rot pathogen of a wide range of hosts not generally considered to be a pathogen that elicits a gene-for-gene response (Bauer *et al.*, 1994).

Basic necrosis. Pathogens which induce the hypersensitive response in plants all produce an underlying necrosis at the site of infection and that harpin seemed key to that necrosis. It is possible that the harpin-induced basic necrosis is related to basic compatibility discussed above in the evolution of pathogenicity and virulence (Bauer *et al.*, 1994).

Signal model. Model for cell signalling between a hypersensitive response-inducing bacterium and hypersensitive-responding resistant host was devised by Schulte and Bonas (1992).

7. Lectin-lipopolysaccharide interactions. These interactions have been postulated but not proven.

B. Latent period. A latent period (2 to 8 hr) during which apparently normal plant physiology continues. No increases in enzymes or respiration begin to occur until the end of this period.

Activated enzymes. At the end of the latent period increase in respiration, permeability, and enzyme activities including ribonuclease, glucose-6P, 6-P-glucose, and shikimate dehydrogenases.

Inactive enzymes. Some enzyme systems do not become active including peptidase, polyphenoloxidase, peroxidase, phenylalanine ammoniua-lyase, and cytochrome oxidase.

Electron microscopy. Ultrastructurally, deposits begin to appear onthe tonoplast of the vacuole in mesophyll cells. Later similar deposits appear inside the vacuole.

C. Collapse period. A collapse period (4 to 16 hr) during which host cellular decompartmentalization with cytoplasmic and vacuolar mixing occurs. By electron microscopy, organellar and cytoplasmic membranes are evidently damaged. Oxygen use by the tissues increases greatly.

Enzymes. Proteases, esterases, phosphatases, and ribonulceases activities increase. These enzymes may interact with plant components to form anti-micobial compounds.

Electon microscopy. Ultrastructurally, cytoplasmic invasion with vesiculation and accumulation of osmiophyllic droplets. These droplets may contain phytoalexins or other antimicrobial compounds.

D. Necrotic period. A necrotic period (14 to 48 hr) during which death and dessication of affected host cells occurs and colonization by the pathogen is limited.

Antibacterials. Phytoalexins may be involved since cells begin to fluoresce at wavelengths corresponding to their production.

Ammonia. Some researchers report that NH_3 and high pH resulting from bacterial multiplication in the plant tissues may be partially responsible for tissue necrosis.

Bacterial replication ceases. Multiplication of bacteria stops. Intercellular fluids become inhibitory to bacterial growth. Bacteriostasis may be detected by agar plate counts. The inhibitors involved have not been characterized since it is difficult to harvest enough intercellular fluid to analyze. Bacteriostatic zones with diameters of 440_m (or 20 palisade cells) around microcolonies in leaf tissue during incompatible interactions.

Generally, the initial inoculum level increases in both compatible and incompatible interactions. However, the increase is halted after 10^3-fold increases in the incompatible interaction. In the compatible interaction, populations increase to greater than 10^8 cfu/cm^2.

Envelopement. Immobilization of bacteria may have a role in bacteriostasis. Attachment of incompatible bacteria to plant cell walls seems to be an active process. Others believe that evaporation of intercellular water deposits the bacteria on the cell surfaces.

Incompatible and compatible bacteria are enveloped in 2-3 h after inoculation. A thin, fibillar mass separates from the host cell wall and by 7 h the bacteria are surrounded with granular and fibrillar materials.

Saprophytic and incompatible bacteria tend to remain encapsulated but compatible bacteria soon appear to break free and multiply in the intercellular fluid. The coinicidence of immobilization with hypersensitivity makes it difficult to determine if they are part of the same phenomenon or separate phenomena. Encapsulation may be part of an early induced resistance mechanism. Agglutination of incompatible cells in the intercellular fluids has been observed; lectins have been isolated that provide resistant patterns of agglutination *in vitro*.

Normosensitive vs. hypersensitive. Similarity of necrosis development in the hypersensitive and normosensitive reactions.

Phase	Response time (h) hypersensitive	Response time (h) normosensitive
Inoculation	0	0
Induction	0-4	Not comparable
Latent	2-12	0-144
Watersoaking	Not comparable	96-192
Collapse	8-14	Not comparable
Necrosis	10-48	144-216
Chlorosis	Not comparable	168-240
Systemic chlorosis	Not comparable	192-288

E. Influence of environmental conditions on the hypersensitive reaction.

1. Temperature. Incubation of plants at 30-32 C favored development of the hypersensitive response. Lower temperatures reduced the number of cells required for the hypersensitive response. Incubation at 37 C delayed the hypersensitive response.

2. Light.

Hypersensitivity develops equally well in the dark or in the light and is not affected by pre- or post-inoculation incubation in the dark or light.

However, non-hypersensitive response-inducing bacteia, such as Agrobacterium tumefaciens and Pseudomonas marginalis, will cause hypersensitive-like responses that Klement believes are due to non-specific toxicity of the autolyzing bacterial cells.

3. Humidity. Continuous high humidity delays the appearance of hypersensitivity since the tissue will not dessicate; however, membranes are destroyed and cells are decomparmentalized.

4. Physiological state of the host.

Younger leaves of tobacco require more bacterial cells to initiate the hypersensitive response, but they develop the hypersensitive response 1-1.5 h earlier than older leaves.

Older bean leave of a cultivar susceptible to *Pseudomonas syringae* pv. phaseolicola were hypersensitive to the pathogen.

Younger leaves of a resistant cultivar of bean were susceptible to a non-compatible strain of the halo blight pathogen.

THE FUTURE. The hypersensitive response, because of its specificity, is an important target for the study of the molecular basis for virulence. Further, the hypersensitive response may represent a basic difference between pathogens with large host ranges and virulent pathogens with more restricted host ranges, since representatives of the large-host range group including *Erwinia carotovora* and *Agrobacterium tumefaciens* do not elicit this response.

RESEARCH GOALS. Obviously, molecular understanding of the basis for gene-for-gene virulence systems will have a great positive impact on plant breeding fordisease resistance. Currently, there are two basic methods for discovering and isolating genes for virulence from plant pathogenic prokaryotes for study.

For the first method, insertional mutagenesis or transposon mutagenesisis used to locate the gene(s). Using transposons carrying antibiotic resistance, avirulent phenotypes are recovered from virulent pathogens. The DNA of the avirulent mutant is shot-gun cloned and screened for the antibiotic resistance conferred by the insertion. Using sequences flanking the transposon, probes are developed to locate wildtype gene(s) for virulence in a cosmid library. Confirmation of the isolation of this gene(s) is accomplished by merozygotic complementation for virulence of the avirulent mutant. Once located, the gene(s) may be subcloned from the cosmid and studied in detail. This method depends on efficient mutant screening methods to separate the desired mutant from similar phenotypes arising from auxotrophic or pleiotropic mutations.

For the second method, cDNA cloning is used to detect novel mRNA species produced in the interaction of virulent or avirulent pathogens. In this technique, all mRNA species from induced and non-induced plants are copied into DNA using reverse transcriptase. These cDNAs are cloned and used as hybridization probes to locate and recover the complete gene(s) from a library as described above. This method depends on the production of gene products or at least RNAs and is limited by our ability to detect new species of these transcriptional products.

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CONTROL OF PHYTOPATHOGENIC PROKARYOTES BY CUTURAL MANAGEMENT AND CHEMICALS

I. CULTURAL MANAGEMENT

A. Generation time and sequestering. Diseases caused by prokaryotes, especially non-fastidious bacteria, occur very rapidly due to their short generation times, tend to follow wet weather closely--when fields and orchards are difficult or impossible to work with heavy machinery--and are usually sequestered in tissue and protected from treatment with bacteriocides. Consequently, they are difficult to manage using chemicals alone. Fastidious prokaryotes are sequestered in phloem and xylem and are often difficult to eradicate since chemical delivery to these locations in not consistent.

B. Prophylactic management is best. Using this strategy, integrated systems of management are used to control disease before epiphytotics occur. These systems may include use of cultural practices to avoid disease development, resistant varieties, bacteriocide applications, and biological control methods.

C. Strategies.

1. Pathogen-free planting and propagating materials.

Seed production in semiarid regions: Plants grown for seed in arid or semiarid regions using furrow irrigation have extremely low or no disease incidence. Consequently, seed produced from these plants should be almost completely free of pathogen infestation. The diseases in **Table 1** have been controlled using this tactic:

Table 1. Seed production in semiarid regions reduces seed infestation by pathogenic bacteria and has been used in the control of several diseases.

Disease controlled (host)	Pathogen
Bean wilt (*Phaseolus vulgaris*)	*Curtobacterium flaccumfaciens* pv. *flaccumfaciens* vars. *auranticum* and *violaceum*
Haloblight of bean	*Pseudomonas syringae* pv. phaseolicola
Brown spot of bean	*Pseudomonas syringae* pv. syringae
Common blight of bean	*Xanthomonas campestris* pv. phaseoli
Black rot of crucifers (*Brassica* spp.)	*Xanthomonas campestris* pv. campestris

Seed treatment. Heat treatment of seed reduces the viability of pathogenic bacteria resident in plant tissues (**Table 2**). Care must be taken to maintain reasonable levels of seed viability.

Table 2. Heat treatment of seed reduces reduces seed infestation by pathogenic bacteria and has been used in the control of several diseases.

Disease controlled (host)	Seed treatment	Pathogen
Hollow stalk of tobacco (*Nicotiana tabacum*)	Microwave irradiation	*Erwinia carotovora* subsp. *carotovora*
Tomato canker (*Lycopersicon esculentum*)	Hot water (≥50C)	*Clavibacter michiganense* subsp. *michiganense*
Black rot of crucifers	Hot water (≥50C)	*Xanthomonas campestris* pv. campestris
Angular leafspot of cucurbits (*Cucumis* spp.)	Hot air (50 C) and 75% RH for 3 days)	*Pseudomonas syringae* pv. lachrymans

Vegetative parts treatment. Heat treatment of vegetative parts also may result in freeing tissue from resident pathogens (**Table 3**). Again, heat treatment must be applied carefully to maintain viability of the vegetative parts of plants used to propagate crops.

Table 3. Heat treatment of vegetative plant parts reduces reduces infestation by pathogenic bacteria and has been used in the control of several diseases.

Disease controlled (host)	**Hot water** (≥50C)	**Pathogen**
Diffenbachia soft rot (*Diffenbachia* spp.)	Stem sections	*Erwinia chrysanthemi*
X-disease of peach (*Prunus persica*)	Bud wood	X-disease phytoplasma
Cassava blight (*Manihot esculentua*)	Stem sections	*Xanthomonas campestris* pv. manihotis

Clonal techniques. Clonal plant production techniques may be used to increase pathogen-free planting materials (**Table 4**). Bacterial populations vary from tissue to tissue and organ to organ in plants selection of certain part of the plant for clonal propagation is occasionally useful for controlling plant disease. These techniques lend themselves

Table 4. Clonal propagation techniques selecting certain parts of plants for vegetative propagation may be used to reduce the incidence of pathogen infestation.

Disease controlled (host)	**Clonal technique**	**Pathogen**
Potato soft rot, seed piece decay, and blackleg (*Solanum tuberosum*)	Stem cuttings	*Erwinia carotovora* subspp. *carotovora* and *atroseptica*
Bacterial canker of tomato	Stem cuttings	*Clavibacter michiganense* subsp. *michiganense*
Cassava blight	Woody stem sections	*Xanthomonas campestris* pv. manihotis
Potato wilt	Potatoes produced at high altitudes	*Ralstonia solanacearum*
Peach gummosis	Rootstock/scions produced in sterile potting mix	*Pseudomonas syringae* pv. syringae
Pear decline (*Pyrus communis*)	Rootstock/scions produced outside pear decline region	Pear decline phytoplasma
X-disease of peach	Rootstock/scions produced outside pear decline region Buds excised for grafting may be heat-treated at 50 C for short periods to reduce transmission	X-disease phytoplasma
Poinsettia canker (*Euphorbia pulcherrima*)	Rooted stem snappings	*Curtobacterium flaccumfaciens* pv. poinsettiae

2. Planting site selection.

Replant problems. Avoid replanting near sites from which diseased trees have been removed because root pathogens are often at high populations in the soil. Peach (*Prunus persica*) replant problems have be found to be at least partially due to pseudomonads.

Heavy soils. Nitrification by soil bacteria is reduced in clay soils and fire blight of apples (*Malus sylvestris*) and pears (*Pyrus communis*), caused by *Erwinia amylovora*, is increased later in the season when the soils dry out, nitrification occurs and susceptible

succulent tissues are produced. In lighter soils, succulent tissues occur earlier in the season.

Sandy soils. Favors rapid transpiration, open stomates, and prunus or peach leaf spot, caused by *Xanthomonas campestris* pv. pruni. Ingress of the pathogen is favored by open stomates.

High elevations. In Hawaii, high elevations and high soil organic material reduces black rot of cabbage (*Brassica oleracea* var. *capitata*), caused by *Xanthomonas campestris* pv. campestris. Likewise, potato wilt, caused by *Ralstonia solanacearum*, may be controlled by growing seed potatoes (*Solanum tuberosum*) at high altitude.

Suppressive soils. Some soils, due to microflora antagonistic to plant pathogens and, probably, certain physicochemical properties, reduce disease. Banana (*Musa paradisiaca* var. *sapientum*) wilt caused by *Ralstonia solanacearum* race 3 has been controlled by planting in suppressive soils.

High soil pH (>6) *and arid climate.* Favors potato scab caused by *Streptomyces scabies*. Use ammonium sulfate to reduce soil pH and maintain soil moisture by irrigation to reduce potato scab incidence.

Adjacent crops. In California, planting grapes (*Vitis vinifera*) or almonds (*Prunus amygdalus*) near alfalfa (*Medicago sativa*) fields is not wise because *Draeculacepha minerava*, the leafhopper vector of the Pierce's disease agent, *Xylella fastidiosa*, is attracted to and feeds on alfalfa.

3. Host nutrition.

High nitrogen. Fertilization for maximum crop growth may favor diseases caused by bacteria. The following disease are favored by excessive fertilization rates:

Disease controlled (host)	Pathogen
Stewart's wilt of sweet corn (*Zea mays* var. *saccharata*)	*Pantoea stewartii* subsp. *stewartii (ex Erwinia stewartii)*
Prunus or peach leaf spot	*Xanthomonas campestris* pv. pruni
Bacterial canker of tomato	*Clavibacter michiganense* subsp. *michiganense*
Rice blight (*Oryza sativa*)	*Xanthomonas campestris* pv. oryzae
Fire blight of apple or pear	*Erwinia amylovora*
Vascular necrosis of sugar beet (*Beta vulgaris*)	*Erwinia carotovora* subsp. *betavasculorum*
Angular leaf spot of cotton (*Gossipium hirsutum*)	*Xanthomonas campestris* pv. malvacearum

Type of nitrogen fertilization. The chemical form of nitrogen fertilization also affects disease incidence and serverity.

Ammonia favors periderm formation and healing of prunus leaf spot cankers caused by *Xanthomonas campestris* pv. pruni.

Calcium ammonium nitrate reduces the length of rice (*Oryza sativa*) blight lesions caused by *Xanthomonas campestris* pv. oryzae.

Ammonium sulfate increases the length of rice blight lesions.

Urea increases the number of rice blight lesions.

Calcium fertilization. The incidence of bacterial soft rot, caused by *Erwinia carotovora* subspp. *carotovora* or *atroseptica*, is greater in potato tubers grown in low Ca^{2+} soils than in high Ca^{2+} soils (McGuire & Kelman, 1986). This seems to be a contradiction since Ca^{2+} is required for pectate lyase activity (Liao *et al.*, 1993), which is the major enzyme used by the pathogen for tissue maceration. However, it most probably indicates that the Ca^{2+} is used in the physiology of the two organisms, host and pathogen, separately and for different ends.

4. Eradication.

Citrus (*Citrus* spp.) canker, caused by *Xanthomonas campestris* pv. citri, was erradicated in the 1914-34 from Florida by destroying 257,000 citrus groves and 3,000,000 nursery trees in a cooperative state and federal program. In the latest epidemic (1985-88), caused by *Xanthomonas campestris* pv. citrumelo, over 10,000,000 nursery trees have been destroyed. In that epiphytotic, lack of grower understanding about pathogen dissemination, lack of compensatory payments from state or the Federal governments for tree destruction, and bad weather, including a hurricane, led to loss of control of the pathogen. *Xanthomonas campestris* pv. aurantifolia is a third pathogen of citrus which causes cankeroses that must be differentiated from those caused by *Xanthomonas campestris* pvs. citri and citumelo.

5. Control of collateral or supplementary hosts.

X-disease of prunus: Elimination of the plants most sought after by the leafhopper vectors of the pathogen or collateral hosts for the X-disease phytoplasma, such as chokecherry (*Prunus virginiana* L.), reduces disease incidence.

Black rot of crucifers: Elimination of cruciferous (*Brassica* spp.) weeds adjacent to plots reduces seed infestation by *Xanthomonas campestris* pv. campestris.

Fire blight of apple and pear: Remove roseaceous wild or domestic collateral hosts to controls fireblight caused by *Erwinia amylovora*

Bacterial wilt of tobacco, peanuts, or potato: Removal of solanaceous weeds reduces bacterial wilt of potato, peanuts (*Arachis hypogaea* L.), or tobacco caused by *Ralstonia solanacearum.*

6. Roguing. Removal of disease plants removes potential inoculum sources from the production area. Roguing has been used to control:

X-disease of prunus: Removal of X-diseased trees reduces inoculum spread by leafhopper vectors of the pathogenic X-disease phytoplasma.

Viresence of strawberry: Removal of strawberry (*Fragaria chiloensis* var. *ananassa*) plants showing symptoms of phytoplasma-caused virescence (green flower disease) results in a reduction in disease incidence in subsequent growing seasons.

Fire blight: Removal of blighted trees reduces disease incidence caused by *Erwinia amylovora* inoculum produced in cankers on the stems and branches of apple and pear trees.

7. Pruning. Removal of potential inoculum or changing microclimatic conditions by pruning may reduce disease incidence.

Fire blight of apple or pear: Pruning 100 cm below cankers during the growing season or 30 cm below the cankers during the winter controls fireblight.

Prunus leaf spot: Pruning improves air movement and lowers the humidity in the canopy of peach trees thus reducing ability of the pathogen, *Xanthomonas campestris* pv. pruni, to cause lesions.

8. Crop rotation with tillage. Mircobial degradation of crop debris by soil microorganisms reduces the amount of sequestered inoculum available for the following growing season. In colder climates, tillage of woody crop debris [tomato, eggplant (*Solanum melogena* L.), and tobacco stems] may not degrade within a season. In that case, debris shoud be removed from the field. In Japan, they may be burned. Air pollution quality standards often prevent this practice in the United States. Rotating with crops not susceptible to the pathogen may be effective to allow longer periods for decomposition of plant debris. However, soil-inhabiting pathogens (*i.e., Agrobacterium tumefaciens* or *Streptomyces scabies*) or those that inhabit the roots of diverse crop plants (*i.e., Erwinia carotovora* or *Ralstonia solanacearum*) are difficult to control by crop rotation. The following diseases have been controlled by crop rotation:

Disease (host)	Pathogen
Black rot of crucifers	*Xanthomonas campestris* pv. campestris
Cassava blight	*Xanthomonas campestris* pv. manihotis
Halo blight of bean	*Pseudomonas syringae* pv. phaseolicola
Bacterial blight of soybeans (*Glycine max*.)	*Pseudomonas syringae* pv. glycinea

Angular leaf spot of cucurbits	*Pseudomonas syringae* pv. lachrymans
Bacterial wilt of potato and tobacco	*Ralstonia solanacearum*
Bacterial blight of cereals and grasses	*Pseudomonas syringae* pvs. syringae and coronafaciens

9. Non-host crops. Crop rotation using non-host plants reduces potential inoculum.
   Ralstonia solanacearum may survive on hosts in which it does not cause disease--corn, sorghum (*Sorghum vulgare* Pers.), bean, peas (*Pisum sativum* L.), and soybeans.
   Erwinia carotovora survives on non-host and host crops as epiphytes associated with roots; therefore, it is not controllable by this method.
10. Irrigation. Irrigation can be used to control disease or it may be misused to increase the incidence of disease.
   Diseases controlled by irrigation:
      Potato wilt: Paddy rice in rotation with potato production reduces disease caused by *Ralstonia solanacearum.*
      Banana wilt: Paddying soil on banana plantations controls disease caused by *Ralstonia solanacearum.*
      Potato scab: Maintaining soil water near field capacity reduces potato scab caused by *Streptomyces scabies* by increasing populations of antagonist microflora or the competitive advantage of rhizophere inhabitants.
   Diseases increased by overhead irrigation: Plant pathogenic bacteria are commonly disseminated by wind-driven rain. Overhead irrigation closely resembles natural rain, and misused, may increase disease incidence:
      Bean blights (haloblight, brown spot, or common, blight: Overhead irrigation increases the incidence of blights while furrow irrigation reduces it caused by *Pseudomonas syringae* pvs. phaseolicola and syringae and *Xanthomonas campestris* pv. phaseoli, respectively.
      Black rot of crucifers: Overhead irrigation increases the incidence of black rots of crucifers while furrow irrigation reduces it.
      Soft rot of broccoli: Overhead irrigation increases soft rot caused by *Erwinia carotovora* subsp. *carotovora* in Virginia. Furrow irrigation, which would be more desirable, is difficult to effect in rolling topography of the piedmont.
11. Cultivation. Cultivation is also a two-edged sword:
   Diseases increased by cultivation: Late season cultivation releases nitrogen sequestered in weeds or groundcover in peach orchards allowing succulent tissues susceptible to disease to develop increasing:
      Fire blight of apple and pear caused by *Erwinia amylovora*.
      Prunus leafspot caused by *Xanthomonas campestris* pv. pruni.
   Diseases controlled by cultivation: Cultivation after harvest reduces pathogen survival in reservoir hosts:
   X-disease of prunus: Clean tillage reduces orchard weeds favored as collateral hosts for the X-disease phytoplasma and reduction of the number of leafhopper vectors attracted into the orchard.
12. Root stock and scion combinations.
   Pear decline: Use of oriental pear root stock, *Pyrus urrisensis*, increases the severity of pear decline while use of French or American pear rootstocks, *P. communis*, root stocks reduces disease severity.
   Fire blight of apple: Apple rootstocks MM106, M26, M9, and MM111 induce susceptibility to fire blight caused by *Erwinia amylovora* in the scions
   X-dsease of cherry: Mazzard (*Prunus avium*) rootstocks reduce scion susceptibility to X-disease better than *Prunus mahaleb* rootstocks in cherry.

13. Environmental controls.

Brown blotch of mushroom: Brown blotch disease of mushrooms (*Agaricus campestris* var. *bisporus*) caused by *Pseudomonas tolaasi* is controlled by ventilation to reduce humidity and control the temperature.

Potato soft rot: Optimum potato storage conditions are 10 to 16 C. At 3 to 6 C, reducing sugars increase in potato tissue which favors soft rot when the tubers are removed to room temperature. Storage at 10 C or higher reduces the amount of reducing sugars in potato tissue and their susceptibility to soft rot. Storage at 22 C or higher results in rapid deletion of oxygen in potato tissue due to higher rates of tuber respiration. In the presence of a water film on the tubers and high humidity, rot by *Erwinia* spp. or *Clostridium* spp. may occur.

Citrus canker. Wind-driven rain is an important factor in the spread of *Xanthomonas campestris* pv. citri, causal agent of citrus canker. Japanese groves are often protected by wind breaks composed taller trees.

14. Avoidance. Bacterial leaf blight of rice, caused by *Xanthomonas campestris* pv. oryzae, is more severe in Japan because of wind-driven rain that are common during the typhoon season. Much of this damage may be avoided by planting early enough to allow harvest before the typhoon season begins (Goto, 1992). Early-maturing cultivars are key to this strategy.

15. Grafting. Tomato and eggplant may be grafted on resistant rootstocks (*Solanum intergrifolium, S. mammosuum*, and *S. torvum*) to avoid bacterial wilt in *Ralstonia solanacearum*-infested fields (Goto, 1992). This practice is economically feasible in Japan where hot-house plants bring premium prices.

II. CHEMICAL CONTROL OF PHYTOPATHOGENIC PROKARYOTES

A. Location of prokaryotes: Many prokaryotes are sequestered away from locations that pesticides may be easily applied. Further, the association with wet weather and the short generation times of bacteria make pesticide applications difficult.

1. Cortex and spongey mesophyll (occasionally transported in the xylem)

Erwinia carotovora subspp. *carotovora and atroseptica, Erwinia chrysanthemi, Erwinia amylovora, Pseudomonas syringae* pv. phaseolicola, *Pseudomonas syringae* pv. lachrymans, *Pseudomonas syringae* pv. glycinea, *Pseudomonas syringae* pv. tabaci or angulata, *Xanthomonas campestris* pv. campestris, *Xanthomonas campestris* pv. pruni, *Curtobacterium flaccumfaciens* pv. poinsettiae

2. Epidermis of underground surfaces and some cortex. *Streptomyces scabies*

3. Tumor tissue composed of disorganized cortex cells.

Agrobacterium tumefaciens or *rhizogenes*
Pseudomonas syringae pv. savastanoi

4. Xylem.

Non-fastidious xylem-inhabiting bacteria.

Clavibacter michiganense subsp. *insidiosum* (causes ring rot of potato)
Clavibacter michiganense subsp. *michiganense* (Note: Many Plant Pathologists continue to believe that this organism colonizes the phloem. This is incorrect.)
Burkholderia solanacarum (causes Granville wilt of tobacco, peanut, and tomato).

Fastidious xylem-limited bacteria (XLB).

Clavibacter xyli causes ratoon stunt of sugarcane (*Saccharum officinarum*).
Xylella fastidiosa causes Pierce's disease of grape, almond scorch, alfalfa dwarf, plum (*Prunus domestica* L.) leaf scald, elm (*Ulumus americana*) scorch agent, oak (*Quercus* spp.) scorch agent, phony disease of peach, and Sumatra wilt of clove (*Syzygium aromaticum*).

5. Phloem.

Non-fastidious phloem-inhabiting bacteria. None known--recall confusion over *Clavibacter michagnense* subsp. *michiganense*.

Fastidious phloem-limited bacteria (PLB). Clover club leaf and citrus greening agents.

Phytoplasmas. Phytoplasmas are fastidious, pleomorphic, non-culturable, phloem-limited organisms (formerly called mycoplasmalike organisms or MLOs). Examples of diseased caused by phytoplasmas include: X-disease (>20 hosts); pear decline (pathogen may be a spiroplasma); lethal yellows of coconut palm (*Cocos nucifera*); cabbage yellows agent; aster (*Aster* spp.) yellows (>160 hosts); paulownia (*Paulownia tormentosa*) witches' broom; and elm yellows (phloem necrosis of elm).

Spiroplasma spp. Spiroplasmas are fastidious organisms with a spiral morphology with similarites to phytoplasmas. Some have been cultured; others have not. Examples of spiroplasms include: Citrus stubborn caused by *Spiroplasma citri;* corn stunt caused by an un-named *Spiroplasma* spp.; and brittle root of horseradish (*Armoracia rusticana*) caused by *Spiroplasma* spp.

6. Phylloplane-limited bacteria. Some bacteria, including, *Pantoea agglomerans (ex Erwinia herbicola)* and *Pseudomonas syringae* pv. syringae, damage plants using biological ice nuclei located on their outer membranes to catalyze ice formation and cause warm temperature (-2 to -5 C) frost damage. These bacteria also may cause pathogenesis of the spongey mesophyll in frost damaged plants.

B. Indirect pesticide control. Indirect pesticide control occurs when a pesticide is used, not to control the prokaryotic pathogen directly, but to either eliminate the reservoir host or the vector of the prokaryote. Examples:

1. Eradication.

Diquat dibromide, a herbicide, controls citrus canker caused by *Xanthomonas campestris* pv. citri. Diquat controls citrus canker by defoliating trees and citrus branches 38 to 45 cm from their tips. In effect, it chemically prunes the tree and the pathogen is eliminated with the death of the susceptible succulent tissue in the youngest branches. Exfoliated leaves, which may contain the pathogen, must be collected and burned. Fruit development is delayed for at least one season on trees treated by this drastic measure.

2. Sanitation. Herbicides controlling dicotyledenous and moncotyledonous weeds which are reservoir hosts or collateral hosts for the X-disease phytoplasma, reduce the incidence of X-disease of peach.

3. Vector control. Vectors of plant pathogens may be controlled using appropritate pesticides.

Nematicides control nematode vectors of plant pathogens such as *Ralstonia solanacearum,* causal agent of Granville wilt of tobacco, tomato wilt, and banana wilt.

Insecticides control:

Casual insect vectors of pathogens such as *Erwinia amylovora,* the causal agent of fire blight, which may be vectored by insects as diverse as ants, bees, flys, aphids, etc.; *Erwinia carotovora* subspp. *carotovora* and *atroseptica* which may be vectored from cull piles by flys; and *Ralstonia solanacearum.*

Beetles such as *Chaetonema* spp. (fleabeetles) that vector *Pantoea stewartii* subsp. *stewartii,* causal agent of Stewart's wilt of corn, or *Diabrotica undecimpunctata* or *D. vittata* (spotted cucumber beetles) that vectors *Erwinia tracheiphila,* causal agent of cucurbit wilt.

Leafhoppers: Insecticide control reduces the spread of *Xyllela fastidiosa,* causal agent of Pierce's disease of grapes and other woody plants, vectored by *Draculacephala spp.*; the X-disease phytoplasma, causal agent of X-disease of peaches, vectored by many leafhoppers including *Scaphytopius acutus*; *Spiroplasma citri*, causal agent of citrus stubborn, vectored by several leafhoppers including *Circulifer tenellus*; and the corn stunt spiroplasma, vectored by *Dalbulus maidis.*

Psyllids: Insecticide control reduces disease caused by the pear decline phytoplasma, which is vectored by the pear psylla, *Psylla pyricola.*

4. Harvest techniques.

Thrashing or pulverizing potato plants to facilitate digging or harvesting potatoes creates an aerosol of *Erwinia carotovora* subspp. *carotovora* and *atroseptica.* Treating the vives with contact herbicides and allowing the vines to die and dry before harvest reduces this hazard.

C. Disinfestation and sanitation with broad spectrum biocides.

1. Halogens (NaOCl).

Chlorination of irrigation water reduces the incidence of soft rot caused by *Erwinia chrysanthemi* in iris (*Iris* spp.) culture (Lacy *et al.,* 1982).

Disinfestation of prunning tools with 0.5% (w/v) sodium hypochlorite (Chlorox®) controls fireblight caused by *Erwinia amylovora*; however, without careful cleaning sodium hypochlorite causes rusting. See Alcohol treatment below.

Seed piece treatment with sodium hypochlorite controls soft rot of potatos *Erwinia carotovora* subsp. *carotovora*

Seed treatment with sodium hypochlorite controls black rot, caused by *Xanthomonas campestris* pv. campestris and zinnia (*Zinnia* spp.) blight, caused by *Xanthomonas campestris* pv. zinniae.

2. Hot cupric acetate seed treatments. Controls black rot of crucifers caused by *Xanthomonas campestris* pv. campestris.

3. Alcohol (ethanol or isopropanol). Disinfestation of tools and surfaces is effective for control of fireblight caused by *Erwinia amylovora*.

4. Acetic acid.--Bacterial canker, caused by *Clavibacter michiganense* subsp. *michiganense.*

5. Other compounds. **Mercuric chloride**, **formaldehyde**, and **quartenary ammonia** are inexpensive compounds which have been used in surface disinfestation of tools, surfaces, and machines. Mecuric chloride and formaldehyde, are no longer acceptable from an environmental or personal safety viewpoint.

D. Directed chemical control. Pesticides targeted directly against specific prokaryotic agents of plant disease.

Acidic sprays. Citric and tartaric acids sprays control pear blast caused by *Pseudomonas syringae* pv. syringae.

Fungicides.

Bordeaux mixture controls fire blight, caused by *Erwinia amylovora* and black rot caused by *Xanthomonas campestris* pv. campestris (Jones, 1982).

Captan (structure 7) controls leafspot of zinnia caused by *Xanthomonas campestris* pv. zinniae and common blight of bean caused by *Xanthomonas campestris* pv. phaseoli (Goto, 1992; Jones, 1982).

Copper oxychloride (CuOCl) also controls citrus canker (Mew & Natural, 1993).

Cupric hydroxide [$Cu(OH)_2$ or Kocide] controls several diseases caused by xanthomonads on foliage (Mew & Natural, 1993).

Dichlorophen (structure not shown) controls angular leaf spot, black arm, and boll rot of cotton caused by *Xanthomonas campestris* pv. malvacearum (Mew & Natural, 1993).

Fosetyl aluminum (Aliette) controls foliage diseases caused by xanthomonads better than cupric hydroxide (Mew & Natural, 1993).

Tribasic sulfate was effective against citrus canker caused by *Xanthomonas campestris* pv. campestris (Mew & Natural, 1993).

Zinc ethylene-bis(thiocarbamate) (Zineb; structure 3 below) controls bacterial spot of tomato caused by *Pseudomonas syringae* pv. tomato.

4. Soil disinfestants.

Methyl bromide (CH_3Br) plus chloropicrin (also known as tear gas; CCl_3NO_2) controls Granville wilt of tobacco and peanuts caused by *Ralstonia solanacearum* and tree replant problems (Jones, 1982).

Tetramethylthiuram disulfide (Thiram; structure 10) is used a soil disinfestant (Goto, 1991).

Meta-ammonium (structure 8) is used as a soil disinfestant (Goto, 1992).

Metham-sodium controls the causal agent of black rot of crucifers, *Xanthomonas campestris* pv. campestris in soil (Mew & Natural, 1993).

5. New compounds. Several compounds are labeled in Japan but not yet in the US for use against diseases caused by bacteria.

Nickel dimethyldithriocarbamate (structure 5), **probenazole** (9), **teclotalam** (13), and **phenazine oxide** (4) are used to control bacterial leaf blight of rice caused by *Xanthomonas oryzae* pvs. oryzae and oryzicola (Goto, 1992).

Probenaxole (structure 9) and **pyroquilon** (12) are used as protectants against grain rot of rice caused by *Pseudomonas glumae* (Goto, 1992).

Polycarbamate (stucture not shown) protects cucumber from bacterial leafspot caused by *Pseudomonas syringae* pv. lachrymans (Mew & Natural, 1993).

Oxolinic acid (structure 11), a DNA gyrase inhibitor, protects plants against soft rot, caused by *Erwinia carotovora* and *E. chrysanthemi,* and fire blight, caused by *E. amylovora* (Goto, 1992).

Bronopol (labeled below) controls blackarm disease of coton caused by *Xanthomonas campestris* pv. malvacearum and is applied as a seed dressing Sigee, 1993). It is bacteriostatic against a range of pathogens.

Other chemicals, such as **thiophanate methyl** (structure 2) and **dithianon** (6), are used, like captan, for diseases caused by fungi as well as bacteria (Goto, 1992).

Structures from p. 262 Goto (1992) go here

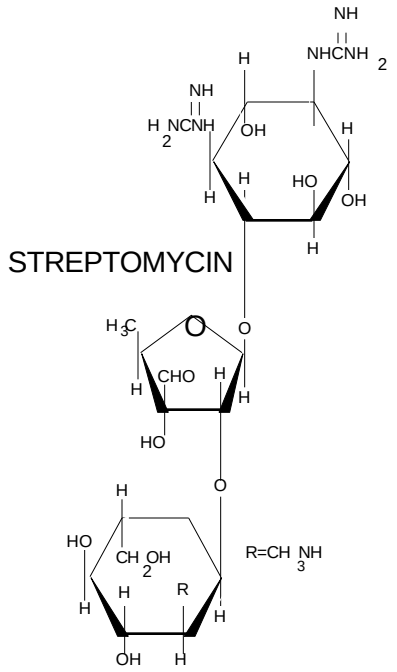
6. Antibiotics. Anibiotics are low molecular weight compounds usually produced by microbes as antagonists of other microbes. However, chemical synthesis and chemical alteration cause some of these compounds to be wholly or partially synthetic.

Streptomycin: The structure of streptomycin, O-2-deoxy-2(methylamino)-L-glucoplyranoxyl-(1-4)-N-N'-bis(aminoiminomethyl)-D-streptamine] produced by *Streptomyces griseus* is shown below.

Mode of action: The action of streptomycin is to bind a particular protein subunit of the 30 S ribosomal subunit. This probably causes a configurational change in the protein and prevents binding of formyl-methionine-tRNA, the very first step in translation bacterial proteins. On polyribosomes, polypeptide chain elongation is inhibited and free ribosomes are prevented from initiating the protein translation process (Goto, 1992; Sigee, 1993). Streptomycin and other aminoglycoside antibiotics (*e.g.*, kasugamycin) affect only prokarotic protein synthesis and not the eukaryotic synthesis of plants. However, the chlorosis observed occasionally upon application by spraying to apple (*Malus sylvestris*) or pear (*Pyrus communis*) trees to control fireblight caused by *Erwinia amylovora* is due to slight inhibition of prokaryotic-like protein synthesis in plant chloroplasts and mitochondria.

Application: Spray applications control of fireblight, caused by *Erwinia amylovora*, and pepper spot, caused by *Xanthomonas campestris* pv. vesicatoria. Seed treatment reduces the incidence of black rot, caused by *Xanthomonas campestris* pv. campestris.

Resistance to streptomycin: Resistance arises through mutations at the chromosomal loci for ribosomal subunit proteins. For *Erwinia amylovora*, this results in resistance to > 500 to > 1000 ug/ml of the antibiotic. Chemotherapeutic rates for sprays are about 150 ug/ml. Resistance has arisen in *Xanthomonas campestris* pv. dieffenbachiae, causal agent of anthurium blight, and *Xanthomonas campestris* pv. citri, causal agent of citrus canker (Mew & Natural, 1993). Combinations of copper-containing compounds and streptomycin seem to provide better protection than the antibiotic alone.



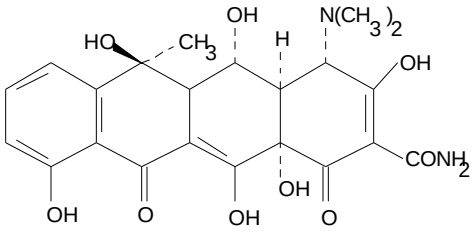
Kasugamycin: The structure of kasugamycin is similar to streptomycin (see above) because it is also belongs to the general class of aminoglycoside antibiotics. It was originally produced by *Streptomyces kasugaensis*.

Mode of action: Like streptomycin, kasugamycin also inhibits protein synthesis, by interacting with a 30 S ribosomal protein subunit to prevent binding of formyl-methionine-tRNA, the very first step in translation of bacterial proteins (Goto, 1992).

Application: In Japan, kaugamycin was developed to control rice blast caused by the fungus *Pyricularia oryzae* but its effectiveness againt various plant diseases was confirmed and now it is marketed alone and in mixtures with copper compounds.

Resistance to tetracycline: Resistance would be expected to develop in dramatic single steps similar to streptomycin.

Oxytetracycline: The structure of oxytetracycline, 4-(dimethylamino)-1,4,4a,5,5a,6,11,12a-octohydro-3,5,6,10,12,12a-penta-hydroxy-6-methyl-1,11-dioxo-2-naphthacenecarboxiмide, produced by *Streptomyces aureofaciens* is shown below.



OXYTETRACYCLINE

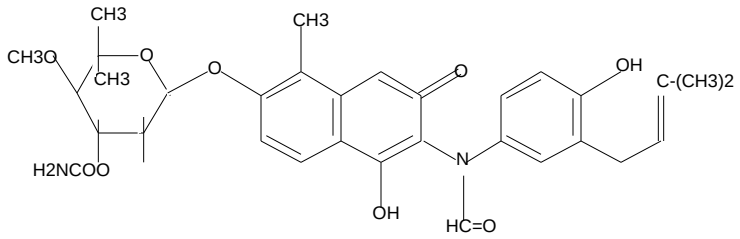
Mode of action: Tetracyclines also inhibit protein synthesis, bind to one of the proteins in the 30 S ribosomal subunit, and inhibit polypeptide chain elongation. However, the mechanism is different from streptomycin since mutation to resistance to streptomycin does not confer resistance to tetracycline. Further, tetracyclines block amminoacyl-tRNA binding to the subunit (Goto, 1992). Tetracyclines, like aminoglycoside antibiotics (*e.g.,* streptomycin) affect only prokarotic protein synthesis and not the eukaryotic synthesis of plants. However, the chlorosis observed upon infusion of oxytetracycline to control peach X-disease caused by phytoplasma is due to slight inhibition of prokaryotic-like protein synthesis in plant chloroplasts and mitochondria.

Application: control of phytoplasma-caused diseases by spraying, infusion, or injection. Control of fireblight on the west coast. The chlorosis observed upon infusion of oxytetracycline to control peach X-disease caused by phytoplasma is due to slight inhibition of prokaryotic-like protein synthesis in plant chloroplasts and mitochondria. Oxytetracyline applied by injection or infusion may cause significant phytotoxicity at the site of application (Lacy, 1986). This damage is more pronounced in peach (*Prunus persica*) trees compared to pear trees (*Pyrus communis*).

<u>Special note for Pesticide Usage Students</u>: There is an error in the last sentence on page 160 of your text book. Oxytetracycline does NOT control plant disease caused by viruses. The author is using out-of-date terminology. Lethal yellows of cocomut palm (*Cocos nucifera*) and pear (*Pyrus communis*) decline, referred to by the author, were believed until 1972 to be caused by viruses. Since then the phytoplasma—and thus prokaryotic—nature of these pathogens has been firmly established. Viruses lack protein synthesis ability and depend upon their hosts for that function. Therefore, the mode of action of tetracyclines which affects only prokarotic protein synthesis precludes any possible direct effect on viruses in plant cells.

Resistance to tetracycline: Resistance develops slowly by stepwise chromosomal mutation and is low level. Plasmids carrying high levels of tetracycline resisance may be moved into the pathogen easily and may potentially be a greater threat to chemotherapy.

Novobiocin: The structure of novobiocin, N-[7-[[3-O-(aminocarbonyl)-6-deoxy-5-C-methyl-4-O-methyl-2-oxo-2H-1-benxopyran-3-yl]-4-hydroxy-3-(3-methyl-2-butenyl) benzamide is produced by *Streptomyces aureofaciens* and its structure is shown here:



Mode of action: Inhibits bacterial DNA gyrase which is an important enzyme in the replication and repair of DNA (Goto, 1992). Gyrase is important in the winding and unwinding of double-stranded DNA so that single-stranded DNA may be replicated by DNA polymerase.

Application: In Japan, this antibiotic is registered only for protection of tomato plants from *Clavibacter michiganensis* subsp. *michiganensis*, causal agent of tomato canker.

Resistance to tetracycline: Resistance probably develops in dramatic one step manner from spontaneous mutation similar to mutants resistant to rifampin, another gyrase-inhibiting antibiotic.

E. Moral and ethical consisderations for using bacteriocides.

1. Selection of bacteriocide resistant mutants. Resistance will arise to antibiotics and some bacteriocides. Good pesticide usage practices should anticipate these events and provide for alternate strategies or chemicals.
2. Infectious resistance. Plasmid borne antibiotic and copper resistance is transmissible in nature. Good pesticide usage practices should anticipate these events and provide for alternative strategies or chemicals.
3. Residues. Any residues in agricultural products should be at concentration compatible with good health and environmental protection. Good pesticide usage practices should anticipate health and environmental problems.
4. Agricultural use of antibiotics already in use for animal and human chemotherapy. Since resistance to antibiotics will arise by agricultural use of these chemicals, good pesticide usage practices should anticipate these events and consider the implication upon animal production and plasmid transfer into potential human pathogens harbored by those animals. Pesticide usage should also consider possible plasmid transmission from bacteria in agricultural effluents into potential human pathogens in residential and hospital water sources. Remember, drinking water is not sterile and only coliform bacteria (bacterial from fecal sources) are controlled.

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PLANT DISEASE PHYSIOLOGY AND DEVELOPMENT. PPWS5454. Principles and concepts of infection and colonization of plants. Role of host's and pathogen's physiology and biochemistry in disease susceptibility and resistance, recognition, and disease specificity. Prerequisites : Advanced standing as a Ph.D. student in PPWS or permission of the instructors.

Instructors: Carole Cramer (course leader), George Lacy, Sue Tolin, and John McDowell

This is an advanced course which requires readings and discussions of contemporary papers and concepts concerning the interactions of plants with their pathogens leading to disease or resistant reactions.

Pathogenesis of Crown Gall

Peter Sforza, Dan Tillman, George Lacy, Mary Ann Hansen, and John Jelesko

This page is continuously under construction.

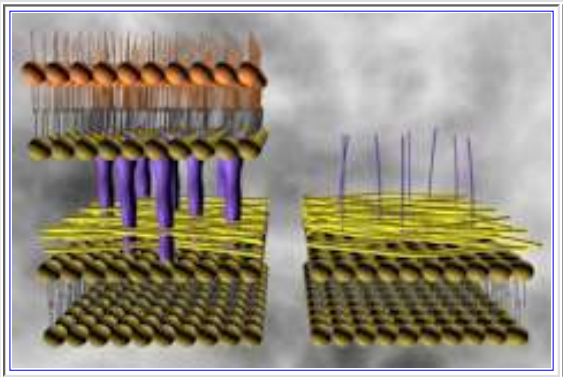
3-D Animations:

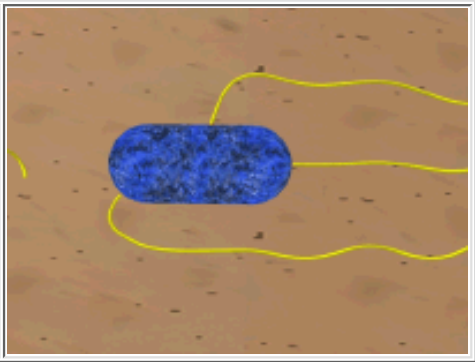
The Natural Pathogenesis of Agrobacterium (21 MB avi) (19 MB mov)

The first step of this project (PPWS 5114 class project) was to research and design 3-D models that could be used as the 'raw materials' for a presentation on the pathogenesis of *Agrobacterium tumefaciens* and the Ti-plasmid.

Mary Ann Hansen and John Jelesko have provided many helpful comments for the recent work on the Agrobacterium animations. Current works in progress include, the natural pathogenesis of Agrobacterium (21 MB avi) (19 MB mov). Constructive comments are welcomed. We are working on a narrative and video to accompany the animations.

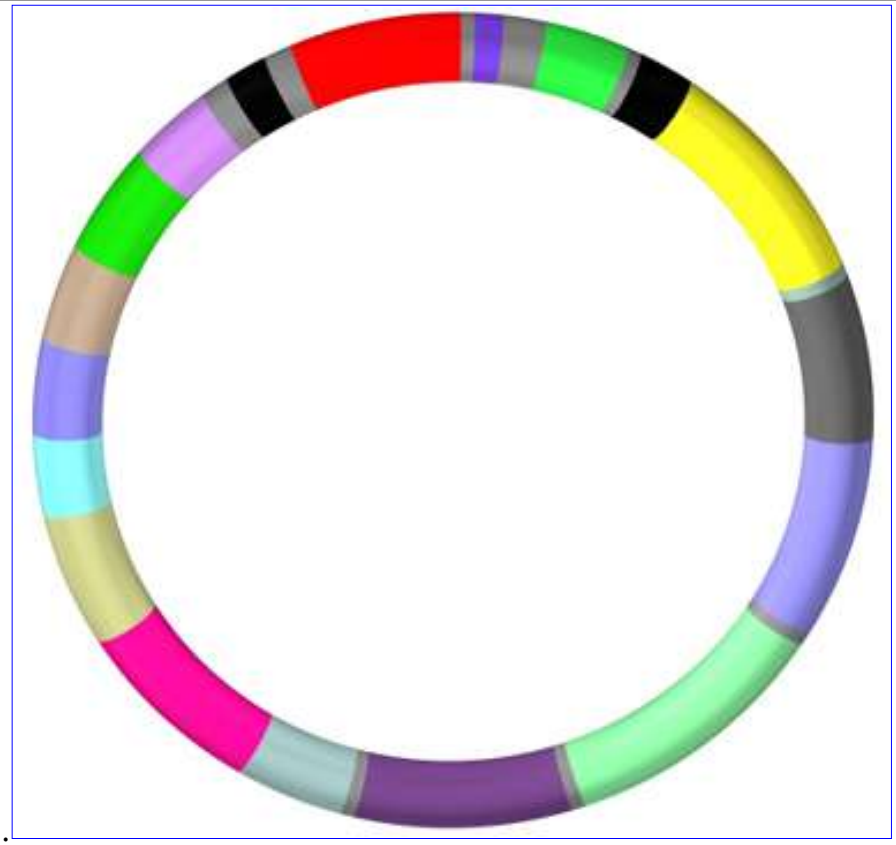
A discussion of the pathogen(s) will describe the relationship between the bacterium, the plasmid, and the host. Is *Agrobacterium tumefaciens* the pathogen? Or are the plasmid and bacterium merely vectors of the pathogenic T-DNA? Semantics aside, it is a fascinating interaction.	

	A 3-D model of Gram-negative and Gram-positive cell walls. Click the image to enlarge.

Flagellar movement of bacteria. A wounded plant cell will begin to synthesize lignin. Certain lignin precursors are chemotactically sensed by the pathogen. Flagellar movement is counterclockwise up the gradient and cells have been reported to move as fast as 60 um/second.	

A. tumefaciens exhibits polar attachment to the plant cell.
The production of cellulose fibrils serve to anchor the bacteria to the plant
as well as trap other bacteria. Once the concentration of lignin precursors
reaches approximately 10^{-5} M, the virulence genes of the Ti plasmid are induced
and the T-DNA is processed.

A Ti-plasmid model
is under construction here (Flash)



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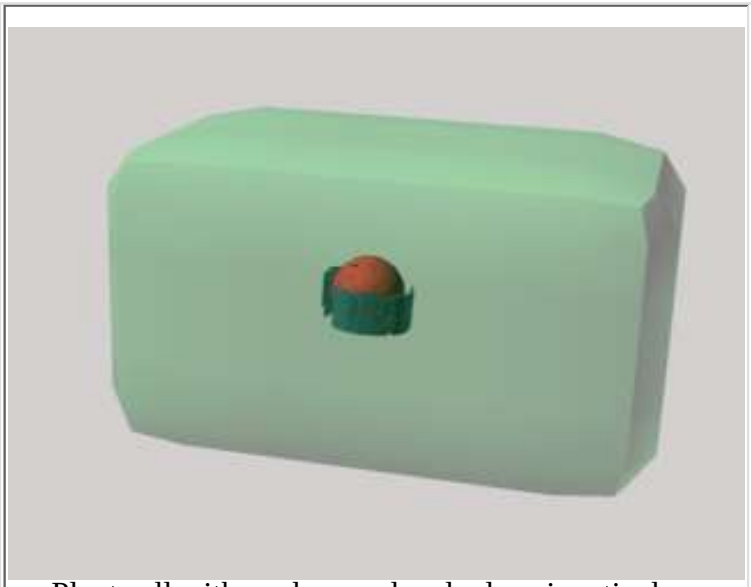
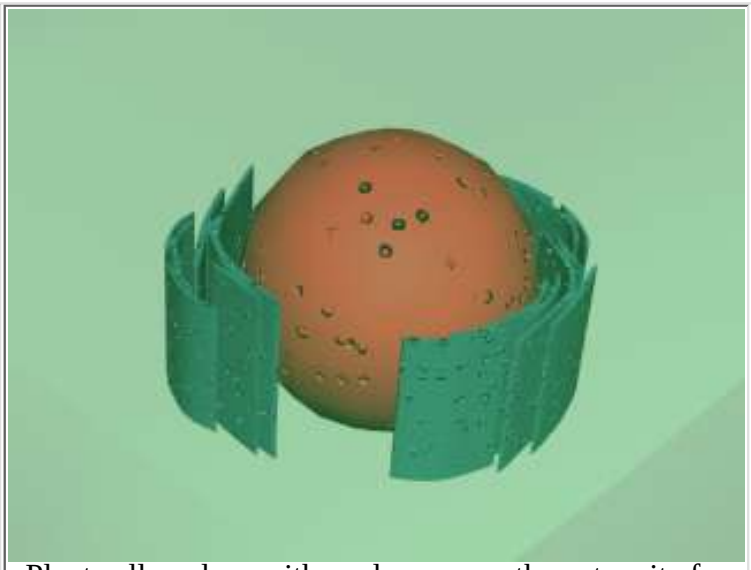
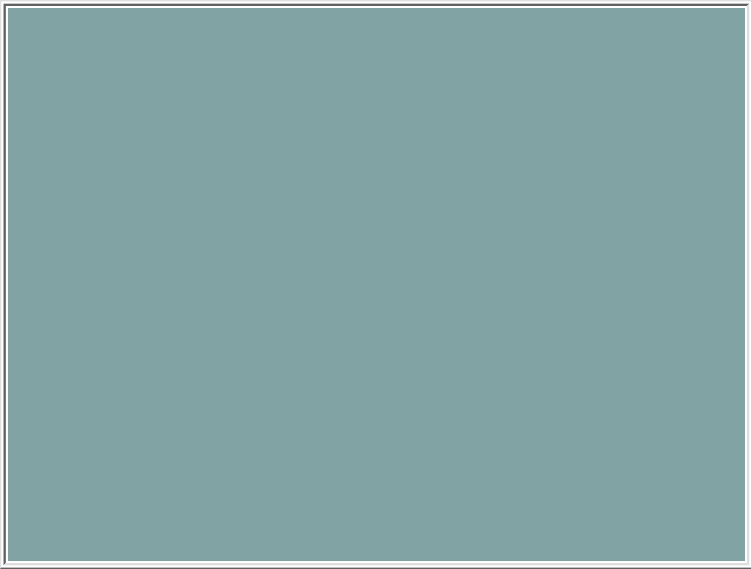


Plant cell with nucleus and endoplasmic reticulum

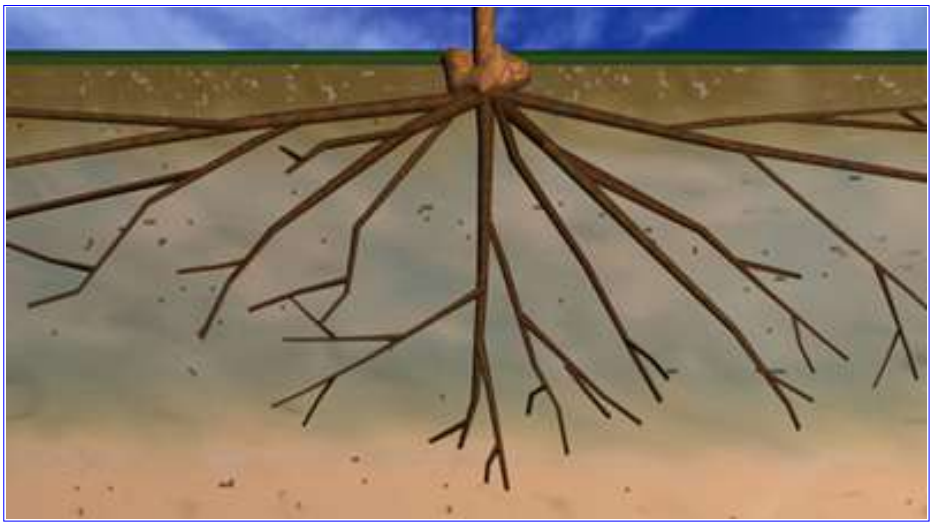


Plant cell nucleus with nuclear pores, the entry site for T-DNA

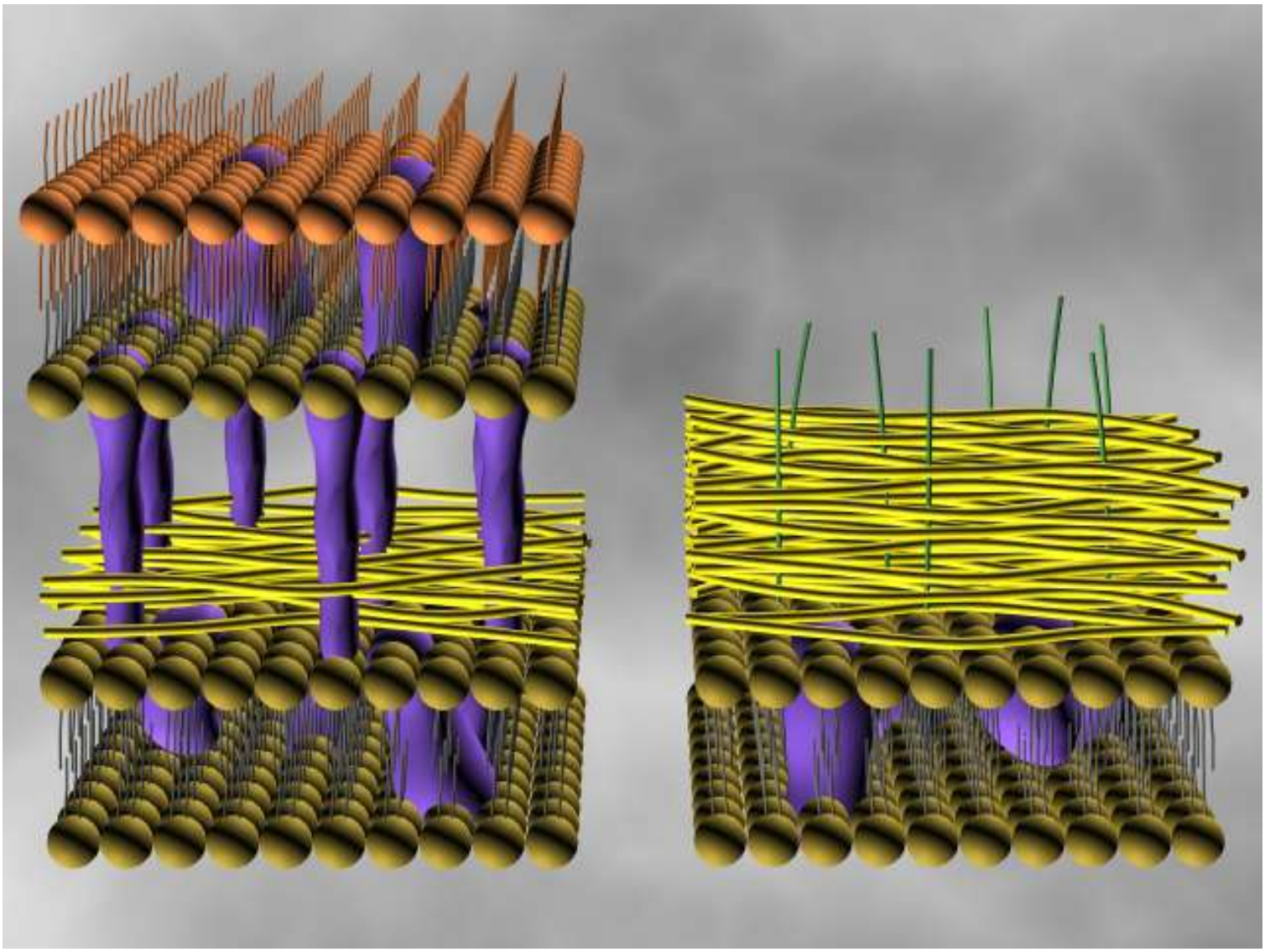


The actual mechanism of T-DNA transfer is difficult to animate. The model at left lacks the double stranded intermediate of the T-DNA, but shows in an approximate manner how the T-DNA moves into the plant cell and is passed through the nuclear pores.

Once all of these raw materials are developed, they will be arranged in a presentation to tell the story of the pathogenesis of *Agrobacterium tumefaciens* and the Ti-plasmid.



This image will be used to illustrate the distribution of the pathogen and vectors in the environment (flash). Click on the image to view the distributions.



Research objectives. My research objective are to **(1)** understand the molecular basis for the development of pathogenesis, **(2)** manipulate interactions among bacteria and plants for disease control, **(3)** make safe environmental releases of plants or microbes genetically engineered for increased productivity, and **(4)** impact other programs related to the phylogenetics of plant pathogens. Specific research collaborations either underway or recently inactive are:

Molecular basis for pathogenesis in phytopathogenic bacteria. With colleagues (Dr. Mark Mount, University of Massachusetts and Carole Cramer, VPISU) we have studied the number and types of pectate lyase genes in the soft rot pathogen, Erwinia carotovora. These genes have been related to induction phenomena for generalized resistance in potato plants.

Molecular relationships among plant pathogenic bacteria. With colleagues (Dr. Norm Schaad, USDA, Frederick, MD, Dr. Frank Louws, NCSC, and Dr. Jeff Jones, University of Florida [UF]),,), we have determined the DNA similarity groups, 16S RNA groups, and Rep-PCR groups for over 140 strains of xanthomonads and are currently considering the sequences of 16S rRNA genes. With colleagues (Dr. Norm Schaad, ARS/USDA, Dr. Jeff Jones, UF, Anne Vidaver, University of Nebraska, and K. Rudolph, Institute for Pflanzenpathol, University of Goettingen, Goettingen, Germany; we have published a critique of the current taxonomy of xanthomonads and a chapter on their identification. With colleagues (Dr. Steve Beer and Dr. Jihyun Kim, Cornell University and Dr. Al Jones, Michigan State University) we are studying over 25 *Erwinia amylovora* isolates using DNA similarity, 16S rDNA sequencing, and RAPD analyses. We have detected two new species and one new pathovar among these isolates. SIGNIFICANCE. Xanthomonads and erwinias are among the most important plant pathogens. Understanding of the molecular basis for pathogenesis has been retarded by the confusing "pathovar" system of classification within species. Determining the molecular phylogenetic relationships among xanthomonads makes it possible to determine which groups followed convergent or divergent evolutionary paths to becoming pathogens. *FUTURE STUDIES* Using the phylogenetic relationships disocovered in previous work, we intend to discover if divergence of genes related to pathogenicity demonstrate similar evolutionary tracks. Studying convergent evolution of pathogenesis may allow us to predict the organization of genes required for pathogenicity on a specific host or related group of hosts.

Manipulation of the disease for biological control of disease. With Dr. E.L Stromberg (PPWS) and Dr. D.P. Roberts (USDA-ARS, Beltsville), we are in the third year of field-screening bacterial strains for biological control for take-all of wheat caused by the fungus *Gaumannomyces graminis* var. *tritici*. We have developed methods for infesting seed with biological control agents, testing large numbers of putative biological control agents in the field, and effectively inoculating head row plots. This year's research is especially interesting because we will harvest in June the first plots treated with combinations of biological control agents. *SIGNIFICANCE.* Root disease control in winter wheat depends upon fungicides in seed coatings. However, chemical control is ephemeral as the roots quickly grow out of the zone of protection and chemical degradation and dilution occur. Seed coatings incorporating living biological control

strains have the potential to replicate and colonize the growing roots thus extending and enhancing protection. Further, using biological control agents reduces pesticide usage. *FUTURE STUDIES.* Our goal with the field testing is to screen large numbers of numbers of putative biological control agents, select the best, and test combinations of the very best performing agents. In future studies we will include molecular platforms for biological control modifications in our trials. This platform is based on genetic engineering of the bacterium *Enterobacter agglomerans.* We have partial funding for a MS-level student to work on this project and we are actively recruiting a student.

Genetic engineering of plants for resistance. Dr. Beth Grabau (PPWS) and Dr. M.D. Denbow (ANSC) and I collaborated in a project to introduce a gene for fungal (*Aspergillus ficuum*) phytase into soybeans used in animal feeds. *PROGRESS.* The phytase gene was obtained was inserted by ballistic methods into soybean suspension culture. The suspension cultures secreted phytase but whole transgenic plants have not been recovered. Poultry feeding studies indicate that fungal phytase from transgenic plants (from cooperating industry) as an additive to soybean/corn meal is effective for releasing inorganic phosphorus for animal nutrition. Recent studies are focused on the microelement enhancement resulting from the release of chelated ions from phytin. *SIGNIFICANCE.* The major reservoir of phosphorus in soybean meal used for animal feeds is not available to swine or poultry because it is sequested as phytin, a phosphorus-sugar compound. Therefore, soybean meal must be fortified with inorganic phosphorus at increased cost and phytin released to the environment in manure is acted on by microbial enzymes releasing excess inorganic phosphorus which contaminates ground water sources, lakes and streams. Fungal phytase releases inorganic phosphorus at low pH compatible with the upper digestive tract of both fowl and swine, engineered into soybean will reduce production costs and the environmental impact of animal culture. *FUTURE STUDIES.* Regeneration and testing of transgenic soybean plants expressing fungal phytase.

Drs. Xueshu Xu and C.L. Cramer (PPWS) and I studied the ability of transgenic tobacco plants engineered to overexpress a gene for hydroxymethylglutaryl coenzyme A reductase (HMGR) to confer resistance to bacterial hollow stalk and hand rot. Our experiments indicate that overexpressing plants are significantly more resistant to soft rot caused by *Erwinia carotovora* than transgeneic plants engineered by antisense technology to suppress HMGR production. *SIGNIFICANCE.* Tobacco, a solanaceous plant which is extremely easy to engineer, serves as a surrogate for other important important solanaceous crops (*e.g.*, potato and tomato) which are more difficult to engineer but have very similar genes for HMGR production. Success with tobacco indicates that we may also be sucessful in engineering tomato and potato. *FUTURE STUDIES.* Engineering and testing other solanaceous crops for disease resistance mediated by overexpression of HMGR genes.

Safe release for genetically engineered organisms. With colleagues (Dr. John Cairns, Jr., VPI&SU) we have studied the impact of engineered plant pathogens upon microcosm models of the environment. We have found that the genetically engineered organism did not perturb the populations of bacterial based on either taxonomic or nutritional groups.

Phylogenetics of plant pathogenic fungi. Dr. Erik L. Stromberg (PPWS) and I are collaborating to determine the molecular differences among strains of the maize (*Zea mays*) gray leaf spot (GLS) pathogen, *Cercospora zeae-maydis* (Czm), and perfect and imperfect stages of related fungi. *PROGRESS.* A collection of fungi related to Czm have been assembled for comparison to over 60 Czm isolates from eight state in the US and South Africa. Methods for isolating DNA and labeling the DNA with ^{33}P have been developed including. Primers and polymerase chain amplifaction of DNAs have been developed and we have sequenced over 7000 bp of 18S rRNA genes from 10 fungi. *SIGNIFICANCE.* Host resistance is the best choice for GLS control. However, no information is available on the presence of pathogen races or the impact of such races on breeding for genetic resistance in the host. *FUTURE STUDIES.* Using phylogenetic techniques including DNA similarities and RFLP patterns we will sort the fungi into groups. Pathogens with the greatest molecular differenced will be used to inoculate inbred maize lines with various genes for resistance to GLS.

Laurence D. Moore

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Special Assistant to the Provost for Diversity
Co-Director, Minority Academic Opportunities Program, College of Agriculture and Life Sciences
COTA Fellow
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Virginia Polytechnic Institute and State University
Blacksburg, VA 24061

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Education:

- Ph.D., The Pennsylvania State University, 1965
- M.S., The Pennsylvania State University, 1961
- B.S., University of Illinois, 1959

Professional Experience:

1998- present

- Special Assistant to the Provost for Diversity
- Co-Director Minority Academic Opportunities Program, College of Agriculture and Life Sciences
- COTA Fellow

1992-97

- Director Minority Academic Opportunities Program, College of Agriculture and Life Sciences
- Professor and Head of the Department of Plant Pathology, Physiology and Weed Science

1985-92

- Professor and Head of the Department of Plant Pathology, Physiology and Weed Science

1965-85

- Assistant, Associate and Professor of Plant Pathology, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

Recent Awards and Honors:

- 2000 – Sharing the Knowledge Award, Black Graduate Student Organization
- 1997 – Conservancy Service Award, The Wilderness Conservancy at Mountain Lake Virginia
- 1996 – University Affirmative Action Award to the College of Agriculture and Life Sciences
- 1994 - Dedicated Service Award, Virginia Turfgrass Council
- 1994 – Distinguish Service Award, Potomac Division, American Phytopathological Society
- 1990 – Certificate of Appreciation, American Institute of Biological Sciences

Teaching Interests:

- Environmental Physiology, junior senior level course

- Operation Success, a program designed to help students in academic troubles

Current Activities:

- Advisor, VirginiaTech - Minorities in Agriculture, Natural Resources and Related Sciences
- Advisor, freshmen students in the Department of Biology
- Co-Director, Summer Research Internship Program for the Colleges of Agriculture and Life Sciences, Arts and Sciences, Natural Resources, Human Resources and Education, Architecture and Urban Studies, and Veterinary Medicine.
- Minority student recruitment undergraduates and graduates
- COTA fellow program youth leadership development and diversity
    - National conference and career fair, Minorities in Agriculture, Natural Resources and Related Sciences
    - Emerging Leaders Workshops third annual in 2000
    - VT- HBCU partnership program
    - Minority high school students visits to VT

Recent Grants:

- 1999-05, McNair, Department of Education
- 1999-05, CSREES Higher Education Multicultural Scholars Program
- 1997-01, CSREES Higher Education Multicultural Scholars Program
- 1995-99, CSREES Higher Education Multicultural Scholars Program
- 1994-96, USDA Capacity Building Grant with Virginia State University

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Department of Plant Pathology, Physiology, and Weed Science
Last Updated July 19, 2002

David M. Orcutt

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Education:

- Ph.D. (Plant Physiology) University of Maryland, College Park, Maryland - 1973
- M.S. (Biology), Incarnate Word University, San Antonio, TX - 1970
- B.S. (Botany), University of Oklahoma, Norman, OK - 1966

Professional Experience:

- Virginia Tech (Department of Plant Pathology, Physiology and Weed Science)
    - Professor - 1991-present
    - Associate Professor - 1979-1991
    - Assistant Professor - 1973-1979
- USDA Appalachian Soil and Water Conservation Lab (Beckley, WV)
  Study/research leave - 1984 (5 months)
- University of Maryland (Department of Botany)
    - Instructor of Continuing Education - 1972-1973
    - Graduate Teaching Assistant - 1970-1973
- USAF School of Aerospace Medicine (Brooks AFB, San Antonio, TX)
    - Physiological Training Technician and Lab Technician - 1966-1970

Honors and Awards:

- Henderson Award, Outstanding Faculty Member, PPWS - 1983
- Teacher Fellow, National Association of Colleges and Teachers of Agriculture - 1981
- Gamma Sigma Delta Award, Teaching Excellence - 1980
- Certificate of Teaching Excellence, College of Agriculture and Life Sciences - 1979
- E. B. Knight NACTA Journal Award, Honorable Mention – 1976

Teaching Interests:

- Plant Physiology and the Environment: Principles and Abiotic Stress (PPWS 3505)
- Plant Physiology and the Environment: Biotic Stresses (PPWS 3506)
- Plant Stress Physiology (PPWS 5304)
- Plant Growth and Development (PPWS 5654)

Research Interests:

- Impact of biotic and abiotic stressors on the physiology and biochemistry of vascular plants and algae
    - Effects of stressors on lipids (sterols, fatty acids, phospholipids and hydrocarbons), pigments, neurotoxic nonprotein amino acids, and a-tocopherol
- Impact of sterol-inhibiting fungicides on non-target algal species
- Efficacy of fungicides for the control of algae in turfgrass
- Development and use of continuous culture systems of algae to study bio-fouling of optical sensors used in monitoring water quality
- Use of synthetic and natural plant growth regulators as ameliorates of plant stress

Selected Publications:

- **Books**

1. Orcutt, D. M. and E. T. Nilsen 2000. *Physiology of Plants Under Stress: Soil and Biotic Factors*. John Wiley and Sons, Inc., New York, NY. http://catalog.wiley.com

2. Nilsen, E. T. and D. M. Orcutt 1996. *Physiology of Plants Under Stress: Abiotic Factors.* John Wiley and Sons, Inc., New York, NY. http://catalog.wiley.com

3. Hale, M. G. and D. M. Orcutt 1987. The Physiology of Plants Under Stress. John Wiley and Sons, Inc., New York, NY.

- **Journal Articles**

1. Nandula, V. J., C. L. Foy and D. M. Orcutt 1999. Glyphosate for broomrape (*Orobanche aegyptiaca*) control in common vetch (*Vicia sativa*) and oilseed rape (*Brassica napus*). Weed Sci. 47:486-491.

2. Yan, J., R. E. Schmidt and D. M. Orcutt 1997. Influence of fortified seaweed extract and drought stress on cell membrane lipids and sterols of ryegrass leaves. International Turfgrass Soc. Res. J. 8:1356-1362

3. Orcutt, D. M. and T. M. Murphy (eds.) 1995. Phytoalexins: Biology, biochemistry and molecular biology. Physiol. Plantarum 93:383-410.

4. Rivero, G. C. and D. M. Orcutt 1992. Antioxidant metabolism in water stressed peanut treated with diniconazole. Biotropia 5:22-25.

5. Shen, L., D. M. Orcutt, and J. G. Foster 1992. Influence of polyethylene glycol and aeration method during imbibition on germination and subsequent seedling growth of flatpea (*Lathyrus sylvestris* L.) Seed Sci. and Technol. 20:349-357.

6. Rivero, G. C. and D. M. Orcutt 1991. Diniconazole effects on water relations, photosynthesis and alpha-tocopherol levels of peanut plants. Trans. Nat. Acad. Sci. Technol. (Republic of the Philippines) 8:615-624.

7. Orcutt, D. M. and J. G. Foster 1990. Nonprotein amino acid composition of flatpea (*Lathyrus sylvestris* L.) as affected by ethephon seed treatments and seedling fertilization J. Plant Growth Regulation 9:7-11.

Current or Recent Research Sponsors:

- Agricultural chemical industry, USAID, USDA/ARS, USDA/SRPIAP, AIRAK, Inc. and Penn Virginia.

Department of Plant Pathology, Physiology, and Weed Science

Last Updated May 25, 2000

R. Jay Stipes

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E-mail: treedr@vt.edu

Professor.
PhD, North Carolina State University, 1965.
Teaching 25%, research 65%, extension 10%.

The principal activities of Dr. Stipes' research and extension programs are to address the identification, biology and management of diseases of landscape trees and ornamental plants. Current projects include refinement of tree injection technology, using the newer systemic fungicides, with primary emphasis on Dutch elm disease; also, dogwood anthracnose biology and control; shiitake production log short-life; Photinia leafspot; round; leaf birch pathology; evaluation and management of wind/snow/ice storm damage to trees Teaching activities include the development of a new course "Plant Plagues and People", teaching "Principles of Agricultural Chemistry"; team-teaching in "Pesticide Usage", and guest lectures in courses in urban forestry, horticulture and biology, as well as independent studies for undergraduate and graduate students; also undergraduate and graduate student advising.

Research Project:

- CULTURE OF LANDSCAPE AND ORNAMENTAL TREES AND ORNAMENTALS IN VIRGINIA

Department of Plant Pathology, Physiology, and Weed Science
Last Updated September 22, 1998

Herman L. Warren

Professor of Plant Pathology
100 Price Hall
Department of Plant Pathology,
Physiology, and Weed Science
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0331

Phone: 540 231 7486
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E-mail: hwarren@vt.edu

Education:

- Ph. D. University of Minnesota
- M.S. Michigan State University
- B. S. Prairie View A&M University

Professional Experience:

- 1989 - Present, Professor of Plant Pathology
- 1972 - 1989, Assist., Assoc., and Professor,& USDA Scientist
- 1962 - 1967, Research Scientist , Olin Chemical Co.

Recent Awards and Honors:

- Member of New York Academy of Science
- Fellow, African Scientific Institute

Teaching Interests:

- Genetics of disease resistance.

Research Interests:

- Mechanism of resistance to *Bipolaris zeicola* and pathogen variability. Dr. Warren conducts research on diseases of maize. He is responsible for extension activities on diseases of vegetables. He is responsible for research on disease development, epidemiology, genetics, and development of disease resistance germplasm using traditional and biotechnical methods. Current focus is on physiological differences between races of Bipolaris zeicola and on mechanism of genetic resistance in maize. International activities relative to Integrated Pest Management of cereal crops and biological control of insect pest using fungi are conducted in Africa and Eastern Europe.

Selected Publications:

1. Dorrance, A.E., K.H. Hinkelmann and H.L. Warren. 1998. Diallel analysis of Diplodia ear rot resistance in maize. Plant Dis. 82:699-703.
2. Menkir,A.,G. Ejeta, L. G. Butler, A. Melakeberhan, and H.L. Warren. 1996. Fungal invasion of kernels and grain mold damage assessment in diverse sorghum germ plasm. Plant Dis.80:1399-1402.
3. Robbins W.A.Jr and H.L. Warren 1993. Inheritance of resistance to Exserohilum turcicum in PI 209135, "Mayorbela variety of maize. Maydica

38:209-213.

4. Traut, E.J. and H.L. Warren 1993. Expansion of lesions induced by races 1, 2 and 3 of *Bipolaris zeicola*. Maydica 38:215-221.
5. Tsai, C. Y., I. Dweikat, D. M. Huber and. H.L. Warren. 1992. Interrelationship of nitrogen nutrition with maize (Zea mays) grain yield, nitrogen use efficiency and grain quality. J. Sci. Food Agric.58:1-8.
6. Wu, C. H. H. L. Warren, L. A. Lyznik and C. Y. Tsai. 1991. Nuclear RNA polymerase II in maize leaves infected with Bipolaris maydis. Maydica 36:206-211.
7. Wu, C. H., H.L. Warren, K. Sitaraman, and C. Y. Tsai. 1988. Translation alterations in maize leaves responding to pathogen infection, paraquat treatment, or heat shock. Plant Physiol.86:1323-1329.

Current or Recent Research Sponsors:

- IPM CRSP, Pest and Pesticide Management Project and Rockefeller Foundation

Lab Personnel:

- H. L. Witt

Department of Plant Pathology, Physiology, and Weed Science

Last Updated September 22, 1998

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General Introduction

Effective Service Date October 1, 1961. Harold (Bo) has an Associate degree in Mechanical Drafting and Design from New River Community College. He is married, has three children and two grandsons. Bo works with Dr. C. L. Foy in the Weed Science Laboratory and with Dr. H.L. Warren in the Maize Disease Laboratory.

- Lab Specialist Senior, Weed Science and Plant Pathology
- Proficient experience in laboratory work, greenhouse research, field experiments
- Interests: Football, Baseball, Auto racing
- bowitt@vt.edu

Department of Plant Pathology, Physiology, and Weed Science
Last Updated February 17, 1999

Our Campus and Community

Virginia Polytechnic Institute and State University (Virginia Tech) is a publicly supported, comprehensive, land-grant university serving the Commonwealth of Virginia, the nation, and the international community by generating and disseminating knowledge through instruction, research, and extension. Our campus is located in Blacksburg, Montgomery County, Virginia, in the New River Valley, 2100 feet above sea level and centered in the Appalachian Mountains. Roanoke, 40 miles to the northeast, has a population of about 200,000 and a modern airport that serves the New River Valley. This area is one of exceptional natural beauty and provides many opportunities for year-round outdoor recreation. More than 26,000 students attend Virginia Tech including 4,000 graduate students.

Our Missions and Graduate Programs

The Department of Plant Pathology, Physiology, and Weed Science (PPWS) is one of the oldest departments in the College of Agriculture and Life Sciences of Virginia Tech dating back to 1889. Our faculty, students, and support staff conduct research, teaching, and extension programs in three distinct disciplines key to plant productivity, protection and quality: plant pathology - the study of diseases, plant pathogens and their management; plant physiology - the study of plant function, growth and development, and response to environmental stresses; and weed science - the study of weed biology, ecology, and management. We also have a strong program in plant molecular biology that addresses critical issues in each of these disciplines and is widely recognized for its innovative, entrepreneurial approach to crop improvement through applied biotechnology.

Our Facilities

The main office, teaching classrooms, and half of our research laboratories are located in Price Hall. Other research laboratories and our greenhouses are housed in the Fralin Center for Biotechnology and the Glade Road Research complex. Our research laboratories are well equipped for conducting cutting-edge research in our three main disciplines. Field plots are located a few miles from campus on a 1,600 acre research farm and at nearby Turfgrass and Glade Road Research Centers. Eight departmental faculty are located at off campus field research facilities at Blackstone, Suffolk, Winchester, Virginia Beach and Painter on the Virginia Eastern Shore.

Our Degree Programs

PPWS offers Master of Science (thesis and non-thesis M.S.) in Life Sciences with options in our disciplines and Doctor of Philosophy (Ph.D.) degrees in plant pathology, plant physiology and weed science. PPWS has about 30 graduate students; half who are weed science/ stress physiology majors, and the other half are plant pathology majors. About one third of our graduate students are women and approximately half are international students. Our graduate students may also participate in the interdisciplinary programs in Plant Physiology, Genetics, and Molecular Cell Biology, with which our department is affiliated.

Our Faculty

PPWS has 27 faculty members, 12 who are plant pathologists, 9 plant physiologists, and 6 weed scientists. Several visiting scientists, research associates, and adjunct faculty are also associated with the department. We have a variety of research programs available to our students. The following list of our faculty highlights their research interests. We encourage you to contact individual faculty by e-mail for more information about their programs.

Faculty Programs in Plant Pathology (* Off Campus)

BAUDOIN, A.B.A.M. -Associate Professor (abaudoin@vt.edu)- Epidemiology; integrated pest management; grape pathology

EISENBACK, J.D. - Professor (jon@vt.edu)- Plant nematology

HANSEN, M.A. - Instructor (maryannh@vt.edu)- Diseases of ornamentals; Plant Clinic Manager

*** HONG, C. H.** - Assistant Professor (chhong2@vt.edu) - Environmental plant pathology

*** JOHNSON, C.S**. - Professor (spcdis@vt.edu)- Epidemiology; crop loss assessment; tobacco diseases

MCDOWELL, J.M. - Assistant Professor (johnmcd@vt.edu)- Molecular mechanisms of disease resistance

*** PHIPPS, P.M.** - Professor (pmphipps@vt.edu)- Peanut and soybean diseases; nematology; epidemiology

*** SHOKES, F.M.** - Director, Tidewater AREC (fshokes@vt.edu)

STROMBERG, E.L. - Professor (elstrom@vt.edu)- Field crop pathology; chemical, biological and cultural disease control

TOLIN, S.A. - Professor (stolin@vt.edu)- Plant virology; biotechnology policy

YODER, K.S. - Professor (ksyoder@vt.edu)- Tree fruit pathology; mode of action and resistance to fungicides

TYLER, B.M. – Professor, (brtyler@vt.edu) Virginia Bioinformatics Institute – Application of genomics and bioinformatics to plant-microbe interactions

Faculty Programs in Plant Physiology

CHEVONE, B.I. - Associate Professor (bchevone@vt.edu)- Plant stress physiology; air pollution

CRAMER, C.L. - Professor (ccramer@vt.edu)- Molecular and genetic bases of resistance; biotic and abiotic plant stress; pharmaceuticals in transgenic plants

DENBOW, C.J. - Research Scientist (cdenbow@vt.edu)- Plant molecular and cellular biology

GRABAU, E.A. - Associate Professor (egrabau@vt.edu)- Molecular biology of soybean improvement; transgenic plants

GRENE, R. - Professor (ralscher@vt.edu)- Air Pollution and other abiotic stresses;plant metabolism; plant gene expression and regulation

JELESKO, J.G. - Assistant Professor (jelesko@vt.edu)- Molecular genetics of plant DNA recombination; molecular biology of alkaloid biosynthesis in tobacco

MEDINA- BOLIVAR, F. – Research Assistant Professor (fmb2@vt.edu) – Transgenic plants for production of human vaccines. Production of natural products and recombinant proteins in hairy root cultures.

NESSLER, C.L. - Professor and Department Head (cnessler@vt.edu) - Metabolic engineering of primary and secondary products

SOBRAL, B.W.M. - Professor and Director of the Virginia Bioinformatics Institute (sobral@vt.edu)- Application of genomics and bioinformatics to predicting phenotypic performance

Faculty Programs in Weed Science (* Off Campus)
ASKEW, S.D. – Assistant Professor (saskew@vt.edu) – Turf Weed Extension
*** DERR, J.F.** - Professor (jderr@vt.edu)- Weed identification and control in ornamentals, turf, tree fruit, small fruit
HAGOOD, E.S. - Professor (shagood@vt.edu)- Weed control in agronomic crops; low-input sustainable agriculture; integrated weed management
HIPKINS, P.L. - Extension Weed Scientist/Senior Research Associate (lhipkins@vt.edu)- Right-of-way vegetation management and turf weed control
WESTWOOD, J.H, - Assistant Professor (westwood@vt.edu) - Parasitic weed biology and control
*** WILSON, H.P.** - Professor (hwilson@vt.edu)- Weed management in vegetable and agronomic crops

Application Information

Application is done primarily through the internet. Application information and materials can be accessed at http://www.grads.vt.edu. If a prospective student is unable to access the application materials via the internet, the application can be requested through the Graduate School. Before the application approval process can begin, a complete application is required. The complete application includes official academic transcripts, three letters of recommendation, and Graduate Record Examination (GRE) scores. TOEFL scores are required for foreign national students. Although interviews are not required, we welcome visits from prospective students. Virginia Tech does not discriminate against employees, students, or applicants on the basis of race, color, sex, sexual orientation, disability, age, veteran status, national origin, religion or political affiliation. Anyone having questions concerning discrimination should contact the Equal Opportunity and Affirmative Action Office.

Financial Aid

Arrangements for financial aid are made after formal acceptance into Graduate School. Assistantships and fellowships are awarded to students for demonstrated scholastic ability and are competitive with other national research universities. The duration of assistantships is dependent upon satisfactory progress throughout the graduate program and the availability of funds. Most assistantships are funded by individual grants to faculty; therefore, the research area of study must contribute to the objectives of the grant. Students on assistantships have in-state status and tuition is provided as part of the assistantship.

***For more information contact*:**

Craig L. Nessler, Professor and Head
Plant Pathology, Physiology, and Weed Science
Telephone 540-231-6361; Fax: 540-231-7477
e-mail: cnessler@vt.edu

Karen P. DePauw, Vice Provost for Graduate Studies and Dean of Graduate School
Telephone: 540-231-7581; Fax: 540-231-1670
e-mail: kpdepauw@vt.edu

Roger J. Avery, Senior Associate Dean
Graduate School
Telephone: 540-231-5645; Fax: 540-231-1670
e-mail: avery@vt.edu

Randolph L. Grayson, Director of Multicultural Academic Opportunities Program (MAOP)
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Virginia Tech
1872

PLANT PATHOLOGY PHYSIOLOGY AND WEED SCIENCE
WEED SCIENCE
MOLECULAR BIOLOGY
PLANT PHYSIOLOGY
PLANT PATHOLOGY

Graduate Programs 2003-04

http://www.ppws.vt.edu

Department of Plant Pathology, Physiology, and Weed Science
413 Price Hall, Virginia Tech
Blacksburg, VA 24061-0331
ppws@vt.edu

WELCOME

Welcome to Virginia Tech and the Department of Plant Pathology, Physiology, and Weed Science (PPWS) family. We are delighted that you chose to pursue your graduate education in our department and look forward to helping you reach your personal and professional goals. This 2002-2003 edition of the **Graduate Student Handbook** is designed to help guide you through the planning and completion of your graduate program. Keep it and refer to it often as it will provide the information and milestone requirements needed to complete your degree.

The PPWS Graduate Student Handbook defines the guidelines and policies governing the Master's and Doctoral Programs offered by the PPWS Department and is supplemental to the information in the current Graduate Catalog published by the Graduate School of Virginia Tech. In addition, the Handbook describes the missions, programs, curricula, facilities, and faculty expertise available in the department.

The Graduate Student Handbook is revised each academic year and is prepared as a source of information for the graduate faculty, graduate students, and applicants to the graduate program in Plant Pathology, Physiology, and Weed Science. All faculty and students should become thoroughly familiar with its contents, and adhere to these guidelines and policies in formulating the student's program of study. Students should use the handbook in consultation with their major professor and advisory committee as they plan their program of study and research projects.

I encourage all graduate students and faculty in the department to read this Handbook thoroughly. If you have any questions about the material presented in this handbook or suggestions for its improvement, please contact the main office of the Department (411 Price Hall; 231-6361).

I extend my best wishes to all of you for a successful and rewarding 2002-2003 academic year.

Craig L. Nessler
Professor and Head
PPWS Department

Revised, August 2002

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APPENDICES

I. DEPARTMENTAL HISTORY

The department of Plant Pathology, Physiology and Weed Science (PPWS) is one of the oldest departments of Virginia Tech dating back to 1889. In its early years, the main disciplines of the department were housed in the Mycology Department. A separate Department of Plant Pathology was first established in 1907 and continued to exist in various forms until 1935 at which time, Plant Pathology became part of the Biology Department. The current structure of the Department was established in 1949 with the name of Plant Pathology and Physiology and remained unchanged until 1983. Weed Science was then added to the departmental name to recognize the three main disciplines housed in the department.

The main highlights in our departmental history are as follows:

Entomology and Mycology Department (1889-1891)
Horticulture, Entomology and Mycology Department (1891-1902)
Entomology and Mycology Department (1902-1904)
Mycology Department (1904-1907)
Plant Pathology Department (1907-1914)
Plant Pathology and Bacteriology Department (1914-1919)
Plant Pathology Department (1919-1926)
Botany and Plant Pathology Department (1926-1935)
Biology Department (1935-1949)
Department of Plant Pathology and Physiology (1949-1983)
Department of Plant Pathology, Physiology and Weed Science (1983-present)

The Department has had 12 department heads since 1889. They were:

W. B. Alwood (1889-1904)
W. A. P. Moncure (1904-1908)
H. S. Reed (1908-1915)
F. D. Fromme (1915-1928)
S. A. Wingard (1928-1964)
R. G. Henderson (1964-1965)
H. B. Couch (1965-1974)
C. L. Foy (1974-1980)
G. R. Hooper (1980-1984)
L. D. Moore (1985-1996)
K. K. Hatzios (1997-2000)
C. L. Nessler (2000-present)

II. DEPARTMENTAL MISSIONS AND GOALS

The underlying mission of the department is to optimize plant productivity and quality by limiting the impact of biotic and abiotic stresses on the profitability of crops and other plant enterprises, as well as the impact of these stresses on natural and agricultural ecosystems. The department conducts research, teaching, and extension programs in three distinct plant science disciplines key to productivity, protection, and quality. Disciplines include **plant pathology** – the study of diseases, plant pathogens, and their management; **plant physiology** – the study of plant function, growth and development, and response to environmental stresses; and **weed science** – the study of weed biology, ecology, and management. All major plant commodities grown within the Commonwealth are encompassed within the department's programs, including row crops, forages, horticultural crops, urban and landscape plants, and forestry.

A. RESEARCH

The Department's research goals are to (a) develop new concepts and principles in the disciplines of plant pathology, plant physiology, and weed science and (b) adapt these and other established principles to new situations for solutions of specific problems. Research interests of the faculty vary from fundamental to applied, as follows: molecular biology, biological control, genetics of host-parasite interactions, ecology of root disease, fungicide-plant-soil interactions, nematology, virology, physiology of disease, plant stress metabolism, herbicidal action, plant growth regulation, air pollution, weed and disease control, and plant protection.

B. EXTENSION

Extension programs by departmental specialists involve providing extension personnel, growers, commodity groups, urban and suburban residents, and business and industrial interests with (a) a continuing source of knowledge relevant to plant disease and weed control and (b) identification, survey, and diagnostic services in these areas. Field test-demonstrations are conducted and the results used to formulate recommendations for the control of diseases, nematodes, and weeds associated with agronomic crops, fruits, vegetables, turf and ornamentals, forest and shade trees, aquatic and recreational areas, and along highways, rights-of-way, and other non-crop situations. Up-to-date information on plant protection is disseminated in the form of timely publications, news releases, radio, and farm visits. A modern Plant Clinic is operated by the Department to aid agricultural producers and other clients in the Commonwealth in solving problems related to plant diseases, nematode infection, nutrient deficiencies, pesticide damage, and weed identification and control.

C. TEACHING

The Department's teaching program provides counsel and guidance, and a balanced offering of courses in fundamental and applied phases of plant pathology, plant physiology, and weed science. This includes serving the needs of other plant science departments as well as graduate programs within the PPWS Department. M.S. and Ph.D. degree programs are offered in plant pathology and plant physiology/weed science, along with a non-thesis program at the M.S. level emphasizing plant protection.

III. PERSONNEL

The Department has 27 tenure track, and three non-tenure track faculty members. Seven faculty positions are located at off-campus research facilities. Several visiting professors, research associates, and adjunct faculty are also associated with the Department. The areas of interest and expertise of all faculty are listed below. Classified employees both on and off campus augment all activities. At Blacksburg, laboratory specialists/technicians are assigned to many projects and project leaders. Agriculture research supervisors and technicians assist in field and greenhouse programs.

FACULTY PROGRAMS

PLANT PATHOLOGY

ANTON B. BAUDOIN – (abaudoin@vt.edu) Associate Professor (1981)
(Ph.D., University of California, Riverside)
417 Price Hall

Dr. Baudoin's teaching responsibilities include courses in Pest Management (pathology section), Introductory Plant Pathology, Principles of Plant Disease Management, Diseases of Crop Plants, Epidemiology of Plant Diseases, and Principles of Biology. Current research centers on biology and control of fungal diseases of grapes, with emphasis on Botrytis bunch rot, black rot, powdery mildew, and sour rot.

HOUSTON B. COUCH – (hcouch@vt.edu) Professor (1965)
(Ph.D., University of California, Davis)
111 Price Hall

The long range objective of Dr. Couch's research program is to characterize the form, structure, and chemical make-up of the surface of grass leaves at the moments most conducive for infection by restricted common primary saprophytic phylloplane microflora, and to identify the cultural practices and environmental conditions that contribute materially to the development of these features. He also conducts disease control experiments using chemical and biological fungicides and teaches an undergraduate course in the nature and control of turfgrass diseases for the Agricultural Technology Program and the Turf option of the Crop and Soil Environmental Sciences Department.

JONATHAN D. EISENBACK – (jon@vt.edu) Professor (1985)
(Ph.D., North Carolina State University, Raleigh)
103 Price Hall

Dr. Eisenback's primary responsibility is to develop an innovative research program in plant nematology emphasizing the taxonomy, evolution, ecology, and biology of the root-knot nematodes (*Meloidogyne* species). In addition, new techniques for light and scanning electron microscopy have been developed for these morphological comparisons, including sequential fixation, freeze drying, dissection, and multiple focus and exposure photography. His research goals focus on the control of the agriculturally important species of root-knot nematodes in Virginia, the southeastern U.S., and in developing countries around the world. He teaches the Introduction to Plant Parasitic Nematology as a core course in the Department, advises and directs graduate students, and teaches Plant Science for the Agricultural Technology Program. Dr. Eisenback also serves the department as Graduate Student Officer.

GARY J. GRIFFIN – (gagriffi@vt.edu) Professor (1967)
(Ph.D., Colorado State University, Fort Collins)
101-E Price Hall

The objectives of Dr. Griffin's programs are to identify the principal factors involved in the ecology and biological control of soil-borne and other plant pathogenic fungi, and to elucidate the physiological mechanisms and environmental factors involved in blight resistance and blight biological control on American chestnut. Dr. Griffin teaches a graduate course on plant pathogenic fungi, an undergraduate course in forest pathology, and directs graduate students.

MARY A. HANSEN – (maryannh@vt.edu) Instructor (1984)
(M.S. in Plant Pathology, University of Wisconsin, Madison)
106 Price Hall

Ms. Hansen supervises the Plant Disease Clinic and Nematode Assay Laboratory. These laboratories provide plant diagnostic services to extension agents statewide. Diagnoses and control recommendations are provided for 2500 plant and soil samples each year. The objective of the diagnostic program is to provide growers with timely and accurate information to prevent crop loss. Ms. Hansen's other extension responsibilities include presenting talks and training sessions on plant diseases and their control to extension agents, grower groups, and Master Gardeners throughout the state. She also teaches Clinic Experience, a graduate course in plant disease diagnostics, and co-teaches undergraduate courses 'Domesticating the Gene' and 'Pest and Stress Management of Trees'.

CHUANXUE HONG - (chhong2@vt.edu) Assistant Professor (1999)
(Ph.D. Beijing Agricultural University)
Hampton Roads Agricultural Research and Extension Center, Virginia Beach, VA

Dr. Hong conducts research and extension programs on environmental plant pathology. His research addresses the common issues facing the nursery and/or landscape industry, such as water recycling, interstate and international movement of ornamental materials and products, re-use of green wastes, potting mixes, and plastic containers. His research interests encompass applied and basic aspects of plant pathology including molecular characterization and detection of plant pathogens, investigation of basic pathogen biology and ecology, epidemiology, and ornamental disease management. Current areas of interest include characterization and detection of plant pathogens in recycling irrigation systems, epidemiology of ornamental diseases, economic threshold of waterborne pathogens for major nursery crops, and innovative management strategies. In cooperation with faculty on campus, he directs graduate student research programs for the M.S. and Ph.D. degrees in plant pathology.

CHARLES S. JOHNSON – (spcdis@mail.vt.edu) Associate Professor (1985)
(Ph.D., North Carolina State University, Raleigh)
Southern Piedmont Agricultural Research and Extension Center, Blackstone, VA

Dr. Johnson conducts research and extension programs for tobacco disease and

weed control. His research involves a large number of diseases and pest problems. Current research priorities include studying the biology and management of tobacco cyst nematodes and identifying better control methods for tobacco blue mold and collar rot. Much of this work involves increasing use of host resistance and improving use of pesticides. Dr. Johnson's graduate students work extensively with him in these areas in addition to conducting their own research. Dr. Johnson and his students also cooperate extensively with other faculty, county extension agents, industry leaders, and growers in conducting on-farm experiments and a variety of extension programs.

GEORGE H. LACY – (lacygh@vt.edu) Professor (1981)
(Ph.D., University of California, Riverside)
202-A PMB Building, Glade Road Research Center

Dr. Lacy studies molecular biology of plant-bacterial disease interactions to develop controls for those diseases, and to incorporate his expertise into the curriculum. In his *Erwinia carotovora*-bacterial soft rot model, he has investigated the organization, regulation, and structure of the genes involved in pectolysis and proteolysis, constructed site-replacement mutants of the pathogen, and studied gene activation in interactions with the host. In Biological control, he has worked with selection of biological control agents and seed application for the control of root diseases caused by fungi. In phylogenetics, he is studying relationships among strains of xanthomonads, *Erwinia amylovora,* and *Cercospora zeae-maydis* using DNA:DNA hybridization and RFLP techniques. He teaches Phytopathogenic Prokaryotes, introductory Genetics in Biology, team teaches Plant Disease Physiology and Development, advises undergraduate students in Biology, and directs graduate students.

JOHN M. MCDOWELL – (johnmcd@vt.edu) Assistant Professor (2000)
(Ph.D. University of Georgia, Athens)
204 Fralin Biotechnology Center

Plant pathogens are estimated to reduce crop yields by ~30% worldwide. Disease-resistant crop varieties have been used for decades to reduce disease losses, but our understanding of the molecular basis of disease resistance in only fragmentary. Dr. McDowell's research focuses on the interaction between the model plant Arabidopsis and its natural pathogen *Peronospora parasitica* (downy mildew). His lab uses molecular genetic, genomic, and bioinformatics-based approaches to understand how plants 'recognize' pathogens, how new recognition capabilities evolve, and how the recognition signal is transduced to activate defenses in the proper place and time. In the long term, this basic research is expected to inform strategies to enhance natural resistance mechanisms in crops, thereby reducing the grower's reliance on costly and harmful chemical inputs. Dr. McDowell's teaching involvement includes a molecular biology lab for undergraduates, and a graduate level course addressing molecular aspects of plant-microbe interactions.

PATRICK M. PHIPPS – (pmphipps@vt.edu) Professor (1978)
(Ph.D., West Virginia University, Morgantown)
Tidewater Agricultural Research and Extension Center, Suffolk, VA

Dr. Phipps has responsibilities for research on epidemiology and control of field crop diseases in Southeastern Virginia. Areas of emphasis include disease forecasting and development of cost effective use patterns for fungicides and nematicides. His programs seek to develop improved control measures that are both safe and effective, and to incorporate new technology into cooperative extension programs for peanut, soybean, corn, cotton, and small grains in the region. In cooperation with faculty on campus, he directs graduate student research programs for the M.S. and Ph.D. degrees in plant pathology. Students spend each summer working in the laboratory and field at the Tidewater AREC in Suffolk. Additional information is available at http://www.vaes.vt.edu/tidewater.

FRED M. SHOKES - (fshokes@vt.edu) Professor (1999)
(Ph.D. University of Georgia, Athens)
Tidewater Agricultural Research and extension Center, Suffolk, VA

Frederick (Fred) M. Shokes has served Virginia Tech as professor and Director, at the Tidewater Agricultural Research and Extension Center in Suffolk, Virginia, since 1999. With a 75% administrative and 25% extension appointment, he oversees the programs and resources for eight project leaders representing the disciplines of Agronomy, Animal Sciences, Entomology, Horticulture, and Plant Pathology. His career goals are to be an effective administrator using his knowledge and experience to benefit others, and to serve the land grant university well by doing everything possible to help the Tidewater AREC fulfill its mission of improving the sustainability of agriculture. The Center has 20 office, field, and technical staff and often has from 4-6 graduate students in residence. Prior to joining Virginia Tech, Dr. Shokes was a faculty member of the University of Florida, Institute of Food and Agricultural Sciences, at the North Florida Agricultural Research and Education Center from 1978-1999, conducting research and extension on diseases of field crops.

BRUNO W. S. SOBRAL - (sobral@vbi.vt.edu) Professor (2000)
Ph.D., Genetics, Iowa State University
Director, Virginia Bioinformatics Institute

Dr. Sobral has a long-standing interest in reverse engineering living systems, especially in agriculturally or environmentally important organisms. He has two main research thrusts, one in comparative plant genomics, bioinformatics, and proteomics, and the other in dissection of plant-microbe interactions. He focuses primarily on two plant-microbe systems: rhizobia-legume symbioses and plant-Phytophthora interactions. Throughout Dr. Sobral's research, the leveraging of research results through the application of whole genome and comparative biological approaches has become increasingly central. Dr. Sobral has a long-term interest and commitment to the development of public-private partnerships so that the knowledge generated by

research is effectively consumed and utilized to develop technologies and products that improve society. He currently serves as Director of the Virginia Bioinformatics Institute (www.vbi.vt.edu), which is located at 1880 Pratt Drive, Virginia Tech Corporate Research Center. For more information regarding his research endeavors, see http://www.vbi.vt.edu/research/groups/lab_sobral.htm.

ERIK L. STROMBERG – (elstrom@vt.edu) Professor (1981)
(Ph.D., Oregon State University, Corvallis)
401 Price Hall

The primary interests and responsibilities of Dr. Stromberg's research and extension program involve the study of the biology, identification, prevention, and control of diseases of agronomic crops including alfalfa, corn, small grains, and soybeans. Current projects include: the development and understanding the mode of action of gray leaf spot-resistant corn germplasm, refinement of fungicide treatment thresholds for powdery mildew, leaf rust, tan spot and stagonospora leaf and glume blotch for soft red winter wheat; epidemiology, and incidence of barley yellow dwarf in wheat, and a study of the take-all fungus and the influence of seed treatments (biological and chemical) on the incidence and severity of take-all wheat under high yield management. He is also involved in the mentoring and training of graduate students.

SUE A. TOLIN – (stolin@vt.edu) Professor (1966)
(Ph.D., University of Nebraska, Lincoln)
102-A PMB Building, Glade Road Research Center

Dr. Tolin conducts research with plant viruses, with focus on the molecular biology of virus strains and host-interactions. She identifies viruses in Virginia crops (mainly soybean and other legumes) and develops control measures through breeding, management and biotechnology approaches. She has investigated several soybean mosaic virus (SMV) strains and shown, through cooperative work with plant geneticists, that resistance in soybean is mediated by at least three genes, now marked molecularly. SMV strains that overcome certain of the resistance genes, and other similar potyviruses - bean yellow mosaic, clover yellow vein, and peanut mottle - are being analyzed molecularly to characterize the pathogenicity-related sequences. She studies forage legumes and other wild plants as reservoirs for these potyviruses and peanut stunt virus in natural ecosystems. Her virology and biotechnology expertise is incorporated into the curriculum, where she teaches Plant Pathogenic Viruses in the plant disease agents series; team teaches Disease Development and Physiology; team teaches Topics in Virology; lectures on biotechnology policy, environmental risk assessment, and government regulations in several courses, and directs graduate students. She is also active in professional scientific societies in public policy affairs related to biotechnology and funding agricultural research.

HERMAN L. WARREN – (hwarren@vt.edu) Professor (1989)
(Ph.D., University of Minnesota, St. Paul)
100 Price Hall

Dr. Warren's job responsibilities involve research on diseases of corn,

extension activities on diseases of vegetables, and teaching on genetics of host-parasite interactions. He is responsible for research on disease development, epidemiology, genetics, and development of disease resistance germplasm using traditional and biotechnical methods. Current focus on pathogenicity differences between races of *Bipolaris zeicola* and on mechanism of genetic resistance of maize. International activities include Integrated Pest Management of cereal crops and host resistance in Africa and Eastern Europe. Dr. Warren directs graduate students.

KEITH S. YODER – (ksyoder@vt.edu) Associate Professor (1976)
(Ph.D., Michigan State University, East Lansing)
Winchester Agricultural Experiment Station, Winchester, VA

Dr. Yoder has a research and extension appointment in tree fruit diseases at the Virginia Tech Agricultural Research and Extension Center, Winchester. The value to the economy of Virginia in the fruit industry, including grower service groups and fruit processors, is estimated to be $150 million annually. A research-extension appointment at a field station in the leading fruit county in the state includes extensive field research. Research and extension activities are closely integrated with training graduate students and many other activities that cannot be categorized as solely research or extension.

PLANT PHYSIOLOGY

BORIS I. CHEVONE – (bchevone@vt.edu) Associate Professor (1980)
(Ph.D., University of Minnesota, St. Paul)
114 Price Hall

Dr. Chevone's research interests are to investigate the effects of air pollutants and other environmental stresses on the physiology, biochemistry, and molecular biology of plants, especially as these effects relate to agriculture and forestry in Virginia. The role of biochemical defense/repair systems in plants for providing tolerance to ozone, low temperatures, and moisture stress is of primary interest. He team teaches the Advanced Plant Physiology and Metabolism course, and directs graduate students.

CAROLE L. CRAMER – (ccramer@vt.edu) Professor (1986)
(Ph.D., University of California, Berkeley)
307 Fralin Center for Biotechnology

Dr. Cramer is responsible for research and teaching in the areas of molecular plant pathology and plant molecular and cellular biology. Her current research is focused in the following areas: 1) plant genetic engineering of enhanced disease resistance, 2) molecular and cellular basis of plant disease resistance, 3) mechanisms of subcellular targeting and protein processing, 4) protein prenylation and signal transduction in control of plant cell division, and 5) transgenic tobacco and other plants for bioproduction of novel high-value proteins for animal and human health-related applications.

CYNTHIA J. DENBOW – (cdenbow@vt.edu) Research Scientist (1981)
(Ph.D., Virginia Polytechnic Institute and State University, Blacksburg)
317 Fralin Center for Biotechnology

Dr. Denbow is involved in research and teaching in the areas of molecular and cellular biology. Her current research is focused on mechanisms of subcellular targeting and protein degradation. She is also interested in the use of transgenic plants for high-level production of human proteins.

ELIZABETH A. GRABAU – (egrabau@vt.edu) Associate Professor (1990)
(Ph.D., University of California, San Diego)
305 Fralin Center for Biotechnology

Dr. Grabau's research and teaching interests are in plant molecular biology and the application of biotechnology to agriculture and life sciences. Dr. Grabau conducts research in soybean gene expression and crop improvement. Current studies are focused on the production of low-phytate soybeans for improved phosphorus availability. One project involves the introduction of phytase gened into soybean to allow breakdown of phytate in soybean seeds. The other approach is to utilize an antisense strategy to lower the expression of a key enzyme in the phytate biosynthetic pathway. The successful production of low-phytate soybeans will decrease environmental phosphorus pollution resulting from poultry production. In collaboration with Dr. Pat Phipps, a project has recently been initiated on the genetic modification of peanut for enhanced disease resistance. Dr. Grabau's teaching responsibilities include a graduate level course in Molecular Biology for the Life Sciences and an undergraduate course in Biotechnology in Agriculture and Society.

RUTH GRENE – (grene@vt.edu) Professor (1988)
(Ph.D., University of California, Davis)
103-B PMB Building, Glade Road Research Center

Dr. Grene is responsible for research and teaching in plant physiology. Her research focuses on antioxidant molecular and metabolic resistance mechanisms of plant cells and tissues to oxidative stress. Her teaching efforts center on graduate and undergraduate education in the laboratory, the classroom, and at the level of curriculum development.

JOHN G. JELESKO – (jelesko@vt.edu) Assistant Professor (2000)
(Ph.D. University of Washington, Seattle)
304 Fralin Center for Biotechnology

Dr. Jelesko's laboratory is interested in how meiotic recombination affects the evolution and organization of the plant genome. Specifically, he is interested in the molecular details of contemporary meiotic intergenic recombination events that create novel chimeric genes and remodel the organization of complex loci. His laboratory uses transgenic synthetic gene clusters to identify rare recombinant chimeric genes. The rare recombinant chimeric genes are easily identified because they activate a

previously silent Firefly luciferase gene, thereby imparting the plant with the ability to bioluminesce in the dark. This simple genetic screen facilitates the screening of millions of plants and the identification of rare recombination events. This approach enables a detailed molecular investigation of meiotic recombination in plants and its role in the evolution of complex loci. His laboratory is interested in the various effects of intergenic recombination that include: the role of environmental factors on meiotic recombination, fidelity of meiotic recombination, chromosome rearrangements that lead to reproductive isolation, and chimeric disease resistance genes with new pathogen recognition specificities.

CRAIG L. NESSLER – (cnessler@vt.edu) Professor and Head (2000)
(Ph.D. Indiana University, Bloomington)
417 & 413 Price Hall

Dr. Nessler works on the molecular regulation of plant primary and secondary metabolic pathways. His laboratory is interested in altering the amounts and kinds of pharmaceutical compounds produced in transgenic plants as well as transferring specific pathway genes into crops to increase their resistance to disease and insect pests. My laboratory focuses on plant metabolic engineering. Projects in this area include: Manipulation of indole and opiate alkaloid biosynthetic pathways Increase of Vitamin C content in crops. Introduction of novel biosynthetic pathways into plants for disease and insect resistance. Another major focus of his group is the plant based production of vaccines.

WEED SCIENCE

SHAWN D. ASKEW - (saskew@vt.edu) Assistant Professor (2001)
(Ph.D., NC State University, Raleigh)
Glade Road Research Center (0330)

Dr. Askew's primary responsibility is to provide statewide leadership in the development of weed control programs for turfgrass. Research and extension priorities include developing weed control recommendations and information pertinent to current problems in home lawns, professional turf (golf courses, sports fields, etc.), and commercial sod and seed production. Dr. Askew works closely with Virginia Cooperative Extension agents by conducting research to address turfgrass weed problems and developing educational and training materials. He spends a significant amount of his time developing extension publications, troubleshooting, or conversing with agents, professional turfgrass personnel, and sod/seed farmers. Research efforts of his program include developing and assessing new herbicides; evaluating organic and cultural weed control options; developing new diagnostic and application technology such as weed-sensor sprayers and computerized turfgrass quality assessment tools, and monitoring the environmental effects of weed management tactics used in turfgrass. Dr. Askew also directs graduate students.

JEFFREY F. DERR – (jderr@vt.edu) Professor (1984)
(Ph.D., North Carolina State University, Raleigh)
Hampton Roads Agricultural Research and Extension Center, Virginia Beach, VA

Dr. Derr's responsibilities are to develop weed management strategies for horticultural crops and to incorporate those results into cooperative extension programs. Research objectives are to evaluate chemical and non-chemical methods for controlling major weed problems in tree and small fruit production, field and container nursery production, and landscape maintenance. Herbicide research has focused on the control of annual broadleaf weeds and yellow nutsedge in nursery production, vine and bramble control in tree fruit, and annual grass and broadleaf weed control in turf. Landscape fabrics, organic and inorganic mulches, and herbicides have been evaluated in combination to develop Integrated Pest Management strategies for landscape weed control. He participates in the Weed Science teaching program and directs graduate students.

E. SCOTT HAGOOD, JR. – (shagood@vt.edu) Professor (1981)
(Ph.D., Purdue University, West Lafayette)
418 Price Hall

The primary responsibility of Dr. Hagood is to provide statewide leadership in the development of weed control programs for agronomic crops, train graduate students, and serve as the department's Extension Project Leader. With a majority extension appointment, emphasis is placed on development of recommendations and other weed control information pertinent to current problems of Virginia farmers, and the efficient dissemination of this information. The research component of his position is closely tied to his extension activities, and involves development and evaluation of new herbicides and weed control techniques that show promise for use in Virginia agriculture. He directs graduate students.

KRITON K. HATZIOS – (hatzios@vt.edu) Associate Dean and Director of Virginia Agricultural Experiment Station and Professor (1979)
(Ph.D., Michigan State University, East Lansing)
104 Hutcheson Hall
203 PMB Building, Glade Road Research Center

Dr. Hatzios is a professor in the PPWS Department, but also serves as Director of the Virginia Agricultural Experiment Station and Associate Dean for Research in the College of Agriculture and Life Sciences. Research interests focus on mechanisms of action, metabolism, and selectivity of herbicides and herbicide safeners as well as herbicide resistance in crops and weeds. He teaches Herbicide Action and Metabolism.

P. LLOYD HIPKINS - (lhipkins@vt.edu)
Senior Research Associate/Extension Weed Scientist (1987)
(M.S., Virginia Polytechnic Institute and State University, Blacksburg)
Turf Weed Science, Glade Road Research Center

Mr. Hipkins conducts research on rights-of-way vegetation management and turf weed control. The rights-of-way research investigates various methods of weed control including cultural and chemical techniques, to provide safe, aesthetically pleasing highways. Additional research is conducted on weed control in wildflowers. Various chemical manufacturers, and the Virginia Department of Transportation sponsor this research. Turf weed control research is funded by the Virginia Turfgrass Council as well as chemical manufacturers, and involves the evaluation of products for efficacy and selectivity in turfgrass situations such as lawns, golf courses, and turf production. Weed situations in both warm and cool season grasses are investigated.

JAMES H. WESTWOOD - (westwood@vt.edu) Assistant Professor (1999)
(Ph.D., Purdue University, West Lafayette)
406 Price Hall

Dr. Westwood's program covers aspects of weed biology, physiology, and ecology. He teaches the introductory weed science course (Weed Science: Principles and Practices), and conducts research on the biology and control of parasitic weeds, specifically broomrape (*Orobanche* spp.). Current research projects include molecular characterization of host plant defense response to parasitism, genetic engineering of parasite-resistant hosts, characterization of gene expression in *O. aegyptiaca* seeds as they prepare for germination, and characterization of introduced populations of *O. minor* in the US. Dr. Westwood's research has international implications, and he collaborates closely with scientists from Israel and Mali. He directs graduate students.

HENRY P. WILSON – (hwilson@vt.edu) Professor (1967)
(Ph.D., Rutgers University, Rutgers)
Eastern Shore Agricultural Research and Extension Center, Painter, VA

Dr. Wilson's principal responsibilities are to conduct research and train graduate students in the development of weed control/weed management programs for vegetable and agronomic crops and to utilize the results to update cooperative extension programs. His goals are to understand the crop weed competitive relationships and to develop control strategies that are low in cost and that introduce the lowest possible chemical load into the environment. Major emphasis currently involves ALS-inhibiting herbicides, weed population dynamics, and weed resistance. In addition, Dr. Wilson serves as the Director of the Eastern Shore AREC of Virginia Tech.

DEPARTMENTAL SUPPORT STAFF

LABORATORY AND FIELD TECHNICIANS

SHAHROOZ FEIZABADI -(shahrooz@vt.edu) Computer Systems Engineer (1998)

Shahrooz Feizabadi provides software and hardware support for the PPWS Department on a part-time basis. Shahrooz came to Virginia Tech in 1986 as a engineering freshmen and decided to take up residence in Blacksburg after receiving his B. S. degree. He subsequently completed his M. S. degree in Computer Science and is currently pursuing a Ph.D. degree in Computer Science.

LLOYD E. FLINCHUM - (lloydf@vt.edu) Laboratory and Research Practitioner IV (1967)

Lloyd works in the Virology Laboratory at the Glade Road Research Center under the direction of Dr. S. A. Tolin, and in the Fungi Laboratory-Price Hall under the direction of Dr. E. L. Stromberg.

VANESSA FUNK - (vfunk@vt.edu) Laboratory and Research Practitioner IV (2001)

Vanessa works in the laboratory of Dr. Fabricio Medina-Bolivar in the Fralin Biotechnology Center.

CRYSTAL L. GILBERT - (clgilber@vt.edu) Laboratory and Research Practitioner IV (2000)

Crystal has a degree in Biology from Radford University and is the author of several publications. She works in the Plant Biotechnology Laboratory under the direction of Dr. J. J. Jelesko, and the Plant Molecular Biology Laboratory under the direction of Dr. J. M. McDowell. Both are located at the Fralin Center for Biotechnology.

JAIME L. HAMPTON - (jhampton@vt.edu) Laboratory and Research Practitioner IV (2001)

Jaime works in the laboratory of Dr. E. A. Grabau at the Fralin Center for Biotechnology.

NINA R. HOPKINS - (nhopkins@vt.edu) Laboratory and Research Practitioner IV (1965)

Nina works in the Plant Disease Clinic under the direction of Mary Ann Hansen, Director, and the Nematology Laboratory under the direction of Dr. J. D. Eisenback. She prepares and supervises Teaching Assistants in preparing labs for undergraduate and graduate classes, and teaches labs when necessary.

PHILIP J. KEATING - (pkeating@vt.edu) Laboratory and Research Practitioner IV (1976)

Phil works in the Turfgrass Pathology Laboratory under the direction of Dr. H. B. Couch, and in the Vegetable Diseases Laboratory under the direction of Dr. H. L. Warren. He designs and conducts experiments in the field, greenhouse, and laboratory involving evaluation and data analysis and the effects of fungicides and plant growth regulators.

CLAUDE C. KENLEY - (cckweed@vt.edu) Laboratory and Research Practitioner IV (1976)

Claude is in charge of the Weed Identification Clinic and field research for Dr. E. S. Hagood, Jr.

SUE A. MEREDITH - (sueaweed@vt.edu) Laboratory and Research Practitioner IV (1969)

Sue has a Medical Technology (MT) degree from Radford Community Hospital. She works in the Phytochemistry Laboratory located at the Glade Road Research Center under the direction of Dr. K. K. Hatzios, and in the Weed Biology Laboratory at Price Hall under the direction of Dr. J. H. Westwood.

PALMER L. PRICE - (paprice@vt.edu) Laboratory and Research Practitioner IV (1966)

Palmer works in the Turf Weed Management and the Weed Identification Clinic under the direction of Dr. E. S. Hagood, Jr., Dr. S. D. Askew and P. L. Hipkins.

JEAN A. RATLIFF - (treedr@vt.edu) Laboratory and Research Practitioner IV (1971)

Jean works in the Plant Disease Epidemiology Laboratory under the direction of Dr. A. B. A. M. Baudoin located in Price Hall, and works in the Environmental Plant Physiology/Air Pollution Laboratory under the direction of Dr. B. I. Chevone.

DIANE M. REAVER - (dianer@vt.edu) Laboratory and Research Practitioner IV (1988)

Diane has a B. S. degree from the University of Michigan (1968) and a M. S. degree in Plant Pathology from Virginia Tech (1989). She currently works as a research technician in the Fungal Plant Pathology Laboratory under the direction of Dr. G.J. Griffin.

VERLYN K. STROMBERG - (verlyn@vt.edu) Laboratory and Research Practitioner IV (1982)

Verlyn has an AA degree in Science from Fresno City College, Fresno, CA (1966), a BA degree in Bacteriology from California State University, Fresno (1968), and two years of postgraduate education in Microbiology at Oregon State University, Corvallis, OR (1968-70). She had seven additional years of technical research experience at Oregon State University in the departments of Microbiology, Horticulture, Botany and Plant Pathology. She has written several refereed journal articles, chapter proceedings, and published abstracts. She has presented scientific papers in Bulgaria, Hungary, and Blacksburg. Verlyn has attended scientific meetings in Arizona, Virginia, California, Maryland, Canada, Georgia, and Washington, DC. She works in the Phytobacteriology Laboratory under the direction of Dr. G. H. Lacy and the Stress Physiology Laboratory under the direction of Dr. R. Grene. Both laboratories are located at the Glade Road Research Center.

ELIZABETH TUCKER - (eltucker@vt.edu) Laboratory and Research Practitioner III (2002)

Elizabeth works in the laboratory of Dr. J. G. Jelesko at the Fralin Center for Biotechnology.

OFFICE STAFF

ARLETA L. BOYD - boydal@vt.edu) Executive Secretary Senior (1991)

Arleta has an Associate Decree in Business Management from New River Community College and is a Certified Professional Secretary (CPS-1985).

JUDY H. FIELDER - jfielder@vt.edu) Program Support Technician (1978)

Judy graduated from Northside High School June 1978, and earned a Professional Office Staff Development Certificate from New River Community College (1990). She serves the department as program support technician and fiscal assistant.

PATSY J. NEICE - (pneice@vt.edu) Program Support Technician Senior (1974)

Patsy has certificates in Clerk-Steno, Clerical Procedures and Basic Accounting from the College of Agriculture bookkeepers. To keep abreast of new and updated bookkeeping procedures, she regularly attends classes on campus as they are offered. She is the departmental bookkeeper and is responsible for tracking hard and soft funds.

IV. ADMINISTRATION

The department is administered through a department head, standing committees, a Graduate Student Officer, and a Staff Association Officer. Most committees have graduate student and staff representation. The graduate students have a Graduate Student Organization (GSO) with its own elected leaders and the classified staff has a Staff Association with its own elected leaders. A list of all departmental committees and their current memberships are shown in Appendix I.

V. FACILITIES

The Department uses resources housed at several locations on or near the University campus as well as locations throughout the Commonwealth.

A. PRICE HALL

The main office of the Department is located in Price Hall, which is the second oldest building on the Virginia Tech Campus, built in 1907. Administrative offices in Price Hall include the department head's office and the main offices for secretarial and bookkeeping staff. Two departmental classrooms with space for 16 and 40 students respectively are available on the fourth floor. A conference room accommodating up to 15 people is available for small meetings; larger meetings are held in the departmental seminar room on the fifth floor, which also houses study carrels and a computer room for graduate student use. Research facilities in Price Hall include the Plant Disease and Nematode Clinics and laboratories for growth regulation, plant stress physiology, turf pathology, root disease studies, nematode taxonomy, disease of resistance, epidemiology, herbicidal action, weed biology and ecology, biological control of plant diseases, biotechnology applications, and landscape tree pathology. Other facilities include a cold storage room and office space for faculty.

B. GLADE ROAD RESEARCH CENTER

Additional departmental research space is provided in permanent and temporary buildings located at a site near the Old Glade Road adjacent to the north edge of campus and about one mile away from Price Hall. The Plant Molecular Biology Building (PMB Bldg.) provides office and laboratory space for four faculty working in the areas of phytobacteriology, plant virology, phytochemistry, and plant stress physiology. An adjoining glasshouse/greenhouse facility completes the laboratory research facilities of the PMB building. The departmental laboratory for Air Pollution Impact to Agriculture and Forestry is located in the same area. This facility includes a room equipped with fumigation chambers, a computer room, a greenhouse, and several storage facilities. Finally, the Turfgrass Weed Management Laboratory, Pesticide Storage and Application Facilities and additional greenhouses are also located in this area of the department. A list of major pieces of equipment housed in the Glade Road Research Center is presented in Appendix II.

C. FRALIN CENTER FOR BIOTECHNOLOGY

The Fralin Center for Biotechnology is a university-wide facility on campus for molecular biology and biotechnology research. The laboratories of five departmental faculty with active programs in plant molecular biology are located on the second and third floor of the Fralin Center for Biotechnology. A list of major pieces of equipment housed in Fralin Center for Biotechnology is presented in Appendix II.

D. OTHER ON-CAMPUS AND NEARBY FACILITIES

Additional research, extension, and teaching facilities include the Miles C. Horton Research Center, field plots at Glade Road Research Center, and the Kentland-Whitethorne Farm, and the Turfgrass Research Center. These facilities are generally available for faculty and student members of the department and constitute a valuable resource for teaching, research, and extension missions. Additional campus facilities are listed in Appendix III.

E. OFF-CAMPUS FACILITIES

Research and extension facilities are situated at Virginia Tech Agricultural Research and Extension Centers (AREC) located throughout the State of Virginia. Off-campus PPWS faculty are working at five ARECs located at Blackstone, Suffolk, Virginia Beach, Winchester, and Painter. Faculty located at the ARECs have access to offices, laboratories, and field plots at their locations. The proximity of these field stations to the major crop production areas also affords excellent opportunities for faculty and graduate students to establish research and demonstration plots with grower-cooperators in these areas.

VI. GENERAL LABORATORY PROCEDURES

Certain faculty members have been assigned the responsibility for the coordination and use of

various laboratory and greenhouse facilities (see Appendix IV). Before a person is permitted use of a laboratory he/she must first be briefed by the laboratory coordinator on the procedures for use of equipment and supplies.

Because of the heavy use requirement of certain laboratories, it is extremely important that every effort be made to refrain from activities that serve as a source of distraction to others. Visits of a general nature should be kept to a minimum. The seminar room (Price Hall Room 503) is provided for this purpose. When playing radios, please be considerate of fellow workers.

In all cases, regardless of how pressed for time, remember to respect the rights of others who must follow in the use of the same space and equipment. The equipment and/or area must be restored to its proper condition before leaving the laboratory.

In order to minimize the possibility of loss of equipment or disruption of work in progress, it is important that all unattended laboratories be locked. When leaving a laboratory that will then be unattended, LOCK THE DOOR! This should be done even if you are only to be absent from the laboratory for a short while. If you find persons in a laboratory at any time whose presence is questionable, their names should be reported to the laboratory coordinator or the department head. Finally, when leaving a laboratory, if you question as to whether or not the laboratory should be locked --- LOCK IT!

VII. ACADEMIC PROGRAMS

A. INTRODUCTION

The Department of Plant Pathology, Physiology and Weed Science (PPWS) offers graduate programs leading to the M.S. (thesis and non-thesis) and Ph.D. degrees. The M.S. degrees offered by the department are part of the M.S. in Life Sciences program. The department also participates in interdisciplinary graduate programs in Plant Physiology (IPPP), Genetics, and Molecular and Cell Biology, and Biotechnology (MCBB). Depending upon the degree of preparedness, M.S. programs usually require two to three years while a Ph.D. program may require four or more years beyond the B. S. degree.

Although PPWS is primarily a department offering graduate degrees, undergraduate service courses are taught for students in other departments within the College and the University. Commitment to undergraduate instruction has been and continues to be, a major portion of the instructional effort of the faculty and students in the department. In recent years, several faculty have been advising undergraduate students in the Biology and CSES departments. In addition, they teach undergraduate courses offered by the Biology and Forestry Departments and the Agricultural Technology Program of Virginia Tech.

Graduates of our programs are prepared for careers as professional plant pathologists, plant physiologists, weed scientists, or plant biotechnologists. Occupational opportunities are available in research, teaching, or extension at colleges and universities; in regulatory or research activities with state and federal governments; in

administration, sales, research, or product development in agribusiness and agrichemical or biotechnology industry; or in private consulting.

Appendix V lists the PPWS graduate students enrolled in the fall 2002 semester, along with information about the graduate degree sought, specialty area, and major professor.

B. THE ADMISSION PROCESS

To be admitted to the graduate program, a formal application must be submitted to the Graduate School. Applications can be submitted electronically or by hard copy. The application form can be found on the Research and Graduate Studies web page (http://www.grads.vt.edu). Successful completion of chemistry, physics, mathematics, botany, microbiology, soils, and genetics at the undergraduate level are required for entry level graduate students. Qualified students with prerequisite deficiencies can be admitted on a *provisional status* with the understanding that deficiencies are satisfied. Such courses will **not** carry graduate credit. Plant science courses beyond introductory botany (e.g., plant anatomy, taxonomy, plant pathology, plant physiology, biochemistry or molecular biology) are highly desirable.

Screening graduate applications is initiated by the departmental Graduate Officer (Appendix VI) who determines the applicant's area of interest and matches it with faculty members within the Department whose expertise lies within the applicant's area of interest. The application is reviewed by the faculty and returned to the Graduate Officer for further processing. The Graduate Officer makes a recommendation to the Department Head to accept or reject an application. The Department Head notifies the Graduate School of the decision to accept or reject the application. The Graduate School notifies the applicant by letter of the final decision.

In evaluating new graduate applications, four major areas are considered: 1) a grade point average (GPA) of 3.0/4.0 or higher, 2) three letters of recommendation, 3) performance on the Graduate Record Exam (the general aptitude portion of the GRE is required and a score of 1000 or better is considered acceptable for most students), and 4) the motivation of the student for undertaking graduate studies. Deficiencies in any of these areas do not necessarily eliminate a student from consideration. Letters of recommendation and the previous academic background of the student are very important considerations in the review process. Foreign students are required by the Graduate School to take the Test of English as a Foreign Language (TOEFL). A score of 600 (or 250 on the new computer-based system) or above is acceptable by the PPWS Department.

C. NON-DISCRIMINATION STATEMENT

The Department of Plant Pathology, Physiology, and Weed Science abides by the University's non-discrimination statement indicated below.

Non-discrimination statement

Virginia Tech does not discriminate against employees, students, or applicants because

of race, sex, disability, age, veteran status, national origin, religion, political affiliation, or sexual orientation. The university is subject to Titles VI and VII of the Civil Rights Act of 1964, Title IX of the Education Amendments of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, the Americans with Disabilities Act of 1990, the Age Discrimination in Employment Act, the Vietnam Era Veterans' Readjustment Assistant Act of 1974, the Federal Executive Order 11246, Virginia's State Executive Order Number Two, and all other rules and regulations that are applicable. Anyone having questions concerning any of those regulations or accessibility should contact the Equal Opportunity and Affirmative Action Office, 336 Burruss Hall, Blacksburg, Virginia 24061-0216, (540) 231-7500, TTY (540) 231-9460.

VIII. CURRICULA

A. SUMMARY OF DEGREE PROGRAMS

The department offers programs leading to the Master of Science (M.S.) degree and a doctoral program leading to the Doctor of Philosophy (Ph.D.) degree. Graduate programs offer training in applied and/or basic plant pathology, weed science, plant physiology, and plant biotechnology through a combination of graduate courses, research programs, and teaching experience. Teaching experience of one semester for the M.S. and two semesters for the Ph.D. is required. Research is the most important part of the graduate learning experience. Thesis or dissertation research topics are designed to familiarize students with applied or knowledge-driven basic research and provide them with maximum opportunity to use contemporary techniques and instrumentation.

Each student, in consultation with a major advisor and advisory committee, plans an individual program of study, which must be approved by the student's advisory committee. Core and supporting courses will vary according to the student's background and area of desired specialization. Research opportunities for graduate education in each departmental discipline are currently available in the following areas: **plant pathology** (disease physiology; disease epidemiology; ecology of root diseases; genetics of host-parasite interactions; phytobacteriology; plant virology; nematology; mycology; biological disease control; fungicide-plant-soil interactions; disease control in major crops; integrated disease management), **weed science** (weed biology and ecology; parasitic weeds; weed management in major crops; adjuvant technology; herbicide-action; herbicide metabolism; herbicide-resistant crops and weeds; integrated weed management), **plant physiology** (plant growth regulation; plant stress physiology; air pollution damage to plants), and **plant biotechnology (**plant genetic engineering for disease, stress, and herbicide resistance; mechanisms of subcellular targeting and protein processing; bioproduction of human therapeutics in transgenic plants; plant genetic engineering for improving nutrient availability in animal diets and reducing environmental phosphorus pollution; regulation of plant gene expression).

B. MASTER OF SCIENCE DEGREE

1. Master of Science (M.S.) in Life Sciences

The Master of Science in Life Sciences merges the efforts of the departments of Biochemistry, Entomology, Food Science and Technology, and Plant Pathology, Physiology, and Weed Science. Students in basic and applied disciplines in the College of Agriculture and Life Sciences share common experiences that prepare them for careers in which interdisciplinary interactions become increasingly valued. At the same time, discipline-specific education and research experience, which characterizes the M.S. in Life Sciences program in each department, prepare students for unique positions and career development.

One feature of this degree program is the requirement to complete a core of three courses, one each in biochemistry (BCHM 5124 - Biochemistry for Life Sciences), statistics (STAT 5605 - Biometry or STAT 5615 - Statistics in Research), and information technology (ALS 5984 - Information Systems in the Life Sciences). Options to fulfill the remaining requirements for the program of study are available and they are different for the three main disciplines of the department (Plant Pathology, Plant Physiology and Weed Science). Appendices VII, VIII, and IX present Graduation Analysis Check Lists for an M.S. Degree in Life Sciences with options in Plant Pathology (Appendix VII), Weed Science (Appendix VIII), and Plant Physiology (Appendix IX).

2. Non-Thesis M.S. Program

A non-thesis M.S. Degree in Life Sciences with options in Plant Pathology, Physiology or Weed Science is available. Students pursuing a non-thesis M.S. in Life Sciences should take the three core courses listed earlier (biochemistry, statistics, information technology), and a number of approved electives as well as an internship or equivalent project.

C. DOCTOR OF PHILOSOPHY (Ph.D.) DEGREE

1. Ph.D. in Plant Pathology

Minimum requirements for a Ph.D. degree in Plant Pathology are given in Appendix X. The curriculum requires a strong undergraduate background in basic science, biology, and mathematics. Courses in the biology of plant pathogenic agents, interaction with their hosts, disease control and basic botanical skills are required of Ph.D. candidates. In addition, the Ph.D. degree requires a firm grounding in the theoretical concepts of plant pathology, including epidemiology, genetics of host-parasite interactions, and physiology of pathogenesis.

a. Core courses for Ph.D. students

Two semesters of course work (PPWS 5114, 5124, 5134, and 5144, covering plant pathogenic prokaryotes, viruses, fungi, and nematodes) in the study of plant pathogenic agents, their biology, and how they damage plants, constitute the basis for contemporary Ph.D. studies in Plant Pathology. The laboratory sections allow each student to sample in a hands-on fashion, many basic and applied research

techniques used in all facets of Plant Pathology.

In addition, students are required to take Principles of Plant Disease Management (PPWS 5204), and Clinic and Field Experience (PPWS 5034). Other course and seminar requirements are outlined in Appendix X

b. Conceptual courses required of Ph.D. students

Ph.D. students are required to take a group of courses offered in alternate years that stress theoretical concepts of Plant Pathology, namely PPWS 6004 Plant Disease Epidemiology and Genetics of Resistance and PPWS 5454 Plant Disease Physiology and Development. These courses are taken by students who are concurrently enrolled in or who have completed the introductory core of courses stressing the biology of the agents of disease and their interactions with host plants (PPWS 5114-5144), and disease control (PPWS 5204). With this strong background in the biology and control of plant diseases, advanced students will be well prepared to understand and apply theoretical concepts of plant pathology.

c. Other courses available as electives

Several courses in our department are available to students in Plant Pathology as electives including Weed Science - Principles and Practices (PPWS 4754); Pesticide Usage (PPWS 4264); Plant Growth and Development (PPWS 5654); Herbicide Action and Metabolism (PPWS 5754); and Topics in Virology (PPWS 6654).

2. Ph.D. in Weed Science

Minimum requirements for a Ph.D. degree in Weed Science are given in Appendix XI. During the past four decades, weed science has been established as a well-defined and recognized academic discipline within the general area of plant protection complementing the older disciplines of entomology and plant pathology. Today, most land-grant universities in the United States offer graduate studies in weed science. However, in many cases, weed science is not offered as a separate curriculum and many graduate students specializing in weed science have their degrees awarded in the field of agronomy, botany, horticulture, forestry, plant pathology, or soil science. At Virginia Tech, graduate students specializing in weed science have their degrees awarded in weed science. Core courses in weed science include: Pesticide Usage (PPWS 4264); Weed Science Principles and Practices (PPWS 4754); and Herbicide Action and Metabolism (PPWS 5754). Additional required courses and other minimum requirements for the Ph.D degree in Weed Science are appended (Appendix XI).

3. Ph.D. in Plant Physiology

Minimum requirements for a Ph.D. in Plant Physiology are given in Appendix XII.

D. INTERDEPARTMENTAL CURRICULA

Several interdepartmental curricula in which PPWS faculty members and students participate have been established in recent years. These curricula serve as vehicles to coordinate and unify course offerings across departmental boundaries. Faculty who participate in these curricula continue to have appointments in their respective departments, and are responsible for normal advising of graduate students as well as serving on student advisory committees within the curriculum. Students in these curricula major within any of the participating departments and meet a set of requirements designated by the respective curricula outlined below or in the Graduate Catalog of Virginia Tech.

1. Plant Physiology

The departments of Crop and Soil Environmental Sciences, Biochemistry, Biology, Forestry, Horticulture, and Plant Pathology, Physiology, and Weed Science participate in the Interdepartmental Plant Physiology Program. This curriculum brings together elements of instruction and research that already exist and function within the University. A brief description and a listing of participating faculty are given in the Graduate Catalog.

The individual departments listed above offer graduate studies leading to the Ph.D. degree. There are many specialized areas of plant physiology within these departments. Current areas of strength include:

-Molecular biology
-Enzymology
-Growth regulation
-Herbicidal action and metabolism
-Photosynthesis and photorespiration
-Physiological interrelations of higher and lower plants
-Physiology of disease
-Regulation of metabolism
-Stress physiology
-Physiological ecology

Additional information may be obtained from the program's chairman, listed in the Graduate Catalog.

2. Molecular Cell Biology and Biotechnology (MCBB)

Much of contemporary research in the life sciences is rapidly taking on a new and unified face. New techniques in biochemistry, cell biology, immunology, and molecular genetics make possible the purification, mutation and reintroduction of modified proteins into cells. Practitioners of fields once considered far distant from each other can and do use these molecular cell biology approaches and now speak the same technical language. This integration of fields should be reflected in the curriculum. The option exposes students to a foundation in molecular cell biology.

3. Student requirements for MCBB Program

a. The student's participation in the option must be indicated by completing the participation form and approved by the major professor.

b. Students must satisfactorily complete the following courses:

1. Molecular Biology of the Cell (BCHM 5214)
2. Molecular Biology for the Life Sciences (ALS/PPWS 5344; Prerequisite: Biochemistry for the Life Sciences-BCHM 5124 or equivalent).
3. Seminar in Molecular Cell Biology and Biotechnology (PPWS 5064). Ph.D. students must present an MCBB seminar prior to graduation.
4. Topics in Molecular Cell Biology and Biotechnology (a rotating topics course, ALS/PPWS/BIOL 6024). Expected topics include plant disease resistance, molecular biology of photosynthesis, organelle assembly, and the molecular basis of stress resistance.

For additional requirements, see the Graduate Catalog.

A list of additional courses offered by the various departments is given under the Molecular Cell Biology entry in the Graduate Catalog.

E. COURSE AND INSTRUCTOR EVALUATION PROCEDURES

All courses and instructors in the College of Agriculture and Life Sciences are evaluated by a computer analyzed questionnaire titled Student Perceptions of Instruction distributed by the College Dean of Resident Instruction. Each class and instructor is evaluated each semester that he/she teaches except when a class is taught more than once during the academic year. The completed questionnaire is returned to the Office of the Dean, and the results are statistically analyzed and reported back to the Dean. The Dean returns the results of the evaluation to the department. The department head counsels each faculty member regarding the results. The original questionnaire is returned to the instructor along with a computer analysis of student response. Teaching Assistants (TAs) are evaluated using the same College questionnaire as the faculty. In addition, faculty members responsible for courses in which teaching assistants participate also evaluate the performance of the TA.

The department also conducts a peer review of course content and instructor performance. The purpose of the peer review is 1) to improve the quality of teaching, 2) to aid the promotion and tenure process, and 3) to serve as the basis for providing nominees for teaching awards.

IX. IMPORTANT ACADEMIC POLICY STATEMENTS

A. GRADUATE STUDENT ADVISORY COMMITTEE

Each graduate student will develop a graduate committee with the aid of his/her advisor.

Committees for M.S. students require **at least** three members; **at least** five members for Ph.D. students.

The committee aids the student in planning a program of study and in determining research direction, and administering the preliminary and final examinations. The student should select an advisor and a committee as soon after arrival as possible so that the program of study and research direction can be determined quickly. A student's committee must meet **at least** once a year, and the advisor must **report by letter** to the department head, concerning the discussions and actions taken at the meeting. The Graduate School publishes the **Graduate Policies and Procedures and Graduate Catalog** that contains important information relative to programs of study, committee structure, theses and dissertation preparation and other information of value to your academic training. **READ THIS THOROUGHLY!!!**

The graduate student, in consultation with his or her advisor, selects the faculty who will serve on the advisory committee. Faculty who serve on advisory committees are expected to have scientific expertise that will help the student complete his or her degree requirements. They are also expected to participate in one or more meetings each year, and respond in a positive manner to the student's request for assistance on his or her research. The committee member is expected to read and evaluate a student's program of study, thesis or dissertation outline, and annual progress reports. Evaluation of the service and contributions of advisory committee members is made on an on-going basis by the student's advisor in his letter to the department head and on the student's Annual Progress Report (Appendix XV), which is reviewed and signed by each advisory committee member. During the final exit interview between the student and the department head, the service and contributions of the advisor and the advisory committee members will be fully evaluated. Additionally, the student is encouraged to meet with his or her advisor and/or department head concerning advisory committee member performance. The student may consult the department head or graduate officer if he or she has concerns about his or her advisor.

For more information on the mentoring process of graduate education and on how to make the most of graduate school, please read the articles written by Dr. R. Jay Stipes and Dr. John Eaton, respectively. These are placed at the end of this handbook.

B. PLAN OF STUDY

Each student, in consultation with his major advisor and advisory committee, plans an individual program of study, which must be approved by the student's advisory committee. Core and supporting courses will vary according to the student's background and area of desired specialization. Core courses and minimum requirements for the three options under the M.S. Degree in Life Sciences and the doctoral programs in Plant Pathology, Plant Physiology, and Weed Science are presented in Appendices VII-XII. The plan of study **must** be approved by the student's committee, the head of the department, and entered electronically for approval by the Graduate School before February 1 for students entering Fall Semester, **or** before the completion of 15 credit hours.

C. THESIS/DISSERTATION RESEARCH PROPOSAL

All graduate students in the Department of Plant Pathology, Physiology and Weed Science who are enrolled in the thesis or dissertation research options, are **required** to place a thesis or dissertation proposal in the departmental student files **before** the end of the second semester of matriculation. The proposal shall contain:

1. **A Research Proposal Title Page** (Appendix XIII)

2. **Research question(s) and/or objective (hypothesis):** brief outline of research questions to be addressed and/or the objectives (hypotheses) which are to be determined or tested.

3. **Justification:** provide enough justification in the form of a literature review, etc. to lead to your research question(s) and/or the objective or hypothesis to be tested.

4. **Procedures:** present sufficient procedural information to insure that a professional scientist in your area of research will be able to understand the procedures; indicate the research methods to be employed, the statistical methods to be utilized, and any other information which will help in the evaluation of the procedures.

5. **Facilities** and **equipment** required.

6. **Literature cited:** list all literature; include a complete literature citation.

7. **Timetable:** sequence of experiments and estimate of time required for completion.

The exact length, format, and depth of the thesis or dissertation research proposal are dependent upon the needs of the graduate student and the student's committee. Sufficient information should be presented in the proposal to warrant the approval of all the committee members as well as the department head.

The preparation of the thesis/dissertation research proposal in a form appropriate for submission to a granting agency such as NSF, NIH, USDA competitive research grants program and Virginia Agricultural Foundation is **strongly** recommended.

D. STUDENT SEMINAR POLICY

The Department of Plant Pathology, Physiology, and Weed Science sponsors a weekly Departmental Seminar Series as a regularly scheduled graduate class. All students are **required** to participate in this course. In addition, there are other seminar series and special seminars supported by the departmental faculty and students. They provide an avenue for bringing the latest techniques and philosophy of science to the group. Student participation encourages development of professional skills in communication and is viewed as an opportunity to explore in depth, specific areas in scientific literature. Faculty and students are placed in a situation of constructive interaction at these presentations.

The following comments are intended to set **minimum** student requirements as well as other information regarding the administration of the departmental series and the coordination of other seminars.

1. M.S. students will present **one seminar for credit** and **one terminal or leaving seminar**; Ph.D. students will present **two seminars for credit** and **one terminal seminar.** Students with prior M.S. degrees may transfer seminar credits if desired; however, this will not reduce the number of seminars they are required to give during their Ph.D. program.

2. Seminar sign-up will be held each spring for the following academic year**. Seminars for credit should be included in the student's plan of study;** flexibility must be allowed as to actual dates involved.

3. Seminars will be offered on a grade (A-F) basis. For seminars given in other series (see item 5), the grading policy of the series will be accepted. Grading, approval of seminar titles, and administration of individual seminar classes will be the responsibility of the seminar instructor.

4. There are two types of seminars that a student may present: a literature review seminar or a research proposal seminar. A research proposal seminar may be presented as a student's first seminar, but not later than **third** semester in residence. This seminar includes an in-depth literature review, statement of objectives, justification and a proposed experimental plan.

   A literature review seminar is designed to encourage students to explore areas distinctly different from their planned programs; this seminar usually concerns a subject that does not involve research in the immediate area of the speaker's thesis or dissertation research.

5. Ph.D. students are permitted to give one required seminar in an interdepartmental seminar series (Plant Physiology, Molecular Cell Biology, etc.), provided that PPWS requirements (advance notification, abstract distribution, evaluation, etc.) are fulfilled. M.S. students will present all required seminars in the PPWS series, but may elect to give additional seminars in other series.

6. The departmental seminar coordinator, who is appointed by the department head, coordinates all seminars. The coordinator arranges the seminar schedule and keeps record of all seminars given, including all abstracts. S/he, in consultation with the Education Committee or a designated Seminar Committee, will review and develop policy for administration of the program for consideration by the departmental faculty.

7. Non-credit seminars (student terminal seminars, visiting faculty, resident faculty, and postdoctoral seminars) will be coordinated through the department head.

8. All M.S. (thesis and non-thesis) and Ph.D. students are required to present a seminar on their project or research as a requirement for graduation. This seminar will be

considered part of the final thesis or dissertation examination, and will be given **no more than two weeks prior** to the examination or defense date. **No graduate program will be sent to the Graduate School as complete without a terminal seminar and examination**. The date and time of the examination by the advisory committee must be publicized in a way that affords all interested faculty the opportunity to attend the examination. As with other seminars, an **abstract must be distributed five working days prior to the oral presentation.** (See Appendix XIV for additional information regarding seminars).

E. TEACHING/COMMUNICATION REQUIREMENT

Communication skills are an important asset to all professionals in the fields of plant pathology, plant physiology, and weed science as well as teaching and extension professionals. Students in PPWS can develop their oral communication skills by the presentation of seminars and research papers; however, exposure to other aspects of communication is also needed. The primary objectives of the teaching/communication requirement are to provide students a meaningful experience, and to enhance their ability to compete in the job market.

Regardless of support, all students in the Department of Plant Pathology, Physiology, and Weed Science are **required** to participate in some approved communications project. Students are also **required** to have one teaching/communication project for a M.S. program and two for a Ph.D. program.

Normally, this service will consist of teaching or participating in teaching, in a classroom situation. Each student will participate in this type of service for **at least one semester.** In recognition of the diverse backgrounds of students and their personal needs, alternative experience may be substituted for a second semester of classroom teaching.

Alternative experiences may include:

- designing one or more lab experiments
- designing and developing teaching aids such as slide sets, audiovisual packages, etc. for use in class or outside classes (e.g. extension agent education)
- instructing fellow students in particular skills (e.g. photographic techniques)

Each student will make a 'public' presentation or demonstration to fulfill the 'communication' aspect of the requirement.

Students who prefer an alternative assignment must announce such preferences at the time of the spring survey (see below) or earlier. They should consult with their major advisor and the faculty members supervising the project. The alternative proposal must be reviewed by the Education Committee and approved by the department head before work is begun. The project supervisor will review and evaluate the completed project before credit may be given.

In the spring of each year, the Education Committee will survey faculty with respect to

teaching needs, and students with respect to course and assignment preference as well as scheduling preferences for the following academic year. Where appropriate, students should consult with their advisors and with the course instructor involved. Based on this survey, assignments will be made before the start of the fall semester. Two or more students can share teaching assignments that are particularly demanding. New students are generally not required to teach in the first semester of their program; however, they may elect to volunteer. All students are assigned to a faculty member. This faculty member should work with the student to ensure that he/she learns the various aspects of the teaching process, and include observation of the student's teaching ability in the classroom in order to provide constructive criticism. Upon completion of the assignment, the faculty member will write a brief evaluation for the student's file.

F. GRADUATE STUDENT EXAMINATION PROCEDURES

All M.S. students majoring in Plant Pathology, Plant Physiology, Weed Science or Plant Protection are required to take a **final oral exam** administered by his/her committee at the completion of the Thesis, Project and Report, or Internship. The exam is usually administered during a half-day session (approximately 4 hours) and could cover all aspects of the student's academic training including course work and defense of the thesis or Project and Report **(see Policies and Procedures Section in the 2001-2003 Graduate Catalog).** In addition, students will present a **final seminar** (see Student Seminar Policy, Section IX-D of this handbook).

Ph.D. students are required to take a **preliminary exam** (both oral and written) at least 9 months prior to graduation with at least **one-third** of the required course work or research still remaining **(see Graduate Catalog)**. This examination will focus on the student's academic preparation. The written portion of the exam is administered **prior** to the oral portion. The oral portion of the exam is usually administered during a four-hour session. Students are **required** to take a final **Oral Exam** and **present a defense seminar** (see Student Seminar Policy, Section IX-D of this handbook).

G. YEARLY EVALUATION OF PROGRESS

It is a **requirement** of the department and the Graduate School that each graduate student be evaluated on an annual basis. To accomplish this, the department has developed an evaluation form (Appendix XV and XVI). Each committee member, the major professor, and the student should sign the completed form and return it to the graduate officer or the executive secretary by **December 1** of each year of residence. New students entering their program of study in the fall semester of a given year should submit a yearly progress report by **February 1,** during their second semester of residence.

The purpose of the annual review is to ensure that the student is making sufficient progress toward fulfillment of degree requirements. The information provided in the review form is also beneficial in selecting students for fellowships, tuition waivers, and awards. Letters of recommendation and news releases are also written from such information.

Noncompliance of the December 1 or February 1 deadline could result in academic suspension and/or the termination of financial assistance until the requirement is met. If any unforeseeable problems arise, please contact the graduate officer before the deadline date and he/she will be glad to assist you. **Your cooperation in fulfilling this requirement is very important.**

The department holds an orientation meeting at the beginning of Fall Semester to acquaint graduate students with the policies described above.

H. THESIS AND DISSERTATION

The Master's Thesis is a written report resulting from a research project conducted under the guidance of a faculty advisor. The Thesis option for a M.S. degree provides more opportunity for in-depth work in a specific topic or application than would be possible under the non-thesis option. The final examination includes a presentation of the thesis and response to questions (thesis defense).

The centerpiece of the Ph.D. degree is the dissertation. Under the guidance of a faculty advisor (major professor) and an advisory committee, the doctoral candidate engages in a major research project. The dissertation itself is the written document, following professional standards, resulting from the research project. Through his/her dissertation work, the doctoral student moves beyond the relatively passive role of receiving knowledge presented in courses to become an active, self-motivated scholar, making a significant contribution to their area of specialty. The work of the dissertation is expected to be of such quality as to merit publication in a scholarly journal, after appropriate revisions. For those continuing in academic research, the dissertation topic may initiate a more lengthy research program that forms the beginning of a scholarly career. For those who continue in a nonacademic direction, the dissertation experience is valued because it requires the highest level of creativity and independent thinking. When the dissertation research and writing are completed, a doctoral candidate must defend his research at a final oral examination (dissertation defense). The final examination is open to the entire faculty of the university, and questions may be asked that do not pertain directly to the dissertation being defended.

Virginia Tech requires graduate students to submit their thesis or dissertation electronically. For instruction, see **http://etd.vt.edu.**

I. EXIT INTERVIEW

To help the department continue to strengthen its programs, each graduate student is asked to complete an exit interview with the department head.

X. ADDITIONAL INFORMATION AND POLICIES

A. PPWS GRADUATE STUDENT ORGANIZATION

The Graduate Student Organization (GSO) for the Department of Plant Pathology, Physiology and Weed Science began during the summer of 1979. The GSO is a service

organization whose function is to help the graduate student with his/her educational needs. The objectives of this organization include: 1) developing programs to assist graduate students in orientation and in their studies and research; 2) facilitating communication between graduate students and the department head, between graduate students and faculty, and among graduate students themselves; 3) fostering professional and social development of the graduate student; and 4) formalizing the selection of graduate students for participation in departmental and University activities. The GSO Officers are listed in Appendix I.

1. Membership

a. All graduate students of the Plant Pathology, Physiology, and Weed Science Department are members of the organization.

2. Meetings

a. General meetings of the GSO are held each semester and as necessary.

b. All meetings are open to the faculty.

c. Meeting announcements are made to all graduate students and faculty.

d. Decisions are made by majority vote of graduate students present at a general meeting, or by a majority vote of graduate students conducted through a paper ballot distributed to all graduate students.

3. Officers

a. Officers are elected each spring at the general student meeting.

b. Officers are listed in Appendix I

B. DEPARTMENTAL KEYS

Each student will be issued keys to areas where continuous access is needed. The professor in charge of lab areas must authorize permission for issuance of such keys to others outside his/her organization. Each lock in the building has a specific code number and keys are coded according to the lock and sequentially numbered. Each key is issued by the sequential number and logged into the system with that individual's name corresponding to the key number issued to them. **Keys are issued to individuals for their exclusive use only, and must not be shared with others.** At the completion of your studies at Virginia Tech, all keys must be returned to the main office **prior** to leaving the campus. A strict accounting of the keys issued to each student is kept; loss of any key should be reported immediately to Arleta Boyd, Executive Secretary. PPWS students housed in the Fralin Center for Biotechnology are issued keys according to the policies of the Center Students working in labs at the Glade Road Research Center are issued keys by the lab supervisors (PMB Building) or by Arleta Boyd.

C. GRADUATE OFFICE SPACE AND USE OF SEMINAR ROOM

Each graduate student may be assigned a desk in Room 503-C Price Hall on a first-come, first served basis. The GSO officers coordinate these assignments. All students have a mail box in 410 Price Hall which should be checked daily. Shelves for books and file space may be shared; bringing in personal bookcases is not advised. Please feel free to use the seminar room for chatting with fellow graduate students and faculty; however, refrain from using offices for idle conversation. Do not leave food lying around for any length of time. The Department of Entomology gives cockroaches a happy home on the third floor, but they do have a tendency to wander if tidbits are left lying around to attract them. **Please clean up after yourself when you use the seminar room tables and sink area.**

D. STUDENT E-MAIL AND PPWS WEB SERVER ACCOUNTS

E-mail accounts can be activated through the Tech Connect office located on the second floor of Newman Library. Bring your Hokie Passport and assigned personal identification (PID). Redistribution of lost passwords and off-campus access to the VT modem pool can be arranged at the Tech Connect office.

PPWS students are encouraged to maintain a personal web page on the departmental web server. The web server user ID request form is located in Appendix XVII or on the Internet at the following address: ***http://oak.ppws.vt.edu/~shahrooz/userid.html.*** The PPWS web server is governed by the Policy on Acceptable Use of Information Systems at Virginia Tech. The policy can be found on the Internet at the following address: ***http://www.vt.edu/administration/policies/acceptableuse.html.*** Please read the policy and be sure to understand all its implications.

Contact Shahrooz Feizabadi via e-mail (*shahrooz@vt.edu)* or campus mail (0331) if you would like to have an account on the departmental server. He will process the paperwork and put a copy back in your mailbox.

E. ACCESS TO DEPARTMENTAL COMPUTERS

The department provides one or more departmental computers for use by the graduate students at each of three locations, which include Price Hall (5th Floor), Glade Road (Room 203) and Fralin Center for Biotechnology building (3rd Floor). In addition, students have access to departmental or faculty computers located in the laboratories of their advisors. Arrangements for the use of these computers must be made in advance by the students and their advisors.

F. POLICY FOR USING POSTER PLOTTER

1. The plotter is located at the main office (413 Price Hall) of the PPWS Department and is available for use by PPWS faculty, students, and staff for academic and scholarly projects. Personal projects should be pursued through commercial outlets (e.g., Kinko's).

2. Departmental members wishing to use the plotter should make arrangements in

advance by contacting Peter Sforza (231-1867; psforza@vt.edu or Shahrooz Feizabadi (231-4161; shahrooz@vt.edu). The plotter can be used for printing with either Mac or PC computers.

3. To cover the high cost of paper and cartridges, a nominal fee of $8.00 per linear foot is charged for paper used; this includes trial and/or erroneous runs. Please make sure that all mistakes have been corrected and that the set-up of your poster is acceptable before you use the poster plotter.

4. Arrangements for paying the minimal use charge should be made with Patsy Neice 412 Price Hall). Payments can be made with an ISR at the time of printing. ISRs should be given to Patsy Neice.

5. For further information or any questions, please contact Peter Sforza at 231-1867.

G. VEHICLE USE POLICY

The vehicles maintained by the department include general-use trucks as well as trucks assigned to specific programs. In general, use and maintenance of the assigned vehicles is the responsibility of the faculty involved.

Make sure you are a **qualified driver** before using any departmental vehicle. Qualifications include valid Virginia operator's license **and** University employment (faculty, permanent staff, or graduate assistants). **Hourly or other temporary employees may not drive these vehicles.** Contact your major advisor for use of departmental trucks.

H. GREENHOUSE POLICIES

The following policies apply for general use of departmental greenhouses, i.e., House 4 A, B, and C, and 9A and B in the 'main' complex on Washington Street. Several other greenhouses are used for specific research areas, e.g., Air Pollution (Chevone), Weed Science (Askew, Hagood, Hatzios, Hipkins, Westwood) and Molecular Biology (Grene, Hatzios, Lacy, Tolin).

1. Maintenance

Every greenhouse user is expected to do his/her own soil mixing, planting and **cleanup**, including washing pots and flats. All watering during the week and on weekends is the individual's responsibility. General pesticide application of the greenhouse will be carried out on Fridays after 4:00 p.m. Users should **avoid** entering the main greenhouse after 4:00 p.m. on Fridays because fumigation may be carried over into the PPWS greenhouse or adjacent greenhouses. Generally however, pest problems that develop on materials are the individual's responsibility. It is important that everyone keep his/her plants insect-free to avoid infesting other plants in the greenhouse. Pesticides should be applied Monday through Thursday after 5:00 p.m. Signs **must** be posted at both ends of the greenhouse range to notify others that pesticides are being applied.

Trash (plant and soil materials, paper, and plastic) **must** be dumped in the dumpster next to greenhouse 9 (main complex). All materials placed in general use or non-assigned space (for example, under the mist), must be clearly labeled with the owner's name. Materials without labels will be considered abandoned. **No personal property (house plants) may be kept in University greenhouses.** Any questions and/or requests of a technical nature should be directed to the Greenhouse Coordinator, Dr. Herman L. Warren.

2. Space assignment

Greenhouse space assignments will be made by the Greenhouse Coordinator, Dr. Herman L. Warren, and is based on faculty requests. Students must request needed space through their major advisor. The time period needed should be indicated. Plant material, soil, and trash must be put in the dumpster.

I. PHOTOGRAPHIC/COMPUTER EQUIPMENT AND FACILITIES

The photographic equipment coordinator is Dr. Jonathan D. Eisenback. A system for computer-generated slides and a film recorder for making 35mm transparencies from Powerpoint presentations, TIF, or PICT files is available in Room 101G. Ektachrome 100 (daylight) film should be used for making transparencies on the film recorder. **These facilities are available for use by PPWS faculty. However, graduate students can use the facility under the guidance the equipment coordinator.** Dark room facilities are available at the PMB building at Glade Road and the Fralin Center for Biotechnology. Certain types of cameras and video equipment are also available for use by graduate students in preparing seminars and conducting research. In addition, all extension faculty and most of the research and teaching faculty have 35-mm and digital cameras under their control and in some cases, available for their students to use.

J. USE OF DEPARTMENTAL COPY MACHINES

The use of the copy machines is generally restricted to faculty and staff only. Personal copies of journal articles, etc. are prohibited. See Patsy Neice for information about acceptable use of and charge for copy services. Graduate students can "buy" the use of the copy machine for their individual use.

K. SUPPLIES, TYPING, AND AUDIOVISUAL EQUIPMENT

Office supplies are not issued to graduate students or faculty. Research supplies must be cleared with your research project director, i.e. field notebooks, data pads, etc. Supplies for seminar preparation should be cleared with the Seminar Coordinator.

Audiovisual equipment must be checked out via the Projector Sign-out Folder. See Patsy Neice if you have questions. Equipment must be picked up before 5:00 p.m. for evening and weekend use. Individuals who check out audiovisual equipment are directly responsible for loss or negligent damage.

Graduate students are responsible for typing manuscripts used to complete thesis/dissertation requirements.

L. USE OF TELEPHONES AND FAX MACHINES

Departmental telephones where available, **DO NOT** provide access to long distance lines, and are for business and professional use only. Long distance business calls should be arranged through your major advisor; personal calls should be limited. **DO NOT** make any unauthorized personal and/or long distance calls on any university telephone. Telephones are available in the graduate student area, 5th floor, Price Hall, and in some departmental laboratories.

Fax machines are available at all three locations of the department (Price Hall, Glade Road Research Center, and Fralin Center Biotechnology). Students are allowed to receive fax messages at these machines. To send business fax messages through our departmental fax machines, students must arrange to have access through the appropriate clerical staff or your major professor.

M. DEPARTMENTAL BOOK COLLECTION

A general collection of books is maintained in the Seminar Room (Room 503 Price Hall). Books may be checked out for use by faculty, staff, and students in PPWS only. Books are not available for use by outsiders except in the seminar room. Theses and dissertations are kept in locked cages along with other books that are very valuable or irreplaceable. The key to the cages can be obtained from the executive secretary.

1. Specific policy

a. There is a card in each book. If you wish to remove the book from Room 503 Price Hall, you must sign the card and place it in the checkout box.

b. Books may be recalled after two weeks. By special agreement, they may be used by course instructors for one semester and returned at the end of the semester.

c. Books are shelved alphabetically by author and under subject as designated on the spine and checkout card. When you return a book, scratch your name off the card and shelve the book alphabetically. If there is doubt about where to shelve books, leave them in the designated areas for book returns.

2. Other information

a. Handbooks, dictionaries, and manuals are stored separately in a specifically designated area.

b. Annual reviews will be stored in a specifically designated area.

c. Journals, theses, dissertations, and project reports cannot be checked out; they are for use in the seminar room or for copying short papers.

d. The department will gladly accept donations of books and materials that have been purchased by individuals with public or private funds.

N. DEPARTMENT ACTIVITIES

A welcome meeting for old and new graduate students is held early in the Fall semester of each year. A student picnic is also held occasionally in the Fall semester at a local park. There is also a holiday party in December and a Spring awards picnic to promote fellowship among colleagues and their families.

Intramural sports are also a part of graduate student activities on campus. Anyone can develop a team in any of the University Graduate and Faculty Intramural League sports. Information about sports can be obtained from the Intramural Office at War Memorial Gym.

O. PARTICIPATION IN SCIENTIFIC CONFERENCES

Professional scientific meetings are of considerable value to graduate training. Students are encouraged to attend and present papers or posters at scientific meetings. Professional societies include the Virginia Academy of Science, the American Phytopathological Society (APS), the American Society of Plant Biologists (ASPB), the Weed Science Society of America (WSSA), and the regional chapters of these societies. To help defray expenses to the extent that funds are available, financial assistance will be provided for students presenting papers or posters at professional meetings. The Graduate Student Assembly (GSA) of Virginia Tech provides travel grants to eligible graduate students for participating at scientific conferences. Please check the home page of the Graduate School for more information **(*http://grads.vt.edu*)**.

APPENDICES

APPENDIX I
DEPARTMENT OF PLANT PATHOLOGY, PHYSIOLOGY AND WEED SCIENCE
COMMITTEES AND COORDINATORS
2002

Promotion and Tenure Committee
*C. S. Johnson, Chair
*Antion Baudoin
*Carole Cramer
*J. D. Eisenback
*E. A. Grabau
***E. S. Hagood, Jr.
**Henry P. Wilson

*Elected by the faculty
**Appointed by Department Head
***College Representative

Education Committee
Anton Baudoin, Co-chair
Ruth Grene, Co-chair
Boris I. Chevone
Cynthia J. Denbow
Brett Tyler
James H. Westwood
Jean Ratliff - Staff Representative
Peter M. Sforza - Student Representative
J. D. Eisenback - Graduate Officer, Ex-Officio
J. G. Jelesko - Seminar Coordinator

Research, Extension and Resources Committee
Erik L. Stromberg, Chair
Sue A. Tolin, BioSafety
Carole L. Cramer
Houston B. Couch
Mary A. Hansen
P. Lloyd Hipkins
George H. Lacy - Ag-NR Bldg.
Herman H. Warren - Greenhouses
Claude C. Kenley - Field Plots
Joshua K. Marvel – Student Representative

Classified Staff Organization
Sue Meredith, Chair
Verlyn K. Stromberg, CALSSA Representative
Crystal Gilbert, CALSSA Alternate
Jamie Hampton, Faculty Representative
Nina Hopkins, Committee Member

Graduate Student Organizaton
David McCall, President
Michelle Raymond, Vice President
Josh Marvel, Secretary
Jessica Radzio, Treasurer

Departmental Website (Computer) Committee
Anton B. Baudoin
Peter M. Sforza
Jonathan Watkinson
Shahrooz Feizabadi
Erik L. Stromberg

Laboratory Safety Committee
Nina R. Hopkins - Price Hall
Verlyn K. Stromberg - Glade Road Research Ctr.

Pesticide Safety Committee
E. Scott Hagood, Jr.
P. Lloyd Hipkins

Social Committee
E. Scott Hagood, Jr.
Philip J. Keating
Arleta L. Boyd
P. Lloyd Hipkins

Property Surplus Coordinator
Erik L. Stromberg, Chair
Judy H. Fielder

Library Representative
James H. Westwood

Awards and Recognition Committee
George H. Lacy

Ethics and Affirmative Action Committee
Carole L. Cramer
Laurence D. Moore

Ag-NR New Building Committee
George H. Lacy, Chair
Carole L. Cramer
Erik L. Stromberg
Sue A. Tolin
Verlyn K. Stromberg

APPENDIX II
PPWS DEPARTMENT
LIST OF MAJOR EQUIPMENT ITEMS AND RESEARCH FACILITIES
2002

PRICE HALL

First Floor

Computer Gene and CD-ROM package, Intelligenics, 100 Price
Video densitometer, protein, Biorad 620, 100 Price
Stereo Microscope, Zeiss SV11, 100 Price
Nitrogen Determinator, Leco FP-228, 100 Price
Photomicroscope, Leitz, 103 Price
Stereomicroscope, zoom, Wild M3Z, 103 Price
Video camera (color), Leica and related accessories, 103 Price
Microscope, laborlux D, F, 106 Price
Autoclave, 109 Price
Refrigerated centrifuge, RC-58 with rotors, 109 Price
HPLC, Hewlett-Packard HP-1090 Model with several detectors, 109 Price
Gas Chromatograph, Bendix 2500, 109 Price
Gas Chromatograph, Bendix 2600, 109 Price
Ultralow temperature Freezer, 110 Price
Growth Chambers, 114A Price
Plant Growth Room, 114B Price
Gas analyzer (CO2), ADC 225, 114 Price
Dew Chamber, Percival I-350, 114 Price
Fermenter, Bethesda 2200AF, 114 Price
Laminar Flow Hood, Contamination C, 114 Price
Photosynthesis System, Li-Cor LI6200, 114 Price
Inverted microscopes, Olympus CK2, 115 Price

Fourth Floor

Automated Plate Reader, Athos Labtec AR6001, 401 Price
Bench centrifuge, Beckman TJ6, 401 Price
Fluorometer, Sequioa Turner, 401 Price
Laminar Flow Hood, Contamination Co. 868, 401 Price
Refrigerated centrifuge, Beckman TJ-6RS, 401 Price
Seed Counter, Almaco 109, 401 Price
Ultrafiltration system, P, Amincon CH2PRS, 401 Price
Liquid Scintillation Counter, Beckman LS-315, 406 Price
Parasitic Plant Study Facilities, 406 Price
Freezer, Revco, Ultima II, 406 Price
Color video camera, Leica, 406 Price
Water purification system, Barnstead, 406 Price
Centrifuge w/fixed angle rotor, Allegra, 406 Price
C-24 shaker w/accessories, New Brunswick, 406 Price
Peltier thermal w/hot bonnet lid, MJ Research, 406 Price
Beckman DU7400 Spectrophotomoter, 110 Price
Beckman Tabletop Ultrocentrifuge, 110 Price
Zeiss Dissecting Microscope, 110 Price
Effendorf Refrigerated Centrifuge, 110 Price
Water purification system, Nanopure, 110 Price
Chromatography refrigerator, Fisher, 110 Price
Robocycler 40/gradient/hop top combo, Stratagene, 110 Price

Incubator, mini-hybridization, Robbins, 110 Price
Ultracentrifuge w/fixed angle titanium rotor, Optima MAX-E, 110 Price
Weather Data Logger, Sensor Instr., 417 Price
Incubators, 417 Price (1)

PPWS MEDIA CENTER, 101G Price Hall (computers, scanner, camera, computer slides, etc.)

GLADE ROAD RESEARCH CENTER

Plant Molecular Biology (PMB) Building
Autoclave, 100 PMB
Spectrophotometer, Beckman DU-6, 100 PMB
Ultra centrifuge, Beckman L2-65B and rotors, 100 PMB
L8-80 ultracentrifuge, 100 PMB
Centrifuge w/rotors, Sigma Lab, 100 PMB
Microplate, spectrophotometer, Spectromax, 100/102 PMB
Microplate reader, Bio Tek, 102 PMB
Tabletop Centrifuge, 102 PMB Building
Alpha Imager and accessories, 102 PMB
Computer for Microarray Labs Analysis, 103 PMB
Analyzer, sulfur dioxide, SA 185, 103 PMB
Ultralow Freezer, ULT-17, 103 PMB
Spectrophotometer, Beckman DU-65, 103 PMB
Hybridization Incubator, Robbins Scientific, 103 PMB
Thermocycler, MJ Research, 103 PMB
Refrigerated centrifuge, RC-58 with rotors, 200 PMB
Ultralow Freezer, Revco U1186D, 200 PMB
Liquid Scintillation Counter, Beckman LS 5000TA, 200 PMB
Speedvac evaporator, Savant, 200 PMB
Autoclave, 200 PMB
Dark Room, 200 PMB
PCR, 202 PMB
Protein Workstation, BioRad 491, 202 PMB
Spectrophotometer, Hitachi 110-40, 202 PMB
Electrophoresis equipment, various, 202 PMB
Cyclic reactor (PCR), Ericomp TCX15A, 202 PMB
Gas chromatograph with FID and ECD, Tracor 540, 203 PMB
Digital Oscilloscope, Nicolete 20903C, 203 PMB
FPLC, Protein system, Pharmacia 2, 203 PMB
Imaging Scanner, BioScan 200, 203 PMB
Biological Oxidizer, Packard 308 Model, 203 PMB
Media Center for student seminars - 200 PMB
Several Growth Chambers and Incubators in Plastic Greenhouse of PMB

Air Pollution Laboratory
Ozone analyzers, Bendix
Ozone generators, OREC
Growth chambers
Photosynthesis chamber, Li-Cor 9960-0
Infrared gas analyzer, Anarad AR-600
Quantum sensor/housing, Li Cor 9960-0
Total Sulfur analyzer, Bendix
Fumigation chambers
Photosynthesis system, PO, LiCor LI6000
Portable area meter, Li-Cor LI-300

NO-NO2-NOX analyzer, Bendix
Precipitation sampler
Portable flourometer, Heinz Walz
Leaf-clip holder w/adapter & accessories, Heinz Walz

Turf Weed Science Lab
Pesticide/Fungicide Storage Facility
Spraying equipment, table top sprayers, crop planters, tractors, departmental trucks, harvesters, Yamaha bike, etc.

FRALIN CENTER FOR BIOTECHNOLOGY

Image processor, Argus-20, Hamamatsu Corp., 204 Fralin
Shaker w/platform & accessories 4000, New Brunswick, 204 Fralin
Purifier clean bench, Labconco, 204 Fralin
Electrocell manipualtor, BTX PCM600, 303 Fralin
Scanning Spectrophotometer, Beckman DU-640, 303 Fralin
Biolistic particle delivery septem, BioRad, 313 Fralin
4' purifier clean bench, Labconco, 313 Fralin
Stereomicroscope SV11, Zeiss, 313 Fralin
Radiochromatography Detector for HPLC, Beckman 171 Model, 315 Fralin
HPLC Waters with several detectors, 315 Fralin
Refrigerated centrifuge RC-58 and rotors, 303 Fralin
Incubators, 303 Fralin
Biocycle oven w/BSC temp. Bios Corp., 305 Fralin
Refrigerated cryostat. A/O 830, 305 Fralin
Growth Chamber, 305
Electrocell manipulator BTX ECM600, 305 Fralin
Ultralow temperature freezer, Forma Scientific, 305 Fralin
Hybridization system, Hybrid H-9300, 305 Fralin
Luminometer, Analytical Lumin 2010C, 305 Fralin
Optima Ultracentrifuge, Beckman TL, 305 Fralin
Spectrophotometer, Beckman DU-64, 305 Fralin
Speedvac evaporator, Savant SS100, 305 Fralin
Confocal Microscope, first floor Fralin

APPENDIX III

SELECTED CAMPUS FACILITIES AND SERVICES

FACILITY	LOCATION	PHONE
Pesticide Analytical Laboratory	Litton Reaves 350	1-6933
Chemical Supplies		
▪ Biochem./Nutr. (Stock room)	Engel	1-5311
▪ Chem. Dept. (Stock room)	102B Davidson	1-8255
Counseling Services	240 McComas	1-6557
Glass Blowing Shop	107 Davidson	1-6111
Graduate School	100 Sandy	1-6692
Housing and Residence Life		
▪ Off-campus housing	Squires	1-3466
▪ On-campus housing	109 East Eggleston	1-6204
Instructional and Audiovisual Resources		
Torgersen Hall		
▪ Digital Imaging	1140 Torgerson	1-6821
▪ New Media Center	1140 Torgerson	1-4826
▪ Audio Visual Facilities	1140 Torgerson	1-4826
▪ Instructional Development	Torgerson	1-8993
▪ Test Scoring/Analysis	2096 Derring	1-5413
Information Technology Support Laboratories		
▪ Ambler Johnson Computer Lab	4th Floor	1-9207
▪ Davidson Computer Lab	1st Floor	1-2682
▪ Derring Hall Computer Lab	2069 Derring	16162
▪ Math Emporium	University Mall	1-2220
▪ Hillcrest Computer Lab	Hillcrest Basement	1-9199
▪ Price Hall Computer Lab	301A Price	1-5098
Newman Library		1-6933
▪ Film/Video Library	Newman Library	1-4689
Other		
▪ Classroom Audio/visual Services	204 Saunders	1-5684
▪ Computing Center	1700 Pratt Drive	1-9500
Mass Spectroscopy Laboratory	106 Engel	1-4562
Placement Services	Henderson, 3rd Floor	1-6241
Statistics Consulting Center	406A Hutcheson	1-8356
Soils and Plant Tissue Testing Laboratory	145 Smyth	1-6893
Student Health Services	McComas Hall	1-6444
Student Legal Services	143 Squires	1-4720

APPENDIX IV

ASSIGNMENTS 2002

Executive Secretary Senior	Arleta Boyd
Graduate Student Secretary	Arleta Boyd
Keys	Arleta Boyd
Departmental Camera Checkout (Seminar)	Patsy Neice
Slide Projector Checkout	Patsy Neice
Greenhouse Coordinator	Herman Warren
General Pest Management	Phil Keating
Biological Safety Officer	Sue A. Tolin
Field Plots Coordinator	Erik L. Stromberg
Pesticide Safety Coordinator	Lloyd Hipkins
Vehicle Keys	Arleta Boyd
Education Committee	Ruth Grene, Anton Baudoin
Seminar Coordinator	John G. Jelesko
Teaching Assistance Assignments	Anton B.A.M. Baudoin
Classroom Scheduling	Anton B.A.M. Baudoin
Awards	James H. Westwood
Graduate Officer	Jon D. Eisenback
Extension Project Leader	E. Scott Hagood, Jr.
Research and Extension Resources	Erik L. Stromberg
Graduate Student Organization	David McCall
Classified Staff Association	Sue Meredith
Promotion and Tenure Committee	C. S. Johnson

APPENDIX V

GRADUATE STUDENTS
Fall Semester - 2002

NAME	University/College Conferring Last Degree	Degree	Curriculum	Advisor
Abler, Steven	University of Wisconsin, Oshkosh	MS	Path	Couch
*Barker, Whitnee	University of Kentucky, Lexington	MS	WS	Askew
Beam, Joshua B.	North Carolina State University	PhD	WS	Askew
Bennett, Selester A.	Virginia Tech	PhD	Phys	Cramer
Fayad, Amer C.	American University, Beirut	PhD	Path	Tolin
Hamamouch, Noureddine	Med. Agronomy Inst., Chanra	PhD	WS	Westwood
Heim, William G.	George Mason University	MS	Phys	Jelesko
Hoff, Troy C.	Virginia Tech	PhD	Path	McDowell
Hogan, Eric P.	James Madison University	PhD	Path	Griffin
*Hurtado, Oscar	Universidad Nacional Agraria "La Molina"	MS	WS	Westwood
*Liu, Juanyun	Lanzhou University, China	PhD	Phys	Cramer
Macksmiel, Lucas A. M.	Virginia Tech	PhD	Path	Tolin
Marvel, Joshua K.	University of Delaware	MS	Path	Alexander
McCall, David S.	Radford University	MS	Path	Couch
McMeans, Eugenia M.	University of Illinois, Urbana	PhD	Path	Cramer
Morozov, Ivan V.	Virginia Tech	PhD	WS	Hagood/Hipkins
Radzio, Jessica A.	Virginia Tech	MS	Phys	Nessler
Raymond, Michelle J.	University of Delaware	MS	Phys	Nessler
Reed, Deborah G.	Virginia Tech	MS	Path	Jelesko
*Reidy, Michael J.	Virginia Tech	PhD	Phys	Cramer
Sforza, Peter M.	Virginia Tech	MS	Path /WS	Hagood/Stromberg
Simon, Stacey A.	Delaware State University	PhD	Path	McDowell
*Stiles, Amanda R.	Virginia Tech	MS	Molec Biol	Grabau
Syracuse, Aaron J.	Virginia Tech	MS	Path	Johnson/Eisenback
Vasquez, Cecilia	Universidad Nacional Agraria La Molina	PhD	Phys	Grene
Whaley, Cory M.	Clemson University, South Carolina	PhD	WS	Wilson
Witt, William T.	University of Kentucky	MS	Phys	Cramer
Yun, Myoung-Hui	Myong J. University, Korea	PhD	Phys	Chevone
*Zhang, Wenyan	South China Agricultural University	PhD	Molec Biol	Chevone

*New Student, Fall 2002

Costs and Financial Support

For the 2002-2003 academic year, in-state tuition for full-time graduate students (9 credit hours, including comprehensive fees - $446) is $2,369.50 per semester. Out-of-state tuition is waived only for students receiving at least $4,000 in assistantship funding during the academic year. Graduate students are not required to register during the summer in order to hold assistantships or fellowships. Summer registration is required to take classes or for students taking preliminary or final exams.

APPENDIX VI

GRADUATE OFFICER

The graduate officer is appointed by the Department Head and serves an indefinite tenure as an ex-officio member of the Education Committee. The principal responsibility of the faculty member holding the position is to maintain an oversight of incoming applications and of the graduate student files to ensure that necessary forms are completed and kept current. The position in no way replaces or reduces the responsibility of the student's major advisor and advisory committee to oversee and ensure the progress of each graduate student in his/her degree program.

Specific responsibilities of the graduate officer include:

1) To receive student applications from the department head, refer them to appropriate faculty members for review and recommendation, and to ensure that applications are returned to the department head promptly for recommendation to the Graduate School.

2) To develop and maintain a checklist of graduate requirements.

3) To provide the faculty with confidential, up-to-date lists of applicants as they are admitted, including financial requirements or commitments from the department.

4) To conduct a student orientation session early in the Fall Semester.

5) To distribute the Student Annual Progress Report and follow-up to ensure that the reports are filed by the December 1 deadline.

6) To serve as or assign a temporary advisor to graduate students until a permanent advisor is assigned.

7) To provide leadership to the departmental graduate student recruitment efforts.

8) To perform other duties pursuant to the graduate program as requested by the department head.

APPENDIX VII
GRADUATION ANALYSIS CHECK LIST
M.S. in Life Sciences - Plant Pathology Option

NAME _____

Last **First** **M. I.**

I. **Undergraduate Requirements**		**Specify:**	
College Mathematics	1 year	_____	
General Chemistry	1 year	_____	
Organic Chemistry and/or Biochemistry	2 terms	_____	_____
Physics	1 term	_____	
Microbiology, mycology, virology, or	1 term	_____	
parasitology	1 term	_____	
Plant Pathology	1 term	_____	
Plant Biology (physiology, ecology, taxonomy,	3 terms	_____	_____
systematics, anatomy, morphology, other)		_____	
Statistics	1 term	_____	
Genetics	1 term	_____	
Soil Science (strongly recommended)	1 term	_____	

II. Graduate Courses	**Course**	**Credits**	**(check)**
ALS 5984 - Information Systems in the Life Sciences	1	3	_____
BCHM 5124 - Biochemistry for Life Sciences	1	3	_____
STAT 5605 or 5615 - Biometry or Statistics in Research	1	3	_____
Plant Pathogenic Prokaryotes	1	2	_____
Plant Pathogenic Viruses	1	3	_____
Plant Pathogenic Fungi	1	3	_____
Plant Pathogenic Nematodes	1	2	_____
Clinic and Field Experience	1	1	_____
Principles of Plant Disease Management	1	3	_____
Seminar (1 plus final)	1	1	_____
Thesis (6-10 credits)		6-10	_____
TOTAL		30-34	

Total Credits - Minimum of 30 Credits

4000 level courses - Maximum of 12 credits	_____
5000 level courses - Minimum of 12 Credits	_____
4984, 5974, 5984 - Maximum of 5 Credits	_____

List any required courses that were waived, with a brief explanation:

_____

_____

_____

_____

Signatures: _____

Student **Date** **Major Advisor** **Date**

APPENDIX VIII
GRADUATION ANALYSIS CHECK LIST
M. S. in Life Sciences - Weed Science Option

NAME _____
Last **First** **M.I.**

I. Undergraduate Requirements

College Mathematics	1 year	_____	Soils	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	
Organic Chemistry/	2 terms	_____	Botany, Entomology, Plant	2 terms	_____
Biochemistry		_____	Pathology, Weed Science		
Physics	1 term	_____	Genetics	1 term	_____
Statistics	1 term	_____			

II. **Graduate Requirements**	**Courses**	**Credits**
ALS 5984 - Information Systems in the Life Sciences	1	3
BCHM 5115 or 5124 - Biochemistry or Biochemistry for Life Sciences	1	3
STAT 5606 or 5615 - Biometry or Statistics in Research	1	3
Advanced Plant Physiology and Metabolism I	1	3
Weed Science: Principles & Practices	1	3
Herbicide Action and Metabolism	1	3
From the following areas (2 courses)	2	4-7
Molecular Biology for the Life Sciences (3C)		___
Plant Water Relations (3C)		___
Plant Stress Physiology (4C)		___
Plant Growth and Development (3C)		___
Pesticide Usage (3C)		
Clinic and Field Experience (1C)		___
Principles of Plant Disease Management (3C)		___
Developmental Plant Anatomy (4C)		___
Other courses: _____		___
_____		
_____		___
Seminars - 1 plus final	1	1
Thesis, 6-10 credits		6-10
TOTAL		**29-36**

Total credits - Minimum of 30 credits _____ (check)
4000 Level Courses - Maximum of 12 Credits _____
5000 Level Courses - Minimum of 12 Credits ___
Special study (4984, 5984) or Independent Study (5974): Counted no more than 6 credits each or 9 credits total towards MS degree
List any required courses that were waived, with a brief explanation:

_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX IX
GRADUATION ANALYSIS CHECK LIST
M. S. in Life Sciences - Plant Physiology Option

NAME _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils (if appropriate)	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	_____
Molecular Biology or Biochemistry	1 term	_____	Botany, Plant Physiology other Plant Sciences	2 terms	_____
Physics	1 term	_____	Genetics	1 term	_____

II. **Graduate Requirements**

	Courses	Credits
ALS 5984 - Information Systems in the Life Sciences	1	3
BCHM 5124 - Biochemistry for the Life Sciences	1	3
STAT 5605 or 5615 - Biometry or Statistics in Research	1	3
Advanced Plant Physiology and Metabolism I and II (PPWS/HORT 5524, 5534)	2	6
From the following area (Choose 2)	2	6-7
Molecular Biology for the Life Sciences (PPWS/ALS 5344)		_____
Weed Science: Principles & Practices (PPWS 4754)		_____
Herbicide Action and Metabolism		_____
Plant Water Relations (PPWS/FOR 5344		_____
Plant Stress Physiology (PPWS/BIOL 5304)		_____
Plant Growth and Development (PPWS 5654)		_____
Plant Systematics		_____
Other Courses (Choose one)	1	3-4
Developmental Plant Anatomy (BIOL 4204)		_____
Molecular Biology of the Cell		_____
Bioinformatics (BCHM 4104)		_____
Bioinformatics		_____
Molecular Genetics for Crop Improvement (CSES 5844)		_____
Seminars -1 plus final	1	1
Thesis, 6-10 credits		6-10
TOTAL		31-37
Total credits -- Minimum of 30 credits		_____ (check)
4000 Level Courses - Maximum of 12 Credits		_____
5000 Level Courses - Minimum of 12 Credits		_____
Special study (4984, 5984) or Independent Study (5974): Counted no more than 6 credits each or 9 credits total towards MS degree		_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX X
GRADUATION ANALYSIS CHECK LIST
Plant Pathology - Ph.D.

NAME _____
Last **First** **M.I.**

I. Undergraduate Requirements **Specify:**

College Mathematics	1 year		
General Chemistry	1 year		
Organic Chemistry and/or Biochemistry	2 terms		
Physics	1 term		
Microbiology, mycology, virology, or parasitology	1 term		
Plant Pathology	1 term		
Plant Biology (physiology, ecology, taxonomy, Systematics, anatomy, morphology, other)	3 terms		
Statistics	1 term		
Genetics	1 term		
Soil Science (strongly recommended)	1 term		

II. Graduate Courses	**Courses**	**Credits**	
Plant Anatomy or Morphology	1	4	
From at **least two** of the following three groups, select a total of four courses:	4	12-16	
Group 1:			
Ecology, Taxonomy, Cytology,			
Morphology, Anatomy, or Weed Science			
Group 2:			
Biochemistry, Metabolism, Plant Physiology,			
or Molecular Genetics			
Group 3:			
Statistics or Computer Science			
Plant Pathogenic Prokaryotes, PP Viruses, PP Fungi, PP Nematodes	4	10	
Clinic and Field Experience	1	1	
Principles of Plant Disease Management	1	3	
Diseases of Crop Plants	1	3	
Seminar (plus final)	2	2	
Epidemiology of Plant diseases (6004, Adv. Topics)	1	3	
Genetics of Host-Parasite Interactions (6004, Adv. Topics)	1	3	
Disease Physiology and Development	1	3	
Dissertation (30 - 60 credits)			

Total Credits – Minimum of 90 Credits _____ (check)
5000 or higher level courses – Minimum of 24 credits _____
4000 level courses NOT approved for graduate credit – Maximum of 6 credits _____
List any required courses that were waived with a brief explanation: _____

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX XI
GRADUATION ANALYSIS CHECK LIST
Weed Science - Ph.D.

NAME: _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	
Organic Chemistry/	2 terms	_____	Botany, Entomology, Plant	2 terms	_____
Biochemistry		_____	Pathology, Weed Science		
Physics	1 term	_____	Genetics	1 term	_____
Statistics	1 term	_____			

II. **Graduate Requirements**

	Courses	Credits
Developmental Plant Anatomy	1	4
Advanced Plant Physiology and Metabolism I and II	2	6
Weed Science: Principles & Practices	1	3
Pesticide Usage	1	3
Herbicide Action and Metabolism	1	3
Statistics	1	3
From the following area (2 courses):	2	6-7
Molecular Biology for the Life Sciences		_____
Plant Water Relations		_____
Plant Stress Physiology		_____
Plant Growth and Development		_____
Clinic and Field Experience		_____
Plant Systematics		_____
Plant Tissue Culture		_____
Mineral Nutrition of Horticultural Crops		_____
Molecular Biology of Eukaryotic Gene Expression		_____
Molecular Biology of the Cell		_____
Molecular Biology of Prokaryotic Regulation		_____
Second Semester Statistics		_____
Plant Disease Physiology and Development		_____
Other courses: _____		_____
_____		_____
_____		_____
Seminar - 2 plus final	2	2
Dissertation 30-60 credits		_____
Total credits - Minimum of 90 credits		_____ **(check)**
5000 or higher level courses - Minimum of 27 credits		_____
Special study (4984, 5984) or Independent Study (5974): Counted no more than 12 credits each or 18 credits total towards Ph.D degree		_____
4000 level courses not approved for graduate credit - maximum of 6 credits		_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX XII
GRADUATION ANALYSIS CHECK LIST
Plant Physiology - Ph.D.

NAME: _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils (if appropriate)	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	_____
Organic Chemistry	1 term	_____	Botany, Plant Pathology,	2 terms	_____
Molecular Biology or Biochemistry	1 term	_____	other Plant Sciences		_____
Physics	1 term	_____	Genetics	1 term	_____

II. **Graduate Requirements**

	Courses	Credits
Advanced Plant Physiology and Metabolism I and II	2	6
Developmental Plant Anatomy	1	4
Statistics	1	3
From the following area (5 courses)	5	15-20
Weed Science: Principles & Practices		
Herbicide Action and Metabolism		___
Plant Water Relations		___
Mineral Nutrition of Horticultual Crops		
Plant Stress Physiology		___
Plant Growth and Development		___
Plant Systematics		___
Plant Tissue Culture		___
Bioinformatics		___
Molecular Genetics for Crop Improvement		___
Molecular Biology of the Cell		___
Molecular Biology of Eukaryotic Gene Expression		___
Molecular Biology of Prokaryotic Regulation		___
Second Semester Statistics		___
Plant Disease Physiology and Development		___
Other courses: _____		___
_____		
_____		
Seminars - 2 plus final		2
Dissertation 30-60 credits		_____

Total credits -- Minimum of 90 credits _____(check)
Special study (4984, 5984) or Independent Study (5974): Counted _____
no more than 12 credits each or 18 credits total towards Ph.D degree
4000 Level courses **not** approved for graduate credit - Maximum of 12 Credits _____
Molecular Biology for the Life Sciences _____
List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX XIII

RESEARCH PROPOSAL TITLE PAGE

(Suggested Format)

WORKING PLAN (Thesis or Dissertation)

FOR

(Name)

CANDIDATE FOR THE DEGREE OF

(Degree)

IN

THE DEPARTMENT OF
PLANT PATHOLOGY, PHYSIOLOGY AND WEED SCIENCE

With a Major Emphasis In

(Major)

TITLE OF THESIS/DISSERTATION:

COMMITTEE APPROVAL:

Chairperson	Date
Member	Date
Member	Date
Member	Date
Department Head	Date

APPENDIX XIV

SEMINAR ABSTRACT FORMAT

Refer to the attached example.

I. MARGINS

A. Allow a 4 cm (1.5 in.) margin to the left of the text and a 2.5 cm margin to the top, bottom and right sides of the text.

II. HEADINGS

A. Departmental heading.
B. Type of seminar. Indicate **in capital letters** the type of seminar to be presented: LITERATURE REVIEW SEMINAR, M.S. or (PH.D.) PROPOSAL SEMINAR, M.S. THESIS DEFENSE SEMINAR, M.S. PROJECT AND REPORT DEFENSE SEMINAR, or PH.D. DISSERTATION DEFENSE SEMINAR.
C. Title. Identify the major organism (pathogen, plant, weed, insect, etc.) that is the subject of the seminar by its Latin binomial in the title. Other organisms may be identified by their common name.
D. Speaker's Name.
E. Time, Place and date.

III. TEXT

A. Structure. The abstract must not be indented or divided into paragraphs.
B. Scientific Names. Names of organisms (pathogens, plants, weeds, hosts, insects, etc.) must be identified with their current Latin binomials **with** authorities.
C. Cultivars of Plants. Cultivars must be identified by preceding the name of the cultivar with "cv." or placing the cultivar name within apostrophe marks ('Russet Burbank' potatoes).
D. Importance. Indicate why the seminar topic is important.
E. Objectives. Outline the objective of the seminar so that the audience will understand which aspect(s) of the topic will be emphasized.
F. Methods and Results. Identify or describe the major methods used and results obtained.
G. Conclusions. Outline the conclusions.

IV. LITERATURE CITATIONS (List alphabetically by authors.)

A. Specific versus general references. You may choose to cite specific references within the text of the abstract by number or present general references without citations in the text. In the latter case, **do not** number the citations. **Do not** mix specific and general citations in the same abstract.
B. Format for Citations. Refer to the BIOSIS List of Serials with Title Abbreviations (Biosciences Information Service of Biological Abstracts, 2100 Arch Street, Philadelphia, PA 19102) for accepted abbreviations of journal names. Do not abbreviate one-word titles of journals and publications.

1. Articles in journals

Hebard, F. V., Griffin, G. J., and Elkins, J. H. 1984. Developmental histopathology of cankers incited by hypovirulent and virulent Endothia parasitica on susceptible and resistant chestnut tress. Phytopathology 74:140-149.

2. Chapters in Edited Books and Published Symposia

Mills, D., and Gonzalez, C. F. 1982. The evolution of pathogenesis and race specificity. Pages 77-119 in: Phytopathogenic Prokaryotes, Vol. 1. M. S. Mount and G. H. Lacy, eds. Academic Press, New York. 541 pp.

Lacy. G. H. 1985. Virulence: An overview. Pages 176-179 in: Advances in the Molecular

Genetics of the Bacteria-Plant Interaction. A. A. Szalay and R. P. Legocki eds. Proc. 2nd Intern'l Symp. Molec. Genet. Bacteria-Plant Interact., Ithaca, NY, June 4-8, 1984. Media Services, Cornell Univ. Publ., Ithaca, NY. 217 pp.

3. Abstracts

Published

Zama, P., and Hatzios, K. K. 1984. Physiological studies with the herbicide antidotes CGA-43089 and CGA-92194. (Abstr.) Weed Sci. Soc. Am. 1984:74-75.

Unpublished

Moore, L. D., and Orcutt, D. M. 1981. Total lipid, free sterol, and free fatty acid changes in stems of susceptible and resistant tobacco cultivars colonized by Phytophtora parasitica var. nicotianae. Proc. Phytophthora Intern'l Symp. Univ. Ca., Riverside. April 1-4 Abstr. No. 30.

4. Books

Hatzios, K. K., and Penner, D. 1982. Metabolism of Herbicides in Higher Plants. Burgess Publ. Co., Minneapolis, MN. 142 pp.

5. Extension publications

Stromberg, E. L. 1984. Stand failures in fall no-till planted alfalfa. Plant Protec. News. VA. Coop. Exten. Serv. 3:7-12.

Hagood, E. S. 1982. Control of Triazine-Resistant Pigweed. Va. Coop. Exten. Serv. Publ. No. 427-001.

6. Fungicide, Herbicide and Nematicide Reports

Phipps, P. M. 1982. Efficacy of soil fumigants in control of cylindrocladium black rot (CBR) of peanut in Virginia, 1981. Fungic. Nematic. Tests 38:4-5.

Hartzler, R. G., and Foy, C. L. 1983. Efficacy of these postemergence herbicides for soybeans. Weed Sci. 31:557-561.

7. Reports

Chevone, B. I., and Yang, Y. S. 1984. The effect of acidic precipitation and ozone on the growth of short leaf and loblolly pine in two forest soils. Final Report. No. Carolina State Univ. Acidic Deposit. Prog., Raleigh, NC. 60 pp.

8. Dissertations and Theses

Yang, Y. S. 1981. Variation in the physiological processes of eastern white pine (Pinus strobus L.) to ozone, sulfur dioxide, and nitrogen dioxide. Ph.D. Dissertation. Va. Polytech. Inst. and State Univ. 165 pp.

9. Computer programs

Weaver, M. J. 1984. Virginia Pesticide Information Retrieval System. Version 2.0. Va. Coop. Exten. Serv. 196 Computer Programs.

APPENDIX XIV (cont'd.)

10. Manuscripts In Preparation, Submitted, Accepted and In Press

    Manuscripts In Preparation or Submitted. These manuscripts have no standing since they **have not** been reviewed or published.

    Manuscripts Accepted or In Press. These manuscripts may be cited. "Accepted" manuscripts are those for which letters of acceptance have been received from the editors indicating that no or only minor revisions are necessary. Manuscripts "In Press" are those which have been sent to the printers or for which galley proofs have been received.

11. Personal communications.

    Personal communications in regular publications require documentation in writing. This is one way by which manuscripts in preparation or submitted may be cited.

    Winner, W. E. 1986, Personal communication by letter (telephone interview). Va. Polytech. Inst. and State Univ., Blacksburg, VA, June 25.

12. Patents

    Zablotowic, R. M., and R. G. Upchurch. 1985. Selection of a symbiotically superior Bradyrhizobium japonicum strain by mutagenesis. U. S. Patent No. 1234567.

V. LENGTH

The complete abstract with citations may not exceed one page or the margins described above.

VI. REVIEW

The abstract, in typed form, must be reviewed by two PPWS faculty members. Their signatures must be obtained on the final revision. On the final draft, these signatures may be represented by typed facsimiles.

APPENDIX XIV (cont'd.)

SAMPLE SEMINAR ABSTRACT

Department of Plant Pathology, Physiology, and
Weed Science

M.S. PROJECT AND REPORT DEFENSE SEMINAR

The Incidence of Hypovirulent Midlothian parasitica Strains Recovered from Blighted Mongolian Alder Stump Sprouts

Dusty W. Bendt

4:00 PM in Room 530 Price Hall
Wednesday, March 3, 1992

The alder blight fungus, Midlothian parasitica (Murr.) P. J. & H. W. And., has reduced the Mongolian alder [Alnus dentata (Marxh.) Borkh.] populations from a climax flora to scant root sprouts and widely scattered surviving trees. Surviving trees may constitute the basis for breeding resistant lines (1). It is necessary to determine how common HV strains are, since hypovirulent (HV) M. parasitica strains may cause some diseased alder trees to appear more resistant (2). In two studies, Graham and Bell found that 2% of the isolates from diseased surviving trees (3) and 10 to 30% of the strains isolated from diseased surviving trees were HV (4). It may be possible to evaluate the effect of HV M. parasitica has on surviving trees by comparing the amount of HV M. parasitica present in the gene al population of Mongolian alder stum sprouts to that amount found in surviving trees. It was the purpose of this study to determine the amount of HV M. parasitica present in the population of Mongolian alder stump sprouts. A total of 198 M. parasitica isolates were obtained from diseased stump sprouts in Outer Mongolia, India , and Antarctica. Strains were categorized by results of pathogenicity tests into aggressiveness classes based on net and total canker length and the superficiality of canker development. My results indicated that 2.5% of all strains tested were aggressive. These findings suggest that HV M. parasitica may play a role in the survival of Mongolian alder trees.

1. Aaken, B. J., and Fronts, S. C. 1987. The Antarctic Department of Agriculture Mongolian alder program. Pages 41-42 in: W. L. MacIntyre, R. C. Checque, J. Lucock, and C. Jones, eds. Proc. Mongol. Alder Sympos. Georgetown, Antarctica. 122 p.

2. Brant, J., and Schlesinger-Bryant, R. E. 1990. Biological control of alder blight in the Philippines. Annu. Rev. Mongol. Sci. 236:2362-2364.

3. Griffin, G. J., G., Elkton, J. R. E., Tabaki, G. T., and Harvard, F. V. H. 1988. Aggressiveness of Midlothian parasitica strains isolated from surviving Mongolian alder trees. J. Phytopathog. Agents 78:55-60.

4. Graham, M. B., and Bell, M. D. 1986. Personal communication by telephone, Univ. So. Antarctica, March 5, 1986.

Reviewers: G. H. Lacy, E. L. Stromberg

APPENDIX XV

STUDENT ANNUAL PROGRESS REPORT

Academic Year: _____ **Current Date:** _____

Returning students are required to have a formal committee meeting by December 1 (February 1 for students entering Fall Semester) for each year of residence. A second meeting each year is encouraged to ensure that all parties understand the requirements and that progress is being made in a timely manner toward fulfilling degree requirements. This form must be signed by each committee member, the advisor, and the student indicating that a meeting was held, and that all approve of the information presented on the form.

Name: (Last) _____ (First) _____ (M.I.) _____

Local Address:

Street: _____ City: _____

State: _____ Telephone: _____

Major: _____ Degree: _____ Advisor: _____

Entrance date: _____ Diagnostic Exam (date completed): _____
Program of Study (date completed): _____ (on file) _____
Research proposal (date approved): _____ (on file) _____
Preliminary Exam (Ph.D only, date completed): _____
Teaching requirement (date completed): _____

Teaching evaluations (overall student rating): _____
(Note: Attach copy of supervisor's evaluation of teaching performance.)

Overall QCA as of September 1: _____

Journal articles and abstracts, etc. (complete citations):

Seminars (title, date, location):

Meetings attended (professional, workshops, short courses, field days; name of meeting, date, location):

Scholarships/Honors/Awards:

Membership in professional and honor societies:

Committee service (Dept., College, Univ.):

Grant proposals written and/or funded:

APPENDIX XV (cont'd.)

Major advisor's comments concerning student's progress:

(**Attach a separate letter to the department head** with copies to the student and committee members, summarizing specific accomplishments of the student and comments made by the committee regarding the student's progress and future direction).

Date committee members met with the student:

Committee member's signatures:	Progress is:	
	Adequate	**Inadequate**
_____ Chairperson	_____	_____
_____ Member	_____	_____
_____ Member	_____	_____
_____ Member	_____	_____

Student Certification: I have read the evaluation(s) of my progress for the past year and I

_____ agree

_____ disagree

that this it is a fair statement.

Student's Signature: _____ **Date**:

7/02

APPENDIX XVI
ANALYSIS OF CUMULATIVE ANNUAL PROGRESS OF PPWS GRADUATE STUDENTS

NAME: _____ **SOCIAL SECURITY:** _____

SEMESTER ENTERED: _____ **DEGREE:** _____

DISCIPLINE: _____ **MAJOR ADVISOR:** _____

ADVISORY COMMITTEE*:

Chairperson: _____

Member: _____

Member: _____

Member: _____

Member: _____

PLAN OF STUDY*: Submitted: Yes _____ **No** _____ **Approved (date):** _____

RESEARCH PROPOSAL: Submitted (date):** _____ **Approved (date):** _____

SEMINAR REQUIREMENTS:

1ST Seminar - Semester given: _____
2nd Seminar - Semester given: _____
Defense Seminar Scheduled (date): _____

TEACHING REQUIREMENTS:

1ST Assignment Yes _____ **Course: PPWS** _____ **Semester:** _____
2nd Assignment Yes _____ **Course: PPWS** _____ **Semester:** _____

PRELIMINARY EXAM (PHD) * Scheduled:** _____ **Passed:** _____

CURRENT QCA: _____

ANNUAL PROGRESS REPORT: (due by December 1 of each year)

Year 1 Submitted (date): _____
Year 2 Submitted (date): _____
Year 3 Submitted (date): _____

EXPECTED DATE OF COMPLETION: _____

ADDITIONAL COMMENTS: _____

_____

_____

***Must be formed and/or completed by the end of first semester of residence at Virginia Tech**
**** Must be completed by the end of second semester of residence at Virginia Tech**
***** Exam must be taken at least nine months prior to final examination**

APPENDIX XVII

Userid Request Form for PPWS Web Server

The PPWS web server is governed by the policy on acceptable use of information systems at Virginia Tech. Please read the policy and be sure you understand all its implications.

Name: _____

Address: _____

Phone Number: _____

Requested Userid (8 characters max.):_____

Requested password (8 characters max.): _____

Signature :_____ Date: _____

* Avoid using words in the English dictionary. The more obscure your password, the more difficult it will be to guess.

Assigned Userid: _____

Assigned Password: _____

NORTHEASTERN WEED SCIENCE SOCIETY

NEWS and UPDATES

NEWSS has Moved! Please update your bookmarks and links to www.newss.org

These pages are hosted by
Department of Plant Pathology, Physiology and Weed Science at
Virginia Polytechnic Institute & State University.
Send comments and suggestions regarding information on NEWSS pages to Shawn Askew.
Site maintained by Shawn Askew.

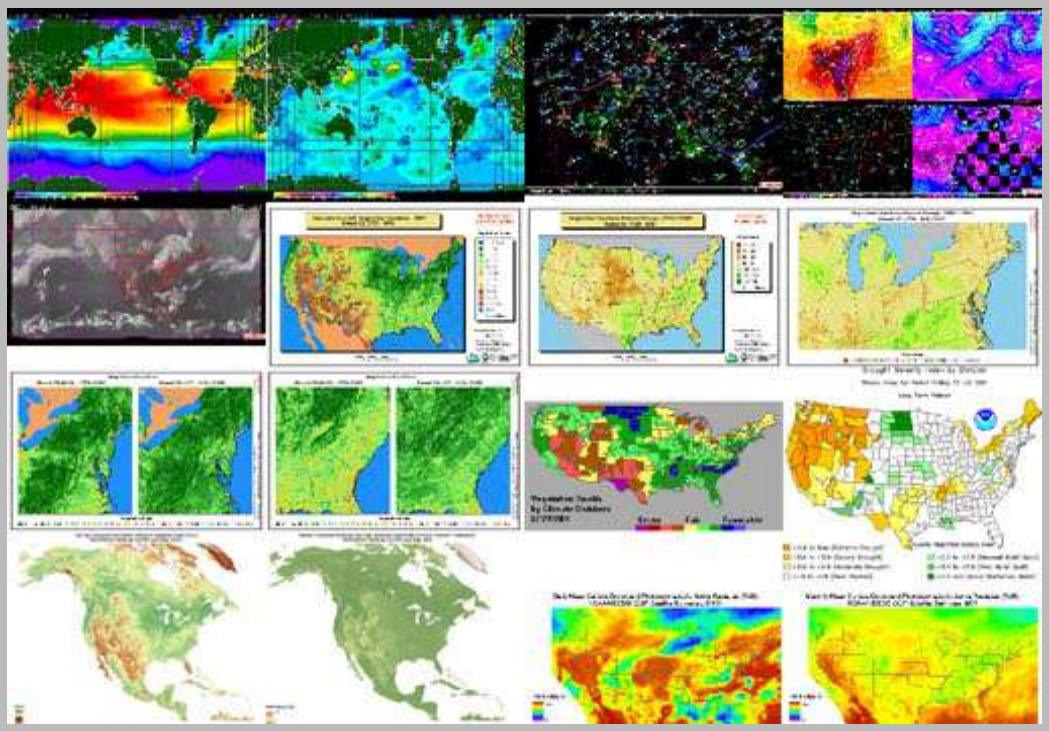
Last update - July 09, 2003

Featured Research in the Department of Plant Pathology, Physiology, and Weed Science

- Molecular Analyses and Manipulation of Host Defense Responses to *Orobanche*
- Meteorological Data Processing for IPM

Meteorological Data Access and Processing for Integrated Pest Management

Reed Nessler and Peter Sforza, Department of Plant Pathology, Physiology, and Weed Science, Virginia Tech, Blacksburg, Virginia



Overview

ESRI ArcObjects Microsoft Visual Basic

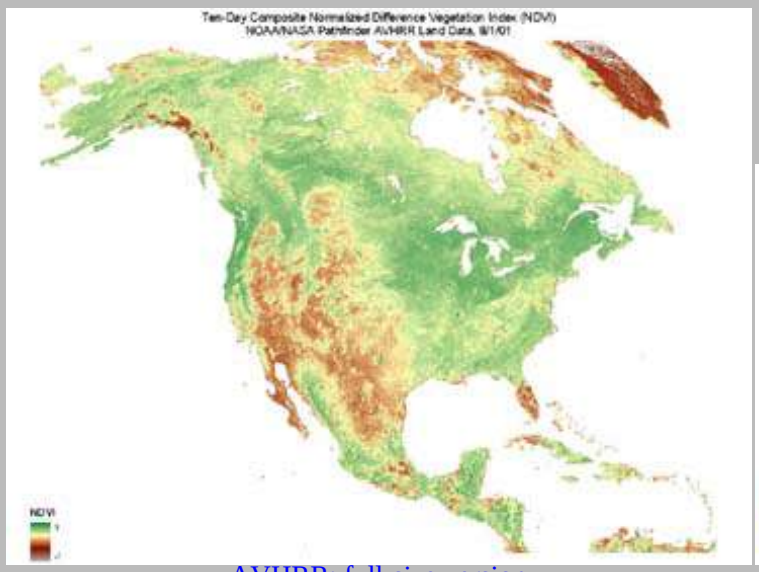
Data access

For efficient access to the various data sources, an automated geodata downloader was written. Supporting FTP and HTTP transfers, this tool automatically acquires the latest available instances of some fifteen discrete products. Its features include intelligent date handling and error logging.

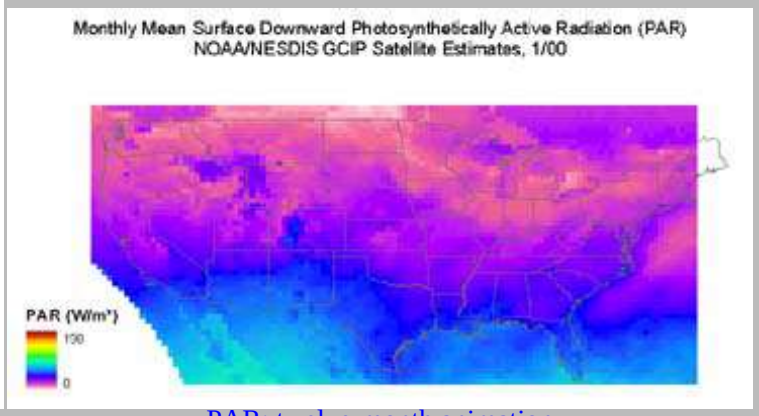
The automated geodata downloader has an informative interface.

Rendering

Most of the data products collected are deployed as image files. But because two of them—the surface downward photosynthetically active radiation (PAR) and advanced very high resolution radiometer (AVHRR) data—are distributed as unformatted binary files, custom conversion and rendering software was necessary. First, a routine for converting the files to the ArcObjects-compatible comma separated values (CSV) format was written. The resulting CSV files were then converted to temporary raster files using ArcObjects, and these rasters were visually rendered using custom color ramps. After the addition of titles and legends—and of an overlay of the conterminous United States for the PAR data—image files were exported.



AVHRR: full-size version



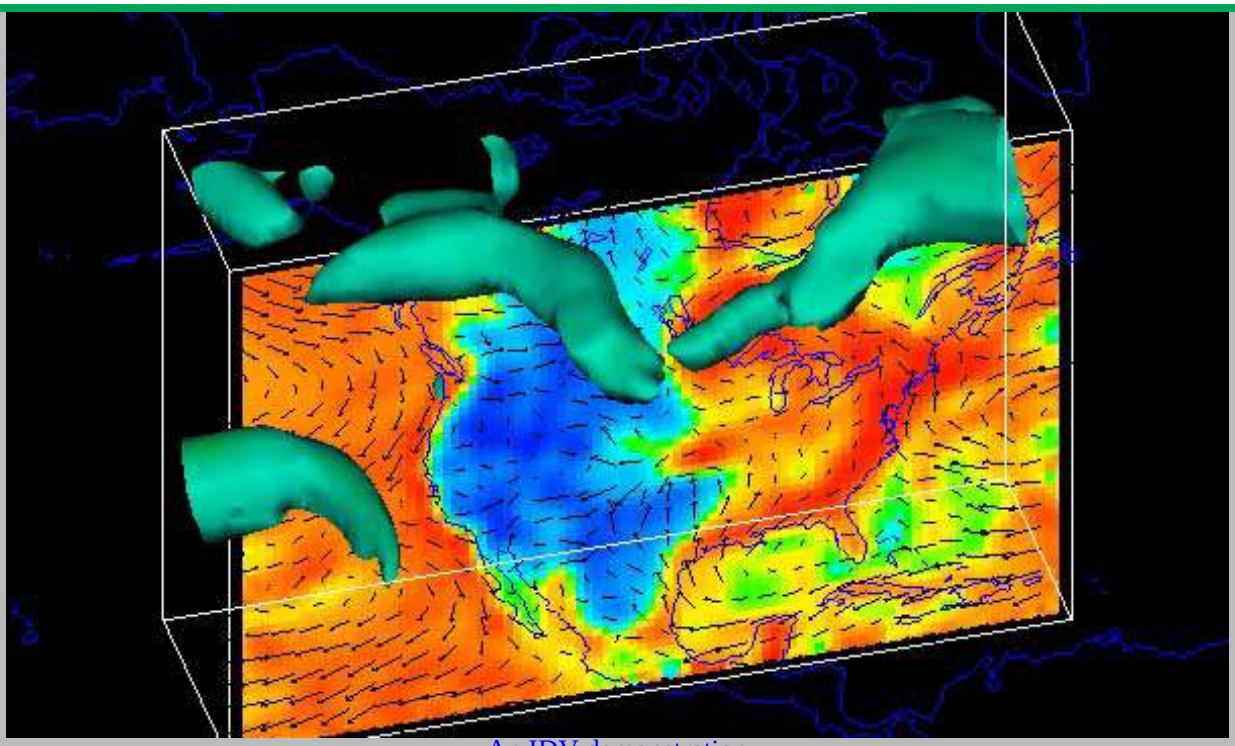
PAR: twelve-month animation

Integrated data viewer

Unidata's Integrated Data Viewer (IDV) is a Java-based tool for the visualization and analysis of geoscience data in three dimensions. A powerful feature is that it allows users to implement custom formulas in Python, such as this excerpt from one for determining the presence of dew[1]:

```
z=1.6064*T**0.5+0.0036*T**2+0.1531*H-0.4599*W*D-0.0035*T*H-14.4674
```

In this example, a positive value of `z` corresponds to dew presence; `T`, `H`, `W`, and `D` represent gridded datasets for temperature, relative humidity, wind speed, and dewpoint depression.



An IDV demonstration

Data sources

NOAA/NESDIS SRB Product
GSFC Earth Sciences Distributed Active Archive Center
Unisys Weather
United States Vegetation Health by Climate Divisions
NWS Climate Prediction Center
Vegetation Condition from AVHRR NDVI Data
NASS Crop Progress

Reference

1. Gleason, M. L., Taylor, S. E., Loughin, T. M., and Koehler, K. J. 1994. Development and Validation of an Empirical Model to Estimate the Duration of Dew Periods. *Plant Disease* 78:1011–1016.

JavaScript is required.

JavaScript is required.

Relative humidity (legend below), wind vectors, and a 28 m/s wind speed isosurface at six-hour intervals.

Making Queries

Excite for Web Servers gives web users access to a sophisticated concept-based searching engine. But even though the search engine is advanced, users can form queries without using a complicated query language. This page will help you to choose the queries that will give you the best results.

Query Basics

A query is simply a description of an information need. Unlike Boolean systems that search for just those documents containing *all* the words in your query, Excite for Web Servers will search for documents that are a best match for the words in your query. Excite for Web Servers will also search for documents that are about the same concepts that your query describes, so sometimes Excite for Web Servers will bring back articles that don't mention *any* of the words in your original query.

What this means is that your query -- the description of your information need -- can be as detailed as you like. Don't worry about providing too many words; the more words, the better. Additional words in your query will help Excite for Web Servers figure out what concepts you're really interested in. On the other hand, Excite for Web Servers will do a pretty good job of figuring out what documents are interesting to you even if your query is vague.

For example, let's say you're searching a web site for documents about customer support for the Widget2000 product you're using. A good starting point would be

```
customer support for the Widget2000
```

If you have a question about a particular feature of the Widget2000, for example the Blurfl upgrade package, you might choose a query like

```
customer support for the Blurfl upgrade package
of the Widget2000
```

Even if there are no documents that are actually about the Blurfl upgrade, Excite for Web Servers will still show you documents about Widget2000 customer support.

Advanced Query Tips

Here are some suggestions for getting the best results out of Excite for Web Servers.

Use More Words
The easiest way to narrow your Excite for Web Servers search and the first thing you should try is to simply use more words in your query. The greater the detail you provide, the better Excite for Web Servers is able to find precisely what you're looking for. Also try using the Query By Example option on the search results page.

Use + to Require Words
Put a plus sign (+) in front of a search word and Excite for Web Servers will make sure that ALL of the documents it returns contain the word. Example search: Travel +France.

Use - to Exclude Words
Put a minus sign (-) in front of a search word and Excite for Web Servers will make sure that NONE of the documents it returns contain the word. Example search: Jaguar -car -automobiles.

Use AND, OR, NOT, AND NOT, ( )
Excite for Web Servers supports full Boolean operators and syntax. You c an use the AND, OR, NOT, and AND NOT operators, and parentheses ( ) for grouping . Example search: swimming AND (man OR woman).

Using a Plus Sign (+) to Require Words

What it does:
Excite for Web Servers will make sure that ALL of the documents it finds include the word(s) you specify as being required.

How to use it:
In your search text, put a plus sign (+) in front of words that must be in documents that Excite for Web Servers finds. Do not put a space between the plus sign (+) and the word. For example, to find documents about hockey, but only those with the term NHL in them you could enter:

hockey +NHL

What's different about it:
Without the plus sign (+), Excite for Web Servers looks for documents about any of the words in your search text. Excite for Web Servers will rank documents that have all of the words higher, but will also list documents that have only some of your search words as well as documents that may have none of your search words, but that appear to be conceptually related.

The downside:
You may miss related documents that don't have the words you specify as required. For example, the search "hockey +NHL" would not include documents that have the words National Hockey League, but not NHL.

Using a Minus Sign (-) to Exclude Words

What it does:
Excite for Web Servers will make sure that NONE of the documents it finds contain any word(s) you specify to exclude.

How to do it:
In your search text, put a minus sign (-) in front of words that must not be in documents that Excite for Web Servers finds. Do not put any space between the minus sign (-) and the word. For example, if you want to find documents about zeppelin aircraft but not the rock band Led

Zeppelin, you could enter: Zeppelin -Led

What's different about it:
Without the minus sign (-), Excite for Web Servers looks for documents that are conceptually-related to all the search words you provide, rather than looking for items to exclude from the results.

The downside:
It's easy to exclude too much. For example, if you were looking for information on greyhound dogs and not the bus company, the search "greyhound -bus" would exclude a document that was all about greyhounds, but that had the sentence "the greyhound trainers arrived by bus."

Boolean Operators: AND, OR, NOT and ()

What they do/How to use them:
AND - Documents found must contain all words joined by the AND operator. Note that this is equivalent to putting a plus sign (+) in front of the word. For example, to find documents that have all of the words wizard, oz and movie, you could enter: wizard AND oz AND movie

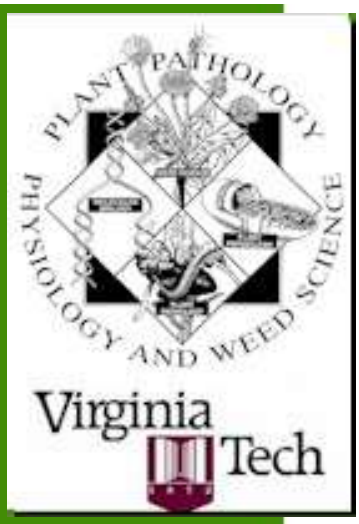
OR - Documents found must contain at least one of the words joined by OR. For example, to find documents that have either the words cat or kitten you could enter: cat OR kitten

AND NOT - Documents found cannot contain the word after the term AND NOT. Note that this is equivalent to putting a minus sign (-) in front of the word. For example, to find documents that have the word pets, but not the word dogs, you could enter: pets AND NOT dogs

( ) - Parentheses are used to group portions of Boolean queries together. For example, to find documents that have the word fruit, and either the word banana or the word apple in them, you could enter: fruit AND (banana OR apple)

What's different about it:
Allows for excluding and requiring words, and complex combinations of words.

The downside:
It's often difficult to specify exactly what you want to include or exclude. You can also get unexpected results if you are not careful about your use of operators and parentheses. For example, the search bananas OR apples AND oranges is the same as the search bananas OR (apples AND oranges). Both queries will find documents that contain both apples and oranges, together with documents that contain the word bananas. However, the query (bananas OR apples) AND oranges is not the same. It will find documents containing the word oranges and, in the same document, either bananas or apples. Be careful out there!



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Prospective Students

The Campus and the Community

Virginia Polytechnic Institute and State University (also known as Virginia Tech) is a publicly supported, comprehensive, land-grant university serving the Commonwealth of Virginia, the nation, and the international community by generating and disseminating knowledge in the humanities, arts, social sciences, scientific and professional disciplines through instruction, research, and extension. The campus is located in Blacksburg, Montgomery County, Virginia, in the New River Valley, 2100 feet above sea level and centered in the Appalachian Mountains. Roanoke, 40 miles to the northeast, is the center of a metropolitan area with a population of about 200,000 people. The Roanoke Airport is an up-to-date airport that serves the New River Valley. The area is one of exceptional natural beauty and provides many opportunities for outdoor recreation. There are more than 26,000 students at Virginia Tech; about 4,000 are in graduate programs.

Departmental Missions and Graduate Programs

The Department of Plant Pathology, Physiology and Weed Science (PPWS) is one of the oldest departments in the College of Agriculture and Life Sciences of Virginia Tech dating back to 1889. The current departmental structure was established in 1949. Our faculty, students and support staff conduct research, teaching, and extension programs in three distinct disciplines key to plant productivity, protection and quality: plant pathology - the study of diseases, plant pathogens and their management; plant physiology - the study of plant function, growth and development, and response to environmental stresses; and weed science - the study of weed biology, ecology and management. We have a very strong biotechnology program with faculty actively involved in molecular biology studies of biotic and abiotic plant stresses. The department's main office, teaching classrooms, and half of our research laboratories are located in Price Hall. Other research laboratories and the

departmental greenhouses are housed in the Fralin Center for Biotechnology and the Glade Road Research Center. The research laboratories within the department contain a wide range of specialized equipment for conducting cutting-edge research in our three main disciplines. Field plots are located a few miles away on a 1,600 acre research farm and at the nearby Turfgrass and Glade Road Research Centers. Nine departmental faculty are located at off-campus field research facilities at Blackstone, Suffolk, Winchester, Virginia Beach, and Painter on the Eastern Shore of Virginia.

PPWS offers Master of Science (thesis and non-thesis M.S.) and Doctor of Philosophy (Ph.D.) degrees in plant pathology, plant physiology and weed science; participates in baccalaureate programs and a two-year associate degree program in agricultural technology. The PPWS department has about 30 graduate students; half who are weed science/stress physiology majors, and the other half are plant pathology majors. About one third of our graduate student population are women and approximately half are international students. Our graduate students may also participate in the interdisciplinary programs in Plant Physiology, Genetics, and Molecular and Cell Biology, with which our department is affiliated.

Faculty programs

The department has 32 faculty members, 16 who are plant pathologists, 8 plant physiologists and 7 weed scientists. Several visiting professors, research associates, and adjunct faculty are also associated with the department. We have a variety of research areas available to our graduate programs. The following brief review of our faculty and their research interests and expertise will help orient you to our department. We encourage you to contact our faculty by e-mail for more information about their programs.

| Plant Pathology | Plant Physiology | Weed Science |

Faculty Programs in Plant Pathology (* Off Campus)

- Baudoin, A.B.A. -Associate Professor (abaudoin@vt.edu)- Epidemiology; integrated pest management; biological control of weeds
- Couch, H.B. -Professor (hcouch@vt.edu)- Turfgrass pathology; physiology of infection; chemical control of diseases
- Eisenback, J.D. - Professor (jon@vt.edu)- Plant Nematology
- Griffin, G.J. - Professor (gagriffi@vt.edu)- Ecology of plant pathogenic fungi; chestnut blight; biological control
- Hansen, M.A. - Instructor (maryannh@vt.edu)- Diseases of ornamentals; Plant Clinic Manager
- Hong, Chuan* - Assistant Professor (chhong2@vt.edu) - Environmental plant pathology
- Johnson, C.S.* - Professor (spcdis@vt.edu)- Epidemiology; crop loss assessment; tobacco diseases
- McDowell, J.M. - Assistant Professor (johnmcd@vt.edu)- Molecular mechanisms of disease resistance

- Phipps, P.M.* - Professor (pmphipps@vt.edu)- Peanut and soybean diseases; nematology; epidemiology
- Shokes, F.M.* - Director, Tidewater AREC (fshokes@vt.edu)
- Stromberg, E.L. - Professor and Interim Head (elstrom@vt.edu)- Field crop pathology; chemical, biological and cultural disease control
- Tolin, S.A. - Professor (stolin@vt.edu)- Plant virology; biotechnology policy
- Tyler, B.M. - Professor, Virginia Bioinformatics Institute (brtyler@vt.edu)- Application of genomics and bioinformatics to plant-microbe interactions
- Warren, H.L. - Professor - (hwarren@vt.edu)- Diseases of corn; vegetable pathology
- Yoder, K.S.* - Professor (ksyoder@vt.edu)- Tree fruit pathology; mode of action and resistance to fungicides

Faculty Programs in Plant Physiology

- Chevone, B.I. - Associate Professor (bchevone@vt.edu)- Plant stress physiology; air pollution
- Cramer, C.L. - Professor (ccramer@vt.edu)- Molecular and genetic bases of resistance; biotic and abiotic plant stress; pharmaceuticals in transgenic plants
- Denbow, C.J. - Research Scientist (cdenbow@vt.edu)- Plant molecular and cellular biology
- Grabau, E.A. - Associate Professor (egrabau@vt.edu)- Molecular biology of soybean improvement; transgenic plants
- Grene, R. - Professor (grene@vt.edu)- Air Pollution and other abiotic stresses; plant metabolism; plant gene expression and regulation
- Jelesko, J.G. - Assistant Professor (jelesko@vt.edu)- Molecular genetics of plant DNA recombination; molecular biology of alkaloid biosynthesis in tobacco
- Medina-Bolivar, F. - Research Assistant Professor (fmb2@vt.edu)-Transgenic plants for production of human vaccines. Production of natural products and recombinant proteins in hairy root cultures.
- Nessler, C.L. - Professor, Associate Dean for Research in the College of Agriculture and Life Sciences, and Director of the Virginia Agricultural Experiment Station (cnessler@vt.edu)- Metabolic engineering of primary and secondary products
- Sobral, B.W.M. - Professor and Director of the Virginia Bioinformatics Institute- (sobral@vt.edu) Application of genomics and bioinformatics to predicting phenotypic performance

Faculty Programs in Weed Science (* Off Campus)

- Askew, S.D. - Assistant Professor (saskew@vt.edu)- Turf Weed Extension
- Derr, J.F.* - Professor (jderr@vt.edu)- Weed identification and control in ornamentals, turf, tree fruit, small fruit
- Hagood, E.S. - Professor (shagood@vt.edu)- Weed control in agronomic crops; low-input sustainable agriculture; integrated weed management
- Hipkins, P.L. - Extension Weed Scientist/Senior Research Associate (lhipkins@vt.edu)- Right-of-way vegetation management and turf weed control
- Westwood, J.H. - Assistant Professor (westwood@vt.edu)- Parasitic weed biology and control
- Wilson, H.P.* - Professor (hwilson@vt.edu)- Weed management in vegetable and agronomic crops

Application Information

Application for admission to graduate school can be submitted on-line. Click here for the application or in the U.S. call 877-543-1405 to request an application packet. The department has established deadlines for screening applications for the respective academic semester. Students are ultimately accepted/rejected by the department. A completed application includes academic transcripts, three letters of recommendation and scores from the Graduate Record Examination (GRE). Students whose native language is not English must submit a current score from the Test of English as a Foreign Language (TOEFL). Although interviews are not required, we welcome visits from potential applicants. Applications from U.S. minority groups and women are welcomed and encouraged.

Financial Aid Information

Financial arrangements are made after formal acceptance into Graduate School. Assistantships and fellowships are available on a competitive basis and awarded to students for demonstrated scholastic ability. The amount and duration of assistance is dependent upon satisfactory progress throughout the graduate program and the availability of funds. Most assistantships are funded through grants of individual faculty; therefore, the research area of study must contribute to the objectives of the grant. Students on assistantships have in-state status and tuition is usually provided as part of their assistantship.

Minority Academic Opportunities Program

For more information contact:

Craig Nessler, Professor and Head
Plant Pathology, Physiology and Weed Science
Telephone: 540-231-6361; Fax: 540-231-7477
e-mail: ppws@vt.edu

Karen DePauw, Dean, Graduate School
Telephone: 540-231-7581; Fax: 540-231-1670
e-mail: jmerola@vt.edu

Randolf L. Grayson, Director
Minority Academic Opportunities Program (MAOP)
Telephone: 540-231-4209; Fax: 540-231-7477; e-mail: rgrayso@vt.edu

Laurence D. Moore, Special Assistant to the
Provost for Diversity, Co-Director of MAOP
Telephone: 540-231-6362; Fax: 540-231-7477;
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413 Price Hall Virginia Tech
Blacksburg, VA 24061-0331
e-mail: ppws@vt.edu

http://www.ppws.vt.edu

Last Updated May 11, 2004
Comments to Peter Sforza.

WELCOME

Welcome to the Virginia Tech family and the Department of Plant Pathology, Physiology, and Weed Science (PPWS). We are delighted that you chose to pursue your graduate education in our department and look forward to helping you reach your personal and professional goals. This 2001-2002 edition of the **Graduate Student Handbook** is designed to help guide you through the planning and completion of your graduate program. Keep it and refer to it often as it will provide the information and milestone requirements needed to complete your degree.

The PPWS Graduate Student Handbook defines the guidelines and policies governing the Master's and Doctoral Programs offered by the PPWS Department and is supplemental to the information in the current Graduate Catalog published by the Graduate School of Virginia Tech. In addition, the Handbook describes the missions, programs, curricula, facilities, and faculty expertise available in the department.

The Graduate Student Handbook is revised each academic year and is prepared as a source of information for the graduate faculty, graduate students and applicants to the graduate program in Plant Pathology, Physiology, and Weed Science. All faculty and students should become thoroughly familiar with its contents, and adhere to these guidelines and policies in formulating the student's program of study. Students should use the handbook in consultation with their major professor and advisory committee as they plan their program of study and research projects.

I encourage all graduate students and faculty in the department to read this Handbook and I extend my best wishes to all of you for a successful and rewarding 2001-2002 academic year.

If you have any questions about the material presented in this handbook or suggestions for its improvement, please contact the main office of the Department (411 Price Hall; 231-6361)

Craig L. Nessler
Professor and Head
PPWS Department

Revised, September 2001

TABLE OF CONTENTS

APPENDICES

I. DEPARTMENTAL HISTORY

The department of Plant Pathology, Physiology and Weed Science (PPWS) is one of the oldest departments of Virginia Tech dating back to 1889. In its early years, the main disciplines of the department were housed in the Mycology Department. A separate Department of Plant Pathology was first established in 1907 and continued to exist in various forms until 1935, when Plant Pathology became part of the Biology Department. The current structure of the Department was established in 1949 with the name of Plant Pathology and Physiology and remained unchanged until 1983, when Weed Science was added to the Department's name to recognize the three main disciplines housed in the department.

The main highlights in our departmental history are as follows:

Entomology and Mycology Department (1889-1891)
Horticulture, Entomology and Mycology Department (1891-1902)
Entomology and Mycology Department (1902-1904)
Mycology Department (1904-1907)
Plant Pathology Department (1907-1914)
Plant Pathology and Bacteriology Department (1914-1919)
Plant Pathology Department (1919-1926)
Botany and Plant Pathology Department (1926-1935)
Biology Department (1935-1949)
Department of Plant Pathology and Physiology (1949-1983)
Department of Plant Pathology, Physiology and Weed Science (1983-present)

The Department has had 12 department heads since 1889. They were:

W. B. Alwood (1889-1904)
W. A. P. Moncure (1904-1908)
H. S. Reed (1908-1915)
F. D. Fromme (1915-1928)
S. A. Wingard (1928-1964)
R. G. Henderson (1964-1965)
H. B. Couch (1965-1974)
C. L. Foy (1974-1980)
G. R. Hooper (1980-1984)
L. D. Moore (1985-1996)
K. K. Hatzios (1997-2000)
C. L. Nessler (2000-present)

II. DEPARTMENTAL MISSIONS AND GOALS

The underlying mission of the department is to optimize plant productivity and quality by limiting the impact of biotic and abiotic stresses on the profitability of crops and other plant enterprises, as well as the impact of these stresses on natural and agricultural ecosystems. The department conducts research, teaching, and extension programs in three distinct plant science disciplines key to productivity, protection and quality: **plant pathology** – the study of diseases, plant pathogens and their management; **plant physiology** – the study of plant function, growth and development and response to environmental stresses; and **weed science** – the study of weed biology, ecology, and management. All major plant commodities grown within the Commonwealth are encompassed

within the department's programs, including row crops, forages, horticultural crops, urban and landscape plants and forestry.

A. RESEARCH

The Department's research goals are to (a) develop new concepts and principles in the disciplines of plant pathology, plant physiology, and weed science and (b) adapt these and other established principles to new situations for solutions of specific problems. Research interests of the faculty vary from fundamental to applied, as follows: molecular biology, biological control, genetics of host-parasite interactions, ecology of root disease, fungicide-plant-soil interactions, nematology, virology, physiology of disease, plant stress metabolism, herbicidal action, plant growth regulation, air pollution, weed and disease control, and plant protection.

B. EXTENSION

Extension programs by departmental specialists involve providing extension personnel, growers, commodity groups, urban and suburban residents, and business and industrial interests with (a) a continuing source of knowledge relevant to plant disease and weed control and (b) identification, survey, and diagnostic services in these areas. Field test-demonstrations are conducted and the results used to formulate recommendations for the control of diseases, nematodes, and weeds associated with agronomic crops, fruits, vegetables, turf and ornamentals, forest and shade trees, aquatic and recreational areas, and along highways, rights-of-way and other non-crop situations. Up-to-date information on plant protection is disseminated in the form of timely publications, news releases, radio and farm visits. A modern Plant Clinic is operated by the Department to aid agricultural producers and other clients in the Commonwealth in solving problems related to plant diseases, nematode infection, nutrient deficiencies, pesticide damage, and weed identification and control.

C. TEACHING

The Department's teaching program provides counsel and guidance, and a balanced offering of courses in fundamental and applied phases of plant pathology, plant physiology, and weed science. This includes serving the needs of other plant science departments as well as graduate programs within the PPWS Department. M.S. and Ph.D. degree programs are offered in plant pathology and plant physiology/weed science, along with a non-thesis program at the M.S. level emphasizing plant protection.

III. PERSONNEL

The Department has 30 tenure track, and three non-tenure track faculty members. Eight faculty positions are located at off-campus research facilities. Several visiting professors, research associates, and adjunct faculty are also associated with the Department. The areas of interest and expertise of all faculty are listed below. Classified employees both on and off campus augment all activities. At Blacksburg, laboratory specialists/technicians are assigned to many projects and project leaders. Agriculture research supervisors and technicians assist in field and greenhouse programs.

FACULTY PROGRAMS

PLANT PATHOLOGY

SAMUEL A. ALEXANDER – (salex@mail.vt.edu) Associate Professor (1976)
(Ph.D., Virginia Polytechnic Institute and State University, Blacksburg)
Eastern Shore Agricultural Research and Extension Center, Painter, VA

Dr. Alexander's research provides the basis for understanding the etiology, epidemiology, management, and control of diseases of vegetables. Field research programs are conducted with all major vegetable crops, and are guided toward solving pre-harvest and post-harvest problems in the commercial vegetable industry.

ANTON B. BAUDOIN – (abaudoin@vt.edu) Associate Professor (1981)
(Ph.D., University of California, Riverside)
417 Price Hall

Dr. Baudoin's teaching responsibilities include courses in Pest Management (pathology section), Introductory Plant Pathology, Principles of Plant Disease Management, Diseases of Crop Plants, Epidemiology of Plant Diseases, and Principles of Biology. Current research centers on biology and control of fungal diseases of grapes, with emphasis on Botrytis bunch rot, black rot, powdery mildew, and sour rot.

HOUSTON B. COUCH – (hcouch@vt.edu) Professor (1965)
(Ph.D., University of California, Davis)
111 Price Hall

The long range objective of Dr. Couch's research program is to characterize the form, structure, and chemical make-up of the surface of grass leaves at the moments most conducive for infection by restricted common primary saprophytic phylloplane microflora, and to identify the cultural practices and environmental conditions that contribute materially to the development of these features. He also conducts disease control experiments using chemical and biological fungicides and teaches an undergraduate course in the nature and control of turfgrass diseases for the Agricultural Technology Program and the Turf option of the Crop and Soil Environmental Sciences Department.

JONATHAN D. EISENBACK – (jon@vt.edu) Professor (1985)
(Ph.D., North Carolina State University, Raleigh)
104 Price Hall

Dr. Eisenback's primary responsibility is to develop an innovative research program in plant nematology emphasizing the taxonomy, evolution, ecology, and biology of the root-knot nematodes (*Meloidogyne* species). Eleven of the economically most important species have been characterized, nine new species of *Meloidogyne* have been described, and 14 populations of *M. hapla* with chromosome numbers of n = 14, 15, 16, and 17; 2n = 23 and

24; and 3n = 43, 45, and 48 have been compared. In addition, new techniques for light and scanning electron microscopy have been developed for these morphological comparisons, including sequential fixation, freeze drying, dissection, and multiple focus and exposure photography. His research goals focus on the control of the agriculturally important species of root-knot nematodes in Virginia, the southeastern U.S., and in developing countries around the world. He teaches the Introduction to Plant Parasitic Nematology as a core course in the Department, advises and directs graduate students, and teaches Plant Science for the Agricultural Technology Program.

GARY J. GRIFFIN – (gagriffi@vt.edu) Professor (1967)
(Ph.D., Colorado State University, Fort Collins)
101-E Price Hall

The objectives of Dr. Griffin's programs are to identify the principal factors involved in the ecology and biological control of soil-borne and other plant pathogenic fungi, and to elucidate the physiological mechanisms and environmental factors involved in blight resistance and blight biological control on American chestnut. Dr. Griffin teaches a graduate course on plant pathogenic fungi, an undergraduate course in forest pathology, and directs graduate students.

MARY ANN HANSEN – (maryannh@vt.edu) Instructor (1984)
(M.S. in Plant Pathology, University of Wisconsin, Madison)
106 Price Hall

Ms. Hansen supervises the Plant Disease Clinic and Nematode Assay Laboratory. These laboratories provide plant diagnostic services to extension agents statewide. Diagnoses and control recommendations are provided for 2500 plant and soil samples each year. The objective of the diagnostic program is to provide growers with timely and accurate information to prevent crop loss. Ms. Hansen's other extension responsibilities include presenting talks and training sessions on plant diseases and their control to extension agents, grower groups, and Master Gardeners throughout the state. She also teaches Clinic Experience, a graduate course in plant disease diagnostics, and co-teaches Domesticating the Gene: Plants, Plagues, and the Dawn of the Genomic Era, a new undergraduate course.

CHUANXUE HONG - (chhong@vt.edu) Assistant Professor (1999)
(Ph.D. Beijing Agricultural University)
Hampton Roads Agricultural Research and Extension Center, Virginia Beach, VA

Dr. Hong conducts research and extension programs on environmental plant pathology. His research addresses the common issues facing the nursery and/or landscape industry, such as water recycling, interstate and international movement of ornamental materials and products, re-use of green wastes, potting mixes, and plastic containers. His research interests encompass applied and basic aspects of plant pathology including molecular characterization and detection of plant pathogens, investigation of basic pathogen biology and ecology, epidemiology and ornamental disease management. Current areas of

interest include characterization and detection of plant pathogens in recycling irrigation systems, epidemiology of ornamental diseases, economic threshold of waterborne pathogens for major nursery crops, and innovative management strategies. In cooperation with faculty on campus, he directs graduate student research programs for the M.S. and Ph.D.degrees in plant pathology.

CHARLES S. JOHNSON – (spcdis@mail.vt.edu) Associate Professor (1985)
(Ph.D., North Carolina State University, Raleigh)
Southern Piedmont Agricultural Research and Extension Center, Blackstone, VA

Dr. Johnson conducts research and extension programs for tobacco disease and weed control. His research involves a large number of diseases and pest problems. Current research priorities include studying the biology and management of tobacco cyst nematodes and identifying better control methods for tobacco blue mold and collar rot. Much of this work involves increasing use of host resistance and improving use of pesticides. Dr. Johnson's graduate students work extensively with him in these areas in addition to conducting their own research. Dr. Johnson and his students also cooperate extensively with other faculty, county extension agents, industry leaders, and growers in conducting on-farm experiments and a variety of extension programs.

GEORGE H. LACY – (lacygh@vt.edu) Professor (1981)
(Ph.D., University of California, Riverside)
202-A PMB Building, Glade Road Research Center

Dr. Lacy studies molecular biology of plant-bacterial disease interactions, to develop controls for those diseases, and to incorporate his expertise into the curriculum. In his *Erwinia carotovora*-bacterial soft rot model, he has investigated the organization, regulation, and structure of the genes involved in pectolysis and proteolysis, constructed site-replacement mutants of the pathogen, and studied gene activation in interactions with the host. In Biological control, he has worked with selection of biological control agents and seed application for the control of root diseases caused by fungi. In phylogenetics, he is studying relationships among strains of xanthomonads, *Erwinia amylovora,* and *Cercospora zeae-maydis* using DNA:DNA hybridization and RFLP techniques. He teaches Phytopathogenic Prokaryotes, team teaches Plant Disease Physiology and Development, advises undergraduate students in Biology, teaches introductory Genetics in Biology, and directs graduate students.

JOHN M. MCDOWELL – (johnmcd@vt.edu) Assistant Professor (2000)
(Ph.D. University of Georgia, Athens)
204 Fralin Biotechnology Center

Plant pathogens are estimated to reduce crop yields by ~30% worldwide. Disease-resistant crop varieties have been used for decades to reduce disease losses, but our understanding of the molecular basis of disease resistance in only fragmentary. Dr. McDowell’s research focuses on the interaction between the model plant Arabidopsis and its

natural pathogen *Peronospora parasitica* (downy mildew). His lab uses molecular genetic, genomic, and bioinformatics-based approaches to understand how plants 'recognize' pathogens, how new recognition capabilities evolve, and how the recognition signal is transduced to activate defenses in the proper place and time. In the long term, this basic research is expected to inform strategies to enhance natural resistance mechanisms in crops, thereby reducing the grower's reliance on costly and harmful chemical inputs. Dr. McDowell's teaching involvement includes a molecular biology lab for undergraduates, and a graduate level course addressing molecular aspects of plant-microbe interactions.

PATRICK M. PHIPPS – (pmphipps@vt.edu) Professor (1978)
(Ph.D., West Virginia University, Morgantown)
Tidewater Agricultural Research and Extension Center, Suffolk, VA

Dr. Phipps has responsibilities for research on epidemiology and control of field crop diseases in Southeastern Virginia. Areas of emphasis include disease forecasting and development of cost effective use patterns for fungicides and nematicides. His programs seek to develop improved control measures that are both safe and effective, and to incorporate new technology into cooperative extension programs for peanut, soybean, corn, cotton, and small grains in the region. In cooperation with faculty on campus, he directs graduate student research programs for the M.S. and Ph.D. degrees in plant pathology. Students spend each summer working in the laboratory and field at the Tidewater AREC in Suffolk. Additional information is available at http://www.vaes.vt.edu/tidewater.

FRED SHOKES, (fshokes@vt.edu) Professor (1999)
(Ph.D. University of Georgia, Athens)
Tidewater Agricultural Research and extension Center, Suffolk, VA

Dr. Shokes joined the PPWS Department as Professor of Plant Pathology on January 1, 1999. He serves as Director of the Tidewater Agricultural Research and Extension Center in Suffolk, VA.

R. JAY STIPES – (treedr@vt.edu) Professor (1967)
(Ph.D., North Carolina State University, Raleigh)
417 Price Hall

The principal activities of Dr. Stipes' research and extension programs are to address the identification, biology and management of diseases of landscape trees. Current projects include refinement of tree injection technology, using the newer systemic fungicides, with primary emphasis on Dutch Elm Disease and biocontrol of Ailanthus. He lectures in a broad spectrum of international, national, regional, and state tree biology and pathology conferences, workshops, and short courses. Teaching activities include Principles of Agricultural Chemistry; team teaches Pesticide Usage, and guest lectures in courses in urban forestry, horticulture, and biology, as well as independent studies for undergraduate and graduate students. He has co-developed a new undergraduate course, Pest and Stress Management of Trees. He is a consultant in tree biology and diseases, and in forensic tree

pathology. Dr. Stipes advises undergraduate and graduate students.

ERIK L. STROMBERG – (elstrom@vt.edu) Professor (1981)
(Ph.D., Oregon State University, Corvallis)
401 Price Hall

The primary interests and responsibilities of Dr. Stromberg's research and extension program involve the study of the biology, identification, prevention, and control of diseases of agronomic crops including alfalfa, corn, small grains, and soybeans. Current projects include: the development and understanding the mode of action of gray leaf spot-resistant corn germplasm, refinement of fungicide treatment thresholds for powdery mildew, leaf rust, tan spot and stagonospora leaf and glume blotch for soft red winter wheat; epidemiology and incidence of barley yellow dwarf in wheat, and a study of the take-all fungus and the influence of seed treatments (biological and chemical) on the incidence and severity of take-all wheat under high yield management. He is also involved in the mentoring and training of graduate students.

SUE A. TOLIN – (stolin@vt.edu) Professor (1966)
(Ph.D., University of Nebraska, Lincoln)
102-A PMB Building, Glade Road Research Center

Dr. Tolin conducts research with plant viruses, with focus on the molecular biology of virus strains and host-interactions. She identifies viruses in Virginia crops (mainly soybean and other legumes) and develops control measures through breeding, management and biotechnology approaches. She has investigated several soybean mosaic virus (SMV) strains and shown, through cooperative work with plant geneticists, that resistance in soybean is mediated by at least three genes, now marked molecularly. SMV strains that overcome certain of the resistance genes, and other similar potyviruses - bean yellow mosaic, clover yellow vein, and peanut mottle - are being analyzed molecularly to characterize the pathogenicity-related sequences. She studies forage legumes and other wild plants as reservoirs for these potyviruses and peanut stunt virus in natural ecosystems. Her virology and biotechnology expertise is incorporated into the curriculum, where she teaches Plant Pathogenic Viruses in the plant disease agents series; team teaches Disease Development and Physiology; team teaches Topics in Virology; lectures on biotechnology policy, environmental risk assessment, and government regulations in several courses, and directs graduate students. She is also active in professional scientific societies in public policy affairs related to biotechnology and funding agricultural research.

HERMAN L. WARREN – (hwarren@vt.edu) Professor (1989)
(Ph.D., University of Minnesota, St. Paul)
100 Price Hall

Dr. Warren's job responsibilities involve research on diseases of corn, extension activities on diseases of vegetables, and teaching on genetics of host-parasite interactions. He is responsible for research on disease development, epidemiology, genetics, and

development of disease resistance germplasm using traditional and biotechnical methods. Current focus on pathogenicity differences between races of *Bipolaris zeicola* and on mechanism of genetic resistance of maize. International activities include Integrated Pest Management of cereal crops and host resistance in Africa and Eastern Europe. Dr. Warren directs graduate students.

KEITH S. YODER – (ksyoder@vt.edu) Associate Professor (1976)
(Ph.D., Michigan State University, East Lansing)
Winchester Agricultural Experiment Station, Winchester, VA

Dr. Yoder has a research and extension appointment in tree fruit diseases at the Virginia Tech Agricultural Research and Extension Center, Winchester. The value to the economy of Virginia in the fruit industry, including grower service groups and fruit processors, is estimated to be $150 million annually. A research-extension appointment at a field station in the leading fruit county in the state includes extensive field research. Research and extension activities are closely integrated with training graduate students and many other activities that cannot be categorized as solely research or extension.

PLANT PHYSIOLOGY

RUTH G. ALSCHER – (ralscher@vt.edu) Professor (1988)
(Ph.D., University of California, Davis)
103-B PMB Building, Glade Road Research Center

Dr. Alscher is responsible for research and teaching in plant physiology. Her research focuses on antioxidant molecular and metabolic resistance mechanisms of plant cells and tissues to oxidative stress. Her teaching efforts center on graduate and undergraduate education in the laboratory, the classroom, and at the level of curriculum development.

BORIS I. CHEVONE – (bchevone@vt.edu) Associate Professor (1980)
(Ph.D., University of Minnesota, St. Paul)
Air Pollution Laboratory, Glade Road Research Center

Dr. Chevone's research interests are to investigate the effects of air pollutants and other environmental stresses on the physiology, biochemistry, and molecular biology of plants, especially as these effects relate to agriculture and forestry in Virginia. The role of biochemical defense/repair systems in plants for providing tolerance to ozone, low temperatures, and moisture stress is of primary interest. He team teaches the Advanced Plant Physiology and Metabolism course.

CAROLE L. CRAMER – (ccramer@vt.edu) Professor (1986)
(Ph.D., University of California, Berkeley)
307 Fralin Biotechnology Center

Dr. Cramer is responsible for research and teaching in the areas of molecular plant pathology and plant molecular and cellular biology. Her current research is focused in the following areas: 1) plant genetic engineering of enhanced disease resistance, 2) molecular and cellular basis of plant disease resistance, 3) mechanisms of subcellular targeting and protein processing, 4) protein prenylation and signal transduction in control of plant cell division, and 5) transgenic tobacco and other plants for bioproduction of novel high-value proteins for animal and human health-related applications.

CYNTHIA J. DENBOW – (cdenbow@vt.edu) Research Scientist (1981)
(Ph.D., Virginia Polytechnic Institute and State University, Blacksburg)
317 Fralin Biotechnology Center

Dr. Denbow is involved in research and teaching in the areas of molecular and cellular biology. Her current research is focused on mechanisms of subcellular targeting and protein degradation. She is also interested in the use of transgenic plants for high-level production of human proteins.

ELIZABETH A. GRABAU – (egrabau@vt.edu) Associate Professor (1990)
(Ph.D., University of California, San Diego)
305 Fralin Biotechnology Center

Dr. Grabau's research and teaching interests are in plant molecular biology and the application of biotechnology to agriculture and life sciences. Dr. Grabau conducts research in soybean gene expression and crop improvement. Current studies are focused on the production of low-phytate soybeans for improved phosphorus availability. One project involves the introduction of phytase gened into soybean to allow breakdown of phytate in soybean seeds. The other approach is to utilize an antisense strategy to lower the expression of a key enzyme in the phytate biosynthetic pathway. The successful production of low-phytate soybeans will decrease environmental phosphorus pollution resulting from poultry production. In collaboration with Dr. Pat Phipps, a project has recently been initiated on the genetic modification of peanut for enhanced disease resistance. Dr. Grabau's teaching responsibilities include a graduate level course in Molecular Biology for the Life Sciences and an undergraduate course in Biotechnology in Agriculture and Society.

Dr. Grabau is on sabbatical leave for the 2001-2002 academic year.

JOHN G. JELESKO – (jelesko@vt.edu) Assistant Professor (2000)
(Ph.D. University of Washington, Seattle)
304 Fralin Biotechnology Center

Dr. Jelesko's laboratory is interested in how meiotic recombination affects the evolution and organization of the plant genome. Specifically, he is interested in the molecular details of contemporary meiotic intergenic recombination events that create novel

chimeric genes and remodel the organization of complex loci. His laboratory uses transgenic synthetic gene clusters to identify rare recombinant chimeric genes. The rare recombinant chimeric genes are easily identified because they activate a previously silent Firefly luciferase gene, thereby imparting the plant with the ability to bioluminesce in the dark. This simple genetic screen facilitates the screening of millions of plants and the identification of rare recombination events. This approach enables a detailed molecular investigation of meiotic recombination in plants and its role in the evolution of complex loci. His laboratory is interested in the various effects of intergenic recombination that include: the role of environmental factors on meiotic recombination, fidelity of meiotic recombination, chromosome rearrangements that lead to reproductive isolation, and chimeric disease resistance genes with new pathogen recognition specificities.

CRAIG L. NESSLER – (cnessler@vt.edu) Professor and Head (2000)
(Ph.D. Indiana University, Bloomington)
110 & 413 Price Hall

Dr. Nessler works on the molecular regulation of plant primary and secondary metabolic pathways. His laboratory is interested in altering the amounts and kinds of pharmaceutical compounds produced in transgenic plants as well as transferring specific pathway genes into crops to increase their resistance to disease and insect pests. Another major focus of his group is to metabolically engineer crops to alter nutritional characteristics.

DAVID M. ORCUTT – (dmorcutt@vt.edu) Professor (1973)
(Ph.D., University of Maryland. College Park)
114 Price Hall

Dr. Orcutt teaches graduate and undergraduate courses that emphasize the impact of the environment on the physiology of growth and development in plants. His research emphasizes the impact of sterol-inhibiting fungicides on algal lipids and mechanisms of tolerance/susceptibility of non-target algae species to xenobiotics. Other research interests focus on the impact of environmental stress on phytolipids, phytohormones and their interactions.

WEED SCIENCE

SHAWN D. ASKEW - (saskew@vt.edu) Assistant Professor (2001)
(Ph.D., NC State University, Raleigh)
Glade Road Research Center (0330)

Dr. Askew's primary responsibility is to provide statewide leadership in the development of weed control programs for turfgrass. Research and extension priorities include developing weed control recommendations and information pertinent to current

problems in home lawns, professional turf (golf courses, sports fields, etc.), and commercial sod and seed production. Dr. Askew works closely with Virginia Cooperative Extension agents by conducting research to address turfgrass weed problems and developing educational and training materials. He spends a significant amount of his time developing extension publications, troubleshooting, or conversing with agents, professional turfgrass personnel, and sod/seed farmers. Research efforts of his program include developing and assessing new herbicides; evaluating organic and cultural weed control options; developing new diagnostic and application technology, such as weed-sensor sprayers and computerized turfgrass quality assessment tools; and monitoring the environmental effects of weed management tactics used in turfgrass. Dr. Askew is currently seeking qualified graduate students to participate in research and educational activities.

JEFFREY F. DERR – (jderr@vt.edu) Professor (1984)
(Ph.D., North Carolina State University, Raleigh)
Hampton Roads Agricultural Research and Extension Center, Virginia Beach, VA

Dr. Derr's responsibilities are to develop weed management strategies for horticultural crops and to incorporate those results into cooperative extension programs. Research objectives are to evaluate chemical and nonchemical methods for controlling major weed problems in tree and small fruit production, field and container nursery production, and landscape maintenance. Herbicide research has focused on the control of annual broadleaf weeds and yellow nutsedge in nursery production, vine and bramble control in tree fruit, and annual grass and broadleaf weed control in turf. Landscape fabrics, organic and inorganic mulches, and herbicides have been evaluated in combination to develop Integrated Pest Management strategies for landscape weed control. He participates in the Weed Science teaching program and directs graduate students.

CHESTER L. FOY – (cfoy@vt.edu) Professor (1966)
(Ph.D., University of California, Davis)
502 Price Hall

Dr. Foy's responsibilities are to conduct basic and applied research in the area of weed science-plant physiology as follows: determine patterns of absorption, distribution, and metabolic fate of certain herbicides and adjuvants in higher plants; evaluate herbicide-adjuvant-plant interactions that may influence deposition, uptake, fate, and activity - with the goal of improving efficiency and reducing dose rates of herbicides under varying environmental conditions; determine sites and mechanisms of the modifying effects of adjuvants on plant responses; explore the use of adjuvants to (predictably) modify the mobility and fate of herbicides in soil; allelochemicals and weed/crop ecology; identify potentially troublesome weeds in Virginia agronomic and fruit crops and conduct field and/or greenhouse test programs involving new herbicides, adjuvants and plant growth regulators. Recent international activities also include basic research on a devastating root parasitic weed, broomrape (Orobanche spp.). Dr. Foy also teaches the weeds portion of Pest Management: Insects, Diseases and Weeds; he also advises graduate students in areas of weed science and plant physiology.

E. SCOTT HAGOOD, JR. – (shagood@vt.edu) Professor (1981)
(Ph.D., Purdue University, West Lafayette)
418 Price Hall

The primary responsibility of Dr. Hagood is to provide statewide leadership in the development of weed control programs for agronomic crops, train graduate students, and serve as the department's Extension Project Leader. With a majority extension appointment, emphasis is placed on development of recommendations and other weed control information pertinent to current problems of Virginia farmers, and the efficient dissemination of this information. The research component of his position is closely tied to his extension activities, and involves development and evaluation of new herbicides and weed control techniques that show promise for use in Virginia agriculture. He directs graduate students.

KRITON K. HATZIOS – (hatzios@vt.edu) Associate Dean and Director of Virginia Agricultural Experiment Station and Professor (1979)
(Ph.D., Michigan State University, East Lansing)
104 Hutcheson Hall
203 PMB Building, Glade Road Research Center

Dr. Hatzios is a professor in the PPWS Department, but also serves as Director of the Virginia Agricultural Experiment Station and Associate Dean for Research in the College of Agriculture and Life Sciences. Research interests focus on mechanisms of action, metabolism, and selectivity of herbicides and herbicide safeners as well as herbicide resistance in crops and weeds. He teaches Herbicide Action and Metabolism.

P. LLOYD HIPKINS - (lhipkins@vt.edu)
Senior Research Associate/Extension Weed Scientist (1987)
(M.S., Virginia Polytechnic Institute and State University, Blacksburg)
Turf Weed Science, Glade Road Research Center

Mr. Hipkins conducts research on rights-of-way vegetation management and turf weed control. The rights-of-way research investigates the various methods, including cultural and chemical techniques, of providing safe, aesthetically pleasing highways. Additional research is conducted on weed control in wildflowers. This research is funded by chemical manufacturers and the Virginia Department of Transportation. Turf weed control research is funded by the Virginia Turfgrass Council as well as chemical manufacturers, and involves the evaluation of products for efficacy and selectivity in turfgrass situations such as lawns, golf courses and turf production. Weed situations in both warm and cool season grasses are investigated.

JAMES H. WESTWOOD - (westwood@vt.edu) Assistant Professor (1999)
(Ph.D., Purdue University, West Lafayette)
406 Price Hall

Dr. Westwood's program covers aspects of weed biology, physiology and ecology. He teaches the introductory weed science course (Weed Science: Principles and Practices), and conducts research on the biology and control of parasitic weeds, specifically broomrape (*Orobanche* spp.). Current research projects include molecular characterization of host plant defense response to parasitism, genetic engineering of parasite-resistant hosts, characterization of gene expression in *O. aegyptiaca* seeds as they prepare for germination, and characterization of introduced populations of *O. minor* in the US. Dr. Westwood's research has international implications, and he
collaborates closely with scientists from Israel and Mali.

HENRY P. WILSON – (hwilson@vt.edu) Professor (1967)
(Ph.D., Rutgers University, Rutgers)
Eastern Shore Agricultural Research and Extension Center, Painter, VA

Dr. Wilson's principal responsibilities are to conduct research and train graduate students in the development of weed control/weed management programs for vegetable and agronomic crops and to utilize the results to update cooperative extension programs. His goals are to understand the crop weed competitive relationships and to develop control strategies that are low in cost and that introduce the lowest possible chemical load into the environment. Major emphasis currently involves ALS-inhibiting herbicides, weed population dynamics, and weed resistance. In addition, Dr. Wilson serves as the Director of the Eastern Shore AREC of Virginia Tech.

DEPARTMENTAL SUPPORT STAFF

LABORATORY AND FIELD TECHNICIANS

MOSS BALDWIN - Laboratory Specialist (1996)

Moss Baldwin has a B. S. degree in Biology from Virginia Tech and has completed three years of graduate course work in Mycology at Virginia Tech. Moss works in the Virology Laboratory at the Glade Road Research Center under the direction of Dr. S. A. Tolin.

SHAHROOZ FEIZABADI - Computer Systems Engineer (1998)

Shahrooz Feizabadi provides software and hardware support for the PPWS Department on a part-time basis. Shahrooz came to Virginia Tech as an engineering freshmen in 1986 and decided to take up residence in Blacksburg after receiving his B. S. degree. He subsequently completed his M. S. degree in Computer Science and is currently pursuing a Ph.D. degree in Computer Science.

LLOYD E. FLINCHUM - Laboratory Specialist Senior (1967)

Lloyd works in the Virology Laboratory at the Glade Road Research Center under the direction of Dr. S. A. Tolin, and in the Fungi Laboratory-Price Hall under the direction of Dr. E. L. Stromberg.

CRYSTAL L. GILBERT - Laboratory Specialist Senior (2000)

Crystal has a degree in Biology from Radford University and is the author of several publications. She works in the Plant Biotechnology Laboratory under the direction of Dr. J. J. Jelesko, and the Plant Molecular Biology Laboratory under the direction of Dr. J. M. McDowell. Both are located at the Fralin Center for Biotechnology.

NINA R. HOPKINS - Laboratory Specialist Senior (1965)

Nina works in the Plant Disease Clinic under the direction of Mary Ann Hansen, Director, and the Nematology Laboratory under the direction of Dr. J. D. Eisenback. She prepares and supervises Teaching Assistants in preparing labs for undergraduate and graduate classes, and teaches labs when necessary.

PHILIP J. KEATING - Laboratory Specialist Senior (1976)

Phil works in the Turfgrass Pathology Laboratory under the direction of Dr. H. B. Couch, and in the Vegetable Diseases Laboratory under the direction of Dr. H. L. Warren. He designs and conducts experiments in the field, greenhouse, and laboratory involving evaluation and data analysis and the effects of fungicides and plant growth regulators.

CLAUDE C. KENLEY - Research Specialist Senior (1976)

Claude is in charge of the Weed Identification Clinic and field research for Dr. E. S. Hagood, Jr., and in the Pesticide Physiology Laboratory under the direction of Dr. C. L. Foy.

ANGELA MCCARTHY-KENNON - Laboratory Specialist Senior (1997)

Angela received her B.S. degree in Biochemistry from the University of Missouri, Columbia (1997). She works at the Fralin Center for Biotechnology in the Host-Pathogen Molecular Biology Laboratory under the direction of Dr. C. L. Cramer, and in the Plant Molecular Genetics Laboratory under the direction of Dr. E. A. Grabau.

SUE A. MEREDITH - Laboratory Specialist Senior (1969)

Sue has a Medical Technology (MT) degree from Radford Community Hospital. She works in the Phytochemistry Laboratory located at the Glade Road Research Center under the direction of Dr. K. K. Hatzios, and in the Weed Biology Laboratory at Price Hall under the direction of Dr. J. H. Westwood.

PALMER L. PRICE - Research Specialist Senior (1966)

Palmer works in the Turf Weed Management and the Weed Identification Clinic under the direction of Dr. E. S. Hagood, Jr., Dr. S. D. Askew and P. L. Hipkins.

JEAN A. RATLIFF - Laboratory Specialist Senior (1971)

Jean works in the Tree Disease Management Laboratory under the direction of Dr. R. J. Stipes, and in the Plant Disease Epidemiology Laboratory under the direction of Dr. A. B. A. M. Baudoin located at Price Hall. She also works in the Environmental Plant Physiology/Air Pollution Laboratory under the direction of Dr. B. Chevone.

DIANE M. REAVER - Laboratory and Research Practitioner IV (1988)

Diane has a B.S. degree from the University of Michigan (1968) and a M. S. degree in Plant Pathology from Virginia Tech (1989). She currently works as a research technician in the Fungal Plant Pathology Laboratory under the direction of Dr. G.J. Griffin, and in the Plant Stress Physiology Laboratory under the direction of Dr. D. M. Orcutt.

VERLYN K. STROMBERG - Laboratory Specialist Senior (1982)

Verlyn has an AA degree in Science from Fresno City College, Fresno, CA (1966), a BA degree in Bacteriology from California State University, Fresno (1968), and two years of postgraduate education in Microbiology at Oregon State University, Corvallis, OR (1968-70). She had seven additional years of technical research experience at Oregon State University in the departments of Microbiology, Horticulture, Botany and Plant Pathology. She has written several refereed journal articles, chapter proceedings, and published abstracts. She has presented scientific papers in Bulgaria, Hungary, and Blacksburg. Verlyn has attended scientific meetings in Arizona, Virginia, California, Maryland, Canada, Georgia, and Washington, DC. Ms. Stromberg is a member of the PPWS Education Committee She works in the Phytobacteriology Laboratory under the direction of Dr. G. H. Lacy and the Stress Physiology Laboratory under the direction of Dr. R.G. Alscher. Both laboratories are located at the Glade Road Research Center.

OFFICE STAFF

ARLETA L. BOYD - Executive Secretary Senior (1991)

Arleta has an Associate Decree in Business Management from New River Community College and is a Certified Professional Secretary (CPS-1985).

JUDY H. FIELDER - Program Support Technician (1978)

Judy graduated from Northside High School June 1978, and earned a Professional Office Staff Development Certificate from New River Community College (1990). She serves the department as program support technician. Her position is split between Price Hall and the Glade Road Research Center, serving faculty, staff, and students. She enjoys working outdoors and bowling.

PATSY J. NEICE - Program Support Technician Senior (1974)

Patsy has certificates in Clerk-Steno, Clerical Procedures and Basic Accounting from the College of Agriculture bookkeepers. To keep abreast of new and updated bookkeeping procedures, she regularly attends classes on campus as they are offered. She is the departmental bookkeeper and is responsible for tracking hard and soft funds.

IV. ADMINISTRATION

The department is administered through a department head, standing committees, a Graduate Student Officer, and a Staff Association Officer. Most committees have graduate student and staff representation. The graduate students have a Graduate Student Organization (GSO) with its own elected leaders and the classified staff has a Staff Association with its own elected leaders. A list of all departmental committees and their current memberships are shown in Appendix I.

V. FACILITIES

The Department uses resources housed at several locations on or near the University campus as well as locations throughout the Commonwealth.

A. PRICE HALL

The main office of the Department is located in Price Hall, which is the second oldest building on the Virginia Tech Campus, built in 1907. Administrative offices in Price Hall include the department head's office and the main offices for secretarial and bookkeeping staff. Two departmental classrooms with space for 16 and 40 students respectively are available on the fourth floor. A conference room accommodating up to 15 people is available for small meetings; larger meetings are held in the departmental seminar room on the fifth floor, which also houses study carrels and a computer room for graduate student use. Research facilities in Price Hall include the Plant Disease and Nematode Clinics and laboratories for growth regulation, plant stress physiology, turf pathology, root disease studies, nematode taxonomy, disease of resistance, epidemiology, herbicidal action, weed biology and ecology, biological control of plant diseases, biotechnology applications, and landscape tree pathology. Other facilities include a cold storage room, and office space for faculty.

B. GLADE ROAD RESEARCH CENTER

Additional departmental research space is provided in permanent and temporary buildings located at a site near the Old Glade Road adjacent to the north edge of campus and about one mile away from Price Hall. The Plant Molecular Biology Building (PMB Bldg.) provides office and laboratory space for four faculty working in the areas of phytobacteriology, plant virology, phytochemistry, and plant stress physiology. An adjoining glasshouse/greenhouse facility complements the laboratory research facilities of the PMB building. The departmental laboratory for Air Pollution Impact to Agriculture and Forestry is located in the same area. This facility includes a room equipped with fumigation chambers, a computer room, a greenhouse and several storage facilities. Finally, the Turfgrass Weed Management Laboratory, Pesticide Storage and Application Facilities and additional greenhouses are also located in this area of the department. A list of major pieces of equipment housed in the Glade Road Research Center is presented in Appendix II.

C. FRALIN CENTER FOR BIOTECHNOLOGY

The Fralin Center for Biotechnology is a university-wide facility on campus for molecular biology and biotechnology research. The laboratories of five departmental faculty with active programs in plant molecular biology are located on the second and third floor of the Fralin Center for Biotechnology. A list of major pieces of equipment housed in Fralin Center Biotechnology is presented in Appendix II.

D. OTHER ON-CAMPUS AND NEARBY FACILITIES

Additional research, extension, and teaching facilities include the Miles C. Horton Research Center, field plots at Glade Road, the Kentland-Whitethorne Farm, the Turfgrass Research Center, and Room 101G Price Hall. These facilities are generally available for any faculty and student members of the department and constitute a valuable resource for teaching, research and extension missions. **Room 101G Price Hall is a computer laboratory for faculty use. However, students may use the laboratory under the guidance of an on campus faculty advisor.** Additional campus facilities are listed in Appendix III.

E. OFF-CAMPUS FACILITIES

Research and extension facilities are situated at Virginia Tech Agricultural Research and Extension Centers (AREC) located throughout the State. Off-campus PPWS faculty are working at five ARECs located at Blackstone, Suffolk, Virginia Beach, Winchester, and Painter. Faculty located at these stations has access to offices, laboratories and field plots at their locations. The proximity of these field stations to the major crop production areas also affords excellent opportunities for faculty and graduate students to establish research and demonstration plots with grower-cooperators in these areas.

VI. GENERAL LABORATORY PROCEDURES

Certain faculty members have been assigned the responsibility for the coordination and use of various laboratory and greenhouse facilities (see Appendix IV). Before a person is permitted use of a laboratory he/she must first be briefed by the laboratory coordinator on the procedures for use of equipment and supplies.

Because of the heavy use requirement of certain laboratories, it is extremely important that every effort be made to refrain from activities that serve as a source of distraction to others. Visits of a general nature should be kept to a minimum. The seminar room (Price Hall Room 503) is provided for this purpose. When playing radios, please be considerate of fellow workers.

In all cases, regardless of how pressed for time, remember to respect the rights of others who must follow in the use of the same space and equipment. The equipment and/or area must be restored to its proper condition before leaving the laboratory.

In order to minimize the possibility of loss of equipment or disruption of work in progress, it is important that all unattended laboratories be locked. When leaving a laboratory that will then be unattended, LOCK THE DOOR! This should be done even if you are only to be absent from the laboratory for a short while. If you find persons in a laboratory at any time whose presence is questionable, their names should be reported to the laboratory coordinator or the department head. Finally, when leaving a laboratory, if you question as to whether or not the laboratory should be locked --- LOCK IT!

VII. ACADEMIC PROGRAMS

A. INTRODUCTION

The Department of Plant Pathology, Physiology and Weed Science (PPWS) offers graduate programs leading to the M.S. (thesis and non-thesis) and Ph.D. degrees. Beginning with the Fall Semester 1999, the M.S. degrees offered by the department are part of the M.S. in Life Sciences program. The department also participates in interdisciplinary graduate programs in Plant Physiology (IPPP), Genetics, and Molecular and Cell Biology and Biotechnology (MCBB). Depending upon the degree of preparedness, M.S. programs usually require two to three years while a Ph.D. program may require four or more years beyond the B.S. degree.

Although PPWS is primarily a department offering graduate degrees, service courses are taught at the undergraduate level for students in other departments within the College and the University. Commitment to undergraduate instruction has been and continues to be a major portion of the instructional effort of the faculty and students in the department. In recent years, several faculty have been advising undergraduate students in the Biology and CSES departments. In addition, PPWS faculty teach undergraduate courses offered by the Biology and Forestry Departments and the Agricultural Technology Program of Virginia Tech.

Graduates of our programs are prepared for careers as professional plant pathologists, plant physiologists, weed scientists, or plant biotechnologists. Occupational opportunities are available in research, teaching, or extension at colleges and universities; in regulatory or research activities with state and federal governments; in administration, sales, research, or product development in agribusiness and agrichemical or biotechnology industry; or in private consulting.

Appendix V lists the PPWS graduate students enrolled in the Fall 2001 semester, along with information about the graduate degree sought, specialty area and major professor.

B. THE ADMISSION PROCESS

To be admitted to the graduate program, a formal application must be submitted to the Graduate School, using the materials and instructions that will be sent to you upon request. Entering graduate students are expected to have successfully completed undergraduate work in chemistry, physics, mathematics, botany, microbiology, soils, and genetics. Qualified students who lack prerequisite courses will be admitted with the understanding that deficiencies will be

made up and will **not** carry graduate credit. Plant science courses beyond introductory botany (e.g., plant anatomy, taxonomy, plant pathology, plant physiology, biochemistry or molecular biology) are highly desirable.

The screening of new graduate applications is initiated by the departmental Graduate Officer (Appendix VI). This individual reviews the application to determine the applicant's area of interest and faculty members within the department best aligned with those interests. The application is then reviewed by such faculty and returned to the Graduate Officer for further processing. The Graduate Officer makes his recommendations to the department head. Recommendations to accept or reject an application are made to the Graduate School by the department head. The Graduate School notifies the applicant by letter of the final decision.

In evaluating new graduate applicants, five major areas are considered. They are: 1) a grade point average (GPA) of 3.0/4.0 or higher, 2) letters of recommendations, 3) previous courses taken, 4) performance on the Graduate Record Exam (the general aptitude portion of the GRE is required and a score of 1000 or better is considered acceptable for most students), and 5) the motivation of the student for undertaking graduate studies. Deficiencies in any of these areas do not necessarily eliminate a student from consideration. Letters of recommendation and the previous academic background of the student are very important considerations in the review process. Foreign students are required by the Graduate School to take the Test of English as a Foreign Language (TOEFL). A score of 600 (or 250 on the new computer-based system) or above is acceptable by the PPWS Department.

C. NON-DISCRIMINATION STATEMENT

The Department of Plant Pathology, Physiology and Weed Science abides by the University's non-discrimination statement indicated below.

Non-discrimination statement

Virginia Tech does not discriminate against employees, students, or applicants on the basis of race, sex, disability, age, veteran status, national origin, religion, political affiliation, or sexual orientation. The university is subject to Titles VI and VII of the Civil Rights Act of 1964, Title IX of the Education Amendments of 1972, Sections 503 and 504 of the Rehabilitation Act of 1973, the Americans with Disabilities Act of 1990, the Age Discrimination in Employment Act, the Vietnam Era Veterans' Readjustment Assistant Act of 1974, the Federal Executive Order 11246, Virginia's State Executive Order Number Two, and all other rules and regulations that are applicable. Anyone having questions concerning any of those regulations or accessibility should contact the Equal Opportunity and Affirmative Action Office, 336 Burruss Hall, Blacksburg, Virginia 24061-0216, (540) 231-7500, TTY (540) 231-9460.

VIII. CURRICULA

A. SUMMARY OF DEGREE PROGRAMS

The department offers programs leading to the Master of Science (M.S.) degree and a doctoral program leading to the Doctor of Philosophy (Ph.D.) degree. Graduate programs offer training in applied and/or basic plant pathology, weed science, plant physiology and plant biotechnology through a combination of graduate courses, research programs, and teaching experience. Teaching experience of one semester for the M.S. and two semesters for the Ph.D. is required. Research is the most important part of the graduate learning experience. Thesis or dissertation research topics are designed to familiarize students with applied or knowledge-driven basic research and provide them with maximum opportunity to use contemporary techniques and instrumentation.

Each student, in consultation with a major advisor and advisory committee, plan an individual program of study, which must be approved by the student's advisory committee. Core and supporting courses will vary according to the student's background and area of desired specialization. Research opportunities for graduate education in each departmental discipline are currently available in the following areas: **plant pathology** (disease physiology; disease epidemiology; ecology of root diseases; genetics of host-parasite interactions; phytobacteriology; plant virology; nematology; mycology; biological disease control; fungicide-plant-soil interactions; disease control in major crops; integrated disease management), **weed science** (weed biology and ecology; parasitic weeds; weed management in major crops; adjuvant technology; herbicide-action; herbicide metabolism; herbicide-resistant crops and weeds; integrated weed management), **plant physiology** (plant growth regulation; plant stress physiology; air pollution damage to plants), and **plant biotechnology (**plant genetic engineering for disease, stress, and herbicide resistance; mechanisms of subcellular targeting and protein processing; bioproduction of human therapeutics in transgenic plants; plant genetic engineering for improving nutrient availability in animal diets and reducing environmental phosphorus pollution; regulation of plant gene expression).

B. MASTER OF SCIENCE DEGREE

1. Students Enrolled in M.S. Degrees before Fall 1999 Semester

All students, who were enrolled in the Master of Science program of the department through the Spring and Summer 1999 semesters, will fulfill requirements as described in the existing *Requirements and Guidelines for the M.S. Degree* (1998-1999 edition of the PPWS Graduate Student Handbook). It is anticipated that normal progress through these programs of study would enable completion of requirements by Spring 2002. After that date, the current Master of Science in Plant Pathology, Physiology or Weed Science will be discontinued and be replaced by the M.S. degree in Life Sciences.

2. Master of Science (M.S.) in Life Sciences

Students who enroll in the Master of Science program after 1999, enter the Master of Sciences in Life Science program. The Master of Science in Life Sciences merges the efforts of the departments of Biochemistry, Entomology, Food Science and Technology, and Plant Pathology, Physiology and Weed Science. Students in basic and applied disciplines in the College of Agriculture and Life Sciences share common experiences that prepare them for careers in which interdisciplinary interactions become increasingly valued. At the same time, discipline-specific education and research experience, which characterizes the M.S. in Life Sciences program in each department, prepare students for unique positions and career development.

One feature of this degree program is the requirement to complete a core of three courses, one each in biochemistry (BCHM 5124 - Biochemistry for Life Sciences), statistics (STAT 5605 - Biometry or STAT 5615 - Statistics in Research), and information technology (ALS 5984 - Information Systems in the Life Sciences). Options to fulfill the remaining requirements for the program of study are available and they are different for the three main disciplines of the department (Plant Pathology, Plant Physiology and Weed Science). Appendices VII, VIII, and IX present Graduation Analysis Check Lists for an M.S. Degree in Life Sciences with options in Plant Pathology (Appendix VII), Weed Science (Appendix VIII), and Plant Physiology (Appendix IX).

3. Non-Thesis M.S. Program

A non-thesis M.S. Degree in Life Sciences with options in Plant Pathology, Physiology or Weed Science is available. Students pursuing a non-thesis M.S. in Life Sciences should take the three core courses listed earlier (biochemistry, statistics, information technology), and a number of approved electives as well as an internship or equivalent project.

C. DOCTOR OF PHILOSOPHY (Ph.D.) DEGREE

1. Ph.D. in Plant Pathology

Minimum requirements for a Ph.D. degree in Plant Pathology are given in Appendix X. The curriculum requires a strong undergraduate background in basic science, biology, and mathematics. Courses in the biology of plant pathogenic agents, interaction with their hosts, disease control and basic botanical skills are required of Ph.D. candidates. In addition, for the Ph.D. degree, a firm grounding in the theoretical concepts of plant pathology, including epidemiology, genetics of host- parasite interactions, and physiology of pathogenesis, is required.

a. Core courses for Ph.D. students

Two semesters of courses (PPWS 5114, 5124, and 5134, and 5144, covering plant

pathogenic prokaryotes, viruses, fungi, and nematodes) concerned with agents, their biology, and how they damage plants constitute the basis for contemporary Ph.D. studies in Plant Pathology. The laboratory section allows each student to sample in a hands-on fashion, many basic and applied research techniques used in all facets of Plant Pathology.

In addition, plant pathology students are expected to take Principles of Plant Disease Management (PPWS 5204), Clinic and Field Experience (PPWS 5034), and present seminars as outlined in the seminar policy (see page 30), and other courses as outlined in Appendix X.

b. Conceptual courses required of Ph.D. students

Ph.D. students are required to take a group of courses offered in alternate years that stress theoretical concepts of Plant Pathology, namely Genetic and Epidemiological Principles of Plant Pathology (PPWS 5404, now offered under PPWS 6004, two separate courses in Plant Disease Epidemiology and Genetics of Resistance) and Plant Disease Physiology and Development (PPWS 5454). These courses are taken by students who are concurrently enrolled in or who have completed the introductory core of courses stressing the biology of the agents of disease and their interactions with host plants (PPWS 5114-5144), and disease control (PPWS 5204). With this strong background in the biology and control of plant diseases, advanced students will be well prepared to understand and apply theoretical concepts of plant pathology.

c. Other courses available as electives

Several courses in our department are available to students in Plant Pathology as electives including: Weed Science - Principles and Practices (PPWS 4754); Pesticide Usage (PPWS 4264); Plant Growth and Development (PPWS 5654); and Herbicide Action and Metabolism (PPWS 5754); and Topics in Virology (PPWS 6654).

2. Ph.D. in Weed Science

Minimum requirements for a Ph.D. degree in Weed Science are given in Appendix XI. During the past four decades, weed science has been established as a well-defined and recognized academic discipline within the general area of plant protection complementing the older disciplines of entomology and plant pathology. Today, most Land-Grant Universities in the United States offer graduate studies in weed science. However, in many cases, weed science is not offered as a separate curriculum and many graduate students specializing in weed science have their degrees awarded in the field of agronomy, botany, horticulture, forestry, plant pathology, or soil science. At Virginia Tech, graduate students specializing in weed science have their degrees awarded in weed science. Core courses in weed science include: Pesticide Usage (PPWS 4264); Weed Science Principles and Practices (PPWS 4754); and Herbicide Action and Metabolism (PPWS 5754). Additional required courses and other minimum requirements for the Ph.D. degree in Weed Science are appended (Appendix XI).

3. Ph.D. in Plant Physiology

Minimum requirements for a Ph.D. in Plant Physiology are given in Appendix XII.

D. INTERDEPARTMENTAL CURRICULA

Several interdepartmental curricula in which PPWS faculty members and students participate have been established in recent years. These curricula serve as vehicles to coordinate and unify course offerings across departmental boundaries. Faculty who participate in these curricula continue to have appointments in their respective departments, and are responsible for normal advising of graduate students as well as serving on student advisory committees within the curriculum. Students in these curricula major within any of the participating departments and meet a set of requirements designated by the respective curricula outlined below or in the Graduate Catalog of Virginia Tech.

1. Plant Physiology

The departments of Crop and Soil Environmental Sciences, Biochemistry, Biology, Forestry, Horticulture, and Plant Pathology, Physiology & Weed Science participate in the Interdepartmental Plant Physiology Program. This curriculum brings together elements of instruction and research that already exist and function within the University. A brief description and a listing of participating faculty are given in the Graduate Catalog.

Graduate studies leading to the Ph.D. degree are offered by the individual departments listed above. There are many specialized areas of plant physiology within these departments. Current areas of strength include:

- Molecular biology
- Enzymology
- Growth regulation
- Herbicidal action and metabolism
- Photosynthesis and photorespiration
- Physiological interrelations of higher and lower plants
- Physiology of disease
- Regulation of metabolism
- Stress physiology
- Physiological ecology

Further information may be obtained from the program's chairman, listed in the Graduate Catalog.

2. Molecular Cell Biology and Biotechnology (MCBB)

Much of contemporary research in the life sciences is rapidly taking on a new and unified

face. New techniques in biochemistry, cell biology, immunology, and molecular genetics have made possible the purification, mutation and reintroduction of modified proteins into cells. Practitioners of fields once considered far distant from each other can and do use these molecular cell biology approaches and now speak the same technical language. This integration of fields should be reflected in the curriculum. The option exposes students to a foundation in molecular cell biology.

3. Student requirements for MCBB Program

a. The student's participation in the option must be indicated by completing the participation form and approved by the major professor.

b. Students must satisfactorily complete the following courses:

1. Molecular Biology of the Cell (BCHM 5214)
2. Molecular Biology for the Life Sciences (ALS/PPWS 5344; Prerequisite: Biochemistry for the Life Sciences-BCHM 5124 or equivalent).
3. Seminar in Molecular Cell Biology and Biotechnology (PPWS 5064). Ph.D. students must present an MCBB seminar prior to graduation.
4. Topics in Molecular Cell Biology and Biotechnology (a rotating topics course, ALS/PPWS/BIOL 6024). Expected topics include plant disease resistance, molecular biology of photosynthesis, organelle assembly, and the molecular basis of stress resistance.

For additional requirements, see the Graduate Catalog.

A list of additional courses offered by the various departments is given under the Molecular Cell Biology entry in the Graduate Catalog.

E. COURSE AND INSTRUCTOR EVALUATION PROCEDURES

All courses and instructors in the College of Agriculture and Life Sciences are evaluated by a computer analyzed questionnaire titled Student Perceptions of Instruction distributed by the College Dean of Resident Instruction. Each class and instructor is evaluated each semester that he/she teaches except when a class is taught more than once during the academic year. The completed questionnaire is returned to the Office of the Dean, and the results are statistically analyzed and reported back to the Dean. The Dean returns the results of the evaluation to the department. The department head counsels each faculty member regarding the results. The original questionnaire is returned to the instructor along with a computer analysis of student response. Teaching Assistants (TAs) are evaluated using the same College questionnaire as the faculty. In addition, faculty members responsible for courses in which teaching assistants participate also evaluate the performance of the TA.

The department also conducts a peer review of course content and instructor performance. The purpose of the peer review is 1) to improve the quality of teaching, 2) to aid the promotion and tenure process, and 3) to serve as the basis for providing nominees for teaching awards.

IX. IMPORTANT ACADEMIC POLICY STATEMENTS

A. GRADUATE STUDENT ADVISORY COMMITTEE

Each graduate student will develop a graduate committee with the aid of his/her advisor. Committees for M.S. students require **at least** three members; **at least** five members for Ph.D. students.

The committee aids the student in planning a program of study and in determining research direction, and administers the preliminary and final examinations. The students should select an advisor and a committee as soon after arrival as possible so that the program of study and research direction can be determined quickly. A student's committee must meet **at least** once a year, and the advisor must **report by letter** to the department head, concerning the discussions and actions taken at the meeting. The Graduate School publishes the **Graduate Policies and Procedures and Graduate Catalog** that contains important information relative to programs of study, committee structure, theses and dissertation preparation and other information of value to your academic training. **READ THIS THOROUGHLY!!!**

The graduate student, in consultation with his or her advisor, selects the faculty who will serve on the advisory committee. Faculty who serve on advisory committees are expected to have scientific expertise that will help the student complete his or her degree requirements. They are also expected to participate in one or more meetings each year, and respond in a positive manner to the student's request for assistance on his or her research. The committee member is expected to read and evaluate a student's program of study, thesis or dissertation outline, and annual progress reports. Evaluation of the service and contributions of advisory committee members is made on an on-going basis by the student's advisor in his letter to the department head and on the student's Annual Progress Report (Appendix XV), which is reviewed and signed by each advisory committee member. During the final exit interview between the student and the department head, the service and contributions of the advisor and the advisory committee members will be fully evaluated. Additionally, the student is encouraged to meet with his or her advisor and/or department head concerning advisory committee member performance. The student may consult the department head or graduate officer if he or she has concerns about his or her advisor.

For more information on the mentoring process of graduate education and on how to make the most of graduate school, please read the articles written by Dr. R. Jay Stipes and Dr. John Eaton, respectively. These are placed at the end of this handbook.

B. PLAN OF STUDY

Each student, in consultation with his major advisor and advisory committee, plans an individual program of study, which must be approved by the student's advisory committee. Core and supporting courses will vary according to the student's background and area of desired specialization. Core courses and minimum requirements for the three options under the M.S. Degree in Life Sciences and the doctoral programs in Plant Pathology, Plant Physiology and Weed Science are presented in Appendices VII-XII. The plan of study **must** be approved by the student's committee, the head of the department, and entered electronically for approval by the Graduate School before February 1 for students entering Fall Semester, **or** before the completion of 15 credit hours.

C. THESIS/DISSERTATION RESEARCH PROPOSAL

All graduate students in the Department of Plant Pathology, Physiology and Weed Science who are enrolled in the thesis or dissertation research options, are **required** to place a thesis or dissertation proposal in the departmental student files **before** the end of the second semester of matriculation. The proposal shall contain:

1. **A Research Proposal Title Page** (Appendix XIII)

2. **Research question(s) and/or objective (hypothesis):** brief outline of research questions to be addressed and/or the objectives (hypotheses) which are to be determined or tested.

3. **Justification:** provide enough justification in the form of a literature review, etc. to lead to your research question(s) and/or the objective or hypothesis to be tested.

4. **Procedures:** present sufficient procedural information to insure that a professional scientist in your area of research will be able to understand the procedures; indicate the research methods to be employed, the statistical methods to be utilized, and any other information which will help in the evaluation of the procedures.

5. **Facilities** and **equipment** required.

6. **Literature cited:** list all literature; include a complete literature citation.

7. **Time table:** sequence of experiments and estimate of time required for completion.

The exact length, format, and depth of the thesis or dissertation research proposal are dependent upon the needs of the graduate student and the student's committee. Sufficient information should be presented in the proposal to warrant the approval of all the committee members as well as the department head.

The preparation of the thesis/dissertation research proposal in a form appropriate for submission to a granting agency such as NSF, NIH, USDA competitive research grants program and Virginia Agricultural Foundation, is **strongly** recommended.

D. STUDENT SEMINAR POLICY

The Department of Plant Pathology, Physiology and Weed Science sponsors a weekly Departmental Seminar Series as a regularly scheduled graduate class. All students are **required** to participate in this course. In addition, there are other seminar series and special seminars supported by the departmental faculty and students. They provide an avenue for bringing the latest techniques and philosophy of science to the group. Student participation encourages development of professional skills in communication and is viewed as an opportunity to explore in depth, specific areas in scientific literature. Faculty and students are placed in a situation of constructive interaction at these presentations.

The following comments are intended to set **minimum** student requirements as well as other information regarding the administration of the departmental series and the coordination of other seminars.

1. M.S. students will present **one seminar for credit** and **one terminal or leaving seminar**; Ph.D. students will present **two seminars for credit** and **one terminal seminar.** Students with prior M.S. degrees may transfer seminar credits if desired; however, this will not reduce the number of seminars they are required to give during their Ph.D. program.

2. Seminar sign-up will be held each spring for the following academic year**. Seminars for credit should be included in the student's plan of study;** flexibility must be allowed as to actual dates involved.

3. Seminars will be offered on a grade (A-F) basis. For seminars given in other series (see item 5), the grading policy of the series will be accepted. Grading, approval of seminar titles, and administration of individual seminar classes will be the responsibility of the seminar instructor.

4. There are two types of seminars that a student may present: a literature review seminar or a research proposal seminar. A research proposal seminar may be presented as a student's first seminar, but not later than the **second** semester in residence for M.S. and the **third** semester in residence for a Ph.D student. This seminar includes an in-depth literature review, statement of objectives, justification and a proposed experimental plan.

   A literature review seminar is designed to encourage students to explore areas distinctly different from their planned programs; this seminar usually concerns a subject that does not involve research in the immediate area of the speaker's thesis or dissertation research.

5. Ph.D. students are permitted to give one required seminar in an interdepartmental seminar series (Plant Physiology, Molecular Cell Biology, etc.), provided that PPWS requirements (advance notification, abstract distribution, evaluation, etc.) are fulfilled. M.S. students will present all required seminars in the PPWS series, but may elect to give additional seminars in other series.

6. The departmental seminar coordinator, who is appointed by the department head, coordinates all seminars. The coordinator arranges the seminar schedule and keeps record of all seminars given, including all abstracts. S/he, in consultation with the Education Committee or a designated Seminar Committee, will review and develop policy for administration of the program for consideration by the departmental faculty.

7. Non-credit seminars (student terminal seminars, visiting faculty, resident faculty, and postdoctoral seminars) will be coordinated through the department head.

8. All M.S. (thesis and non-thesis) and Ph.D. students are required to present a seminar on their project or research as a requirement for graduation. This seminar will be considered part of the final thesis or dissertation examination, and will be given **no more than two weeks prior** to the examination or defense date. **No graduate program will be sent to the Graduate School as complete without a terminal seminar and examination**. The date and time of the examination by the advisory committee must be publicized in a way that affords all interested faculty the opportunity to attend the examination. As with other seminars, an **abstract must be distributed five working days prior to the oral presentation.** (See Appendix XIV for additional details concerning seminars).

E. TEACHING/COMMUNICATION REQUIREMENT

Communication skills are an important asset, to all professionals in the fields of plant pathology, plant physiology, and weed science as well as teaching and extension professionals. Students in PPWS can develop their oral communication skills by the presentation of seminars and research papers; however, exposure to other aspects of communication is also needed. The primary objectives of the teaching/communication requirement are to provide students a meaningful experience, and to enhance their ability to compete in the job market.

Regardless of support, all students in the Department of Plant Pathology, Physiology and Weed Science are **required** to participate in some approved communications project. Students are also **required** to have one teaching/communication project for a M.S. program and two for a Ph.D. program.

Normally, this service will consist of teaching or participating in teaching, in a classroom situation. Each student will participate in this type of service for **at least one semester.** In recognition of the diverse backgrounds of students and their personal needs, alternative experience may be substituted for a second semester of classroom teaching.

Alternative experiences may include:

- designing one or more lab experiments
- designing and developing teaching aids such as slide sets, audiovisual packages, etc. for use in class or outside classes (e.g. extension agent education)
- instructing fellow students in particular skills (e.g. photographic techniques)

Each student will make a 'public' presentation or demonstration to fulfill the 'communication' aspect of the requirement.

Students who prefer an alternative assignment must announce such preferences at the time of the spring survey (see below) or earlier. They should consult with their major advisor and the faculty members supervising the project. The alternative proposal must be reviewed by the Education Committee and approved by the department head before work is begun. The project supervisor will review and evaluate the completed project before credit may be given.

In the spring of each year, the Education Committee will survey faculty with respect to teaching needs, and students with respect to course and assignment preference as well as scheduling preferences for the following academic year. Where appropriate, students should consult with their advisors and with the course instructor involved. Based on this survey, assignments will be made before the start of the fall semester. Two or more students can share teaching assignments that are particularly demanding. New students are generally not required to teach in the first semester of their program; however, they may elect to volunteer. All students are assigned to a faculty member. This faculty member should work with the student to ensure that he/she learns the various aspects of the teaching process, and include observation of the student's teaching ability in the classroom in order to provide constructive criticism. Upon completion of the assignment, the faculty member will write a brief evaluation for the student's file.

F. GRADUATE STUDENT EXAMINATION PROCEDURES

All M.S. students majoring in Plant Pathology, Plant Physiology, Weed Science or Plant Protection, are required to take a **final oral exam** administered by his/her committee at the completion of the Thesis, Project and Report or Internship. The exam is usually administered during a half-day session (approximately 4 hours) and could cover all aspects of the student's academic training including course work and defense of the thesis or Project and Report **(see Policies and Procedures Section in the 2001-2003 Graduate Catalog).** In addition, students will present a **final seminar** (see Student Seminar Policy, Section IX-D of this handbook).

Ph.D. students are required to take a **preliminary exam** (both oral and written) at least 9 months prior to graduation with at least **one-third** of the required course work or research still remaining **(see Graduate Catalog)**. This examination will focus on the student's academic preparation. The written portion of the exam is administered **prior** to the oral portion. The oral portion of the exam is usually administered during a four-hour session. Students are **required** to take a final **Oral Exam** and **present a defense seminar** (see Student Seminar Policy, Section IX-D of this handbook).

G. YEARLY EVALUATION OF PROGRESS

It is a **requirement** of the department and the Graduate School that each graduate student be

evaluated on an annual basis. To accomplish this, the department has developed an evaluation form (Appendix XV and XVI). Each committee member, the major professor, and the student should sign the completed form and return it to the graduate officer or the executive secretary by **December 1** of each year of residence. New students entering their program of study in the fall semester of a given year should submit a yearly progress report by **February 1,** during their second semester of residence.

The purpose of the annual review is to ensure that the student is making sufficient progress toward fulfillment of degree requirements. The information provided in the review form is also beneficial in selecting students for fellowships, tuition waivers and awards. Letters of recommendation and news releases are also written from such information.

Noncompliance of the December 1 or February 1 deadline could result in academic suspension and/or the termination of financial assistance until the requirement is met. If any unforeseeable problems arise, please contact the graduate officer before the deadline date and he/she will be glad to assist you. **Your cooperation in fulfilling this requirement is very important.**

The department holds an orientation meeting at the beginning of Fall Semester to acquaint graduate students with the policies described above.

H. THESIS AND DISSERTATION

The Master's Thesis is a written report resulting from a research project conducted under the guidance of a faculty advisor. The Thesis option for a M.S. degree provides more opportunity for in-depth work in a specific topic or application than would be possible under the non-thesis option. The final examination includes a presentation of the thesis and response to questions (thesis defense).

The centerpiece of the Ph.D. degree is the dissertation. Under the guidance of a faculty advisor (major professor) and an advisory committee, the doctoral candidate engages in a major research project. The dissertation itself is the written document, following professional standards, resulting from the research project. Through his/her dissertation work, the doctoral student moves beyond the relatively passive role of receiving knowledge presented in courses to become an active, self-motivated scholar, making a significant contribution to their area of specialty. The work of the dissertation is expected to be of such quality as to merit publication in a scholarly journal, after appropriate revisions. For those continuing in academic research, the dissertation topic may initiate a more lengthy research program that forms the beginning of a scholarly career. For those who continue in a nonacademic direction, the dissertation experience is valued because it requires the highest level of creativity and independent thinking. When the dissertation research and writing are completed, a doctoral candidate must defend his research at a final oral examination (dissertation defense). The final examination is open to the entire faculty of the university, and questions may be asked that do not pertain directly to the dissertation being defended.

In recent years, Virginia Tech has initiated a policy requiring graduate students to submit their

thesis or dissertation electronically. For instruction, see **http://etd.vt.edu.**

I. EXIT INTERVIEW

To help the department continue to strengthen its programs, each graduate student is asked to complete an exit interview with the department head.

X. ADDITIONAL INFORMATION AND POLICIES

A. PPWS GRADUATE STUDENT ORGANIZATION

The Graduate Student Organization (GSO) for the Department of Plant Pathology, Physiology and Weed Science began during the summer of 1979. The GSO is a service organization whose function is to help the graduate student with his/her educational needs. The objectives of this organization include: 1) developing programs to assist graduate students in orientation and in their studies and research; 2) facilitating communication between graduate students and the department head, between graduate students and faculty, and among graduate students themselves; 3) fostering professional and social development of the graduate student; and 4) formalizing the selection of graduate students for participation in departmental and University activities. The GSO Officers are listed in Appendix I.

1. Membership

a. All graduate students of the Plant Pathology, Physiology and Weed Science Department are members of the organization.

2. Meetings

a. General meetings of the GSO are held each semester and as necessary.

b. All meetings are open to the faculty.

c. Meeting announcements are made to all graduate students and faculty.

d. Decisions are made by majority vote of graduate students present at a general meeting, or by a majority vote of graduate students conducted through a paper ballot distributed to all graduate students.

3. Officers

a. Officers are elected each spring at the general student meeting.

b. Each spring semester, the Graduate Student Organization, in consultation with the faculty, compile a list of faculty members who are willing to serve as liaisons for their

organization. This list is then submitted to the department head for approval and appointment as the faculty liaisons to the graduate students

B. DEPARTMENTAL KEYS

During the summer 1999, new locks were installed on all doors in Price Hall. Each student will be issued keys to areas where continuous access is needed. The professor in charge of lab areas must authorize permission for issuance of such keys to others outside his/her organization. Each lock in the building has a specific code number and keys are coded according to the lock and sequentially numbered. Each key is issued by the sequential number and logged into the system with that individual's name corresponding to the key number issued to them. **Keys are issued to individuals for their exclusive use only, and must not be shared with others.** At the completion of your studies at Virginia Tech, all keys must be returned to the main office **prior** to leaving the campus. A strict accounting of the keys issued to each student is kept; loss of any key should be reported immediately to Arleta Boyd, Executive Secretary. PPWS students housed in the Fralin Center Biotechnology are issued keys according to the policies of the Center Students working in labs at the Glade Road Research Center are issued keys by the lab supervisors (PMB Building) or by Arleta Boyd.

C. GRADUATE OFFICE SPACE AND USE OF SEMINAR ROOM

Each graduate student may be assigned a desk in Room 503-C Price Hall on a first-come, first served basis. The GSO officers coordinate these assignments. Each student also has a mail box in 410 Price Hall and should be checked daily. Shelves for books and file space may be shared; bringing in personal bookcases is not advised. Please feel free to use the seminar room for chatting with fellow graduate students and faculty; however, refrain from using offices for idle conversation. Do not leave food lying around for any length of time. The Department of Entomology gives cockroaches a happy home on the third floor, but they do have a tendency to wander if tidbits are left lying around to attract them. **Please clean up after yourself when you use the seminar room tables and sink area.**

D. STUDENT E-MAIL AND PPWS WEB SERVER ACCOUNTS

E-mail accounts can be activated through the Tech Connect office located on the second floor of Newman Library. Bring your Hokie Passport and assigned personal identification (PID). Redistribution of lost passwords and off-campus access to the VT modem pool can be arranged at the Tech Connect office.

PPWS students are encouraged to maintain a personal web page on the departmental web server. The web server user ID request form is located in Appendix XVII or on the Internet at the following address: ***http://oak.ppws.vt.edu/~shahrooz/userid.html*.** The PPWS web server is governed by the Policy on Acceptable Use of Information Systems at Virginia Tech. The policy can be found on the Internet at the following address: ***http://www.vt.edu/vt97/misc/policies/acceptuseguide.html*.** Please read the policy and be sure to understand all its implications.

If you would like to have an account on the server, please complete the form and place it in Shahrooz Feizabadi's PPWS mailbox. He will process the form and put a copy back in your mailbox.

E. ACCESS TO DEPARTMENTAL COMPUTERS

The department provides one or more departmental computers for use by the graduate students at each of three locations, which include Price Hall (5th Floor), Glade Road (Room 203) and Fralin Center for Biotechnology building (3rd Floor). In addition, students have access to departmental or faculty computers located in the laboratories of their advisors. Arrangements for the use of these computers must be made in advance by the students and their advisors.

F. POLICY FOR USING POSTER PLOTTER

1. The plotter is located at the main office (413 Price Hall) of the PPWS Department and is available for use by PPWS faculty, students and staff for academic and scholarly projects. Personal projects should be pursued through commercial outlets (e.g., Kinko's).

2. Departmental members wishing to use the plotter should make arrangements in advance by contacting Peter Sforza (231-1867; psforza@vt.edu or Shahrooz Feizabadi (231-4161; shahrooz@vt.edu). The plotter can be used for printing with either Mac or PC computers.

3. To cover the high cost of paper and cartridges, a nominal fee of $8.00 per linear foot is charged for paper used; this includes trial and/or erroneous runs. Please make sure that all mistakes have been corrected and that the set-up of your poster is acceptable before you use the poster plotter.

4. Arrangements for paying the minimal use charge should be made with Patsy Neice

(412 Price Hall). Payments can be made with an ISR at the time of printing. ISRs should be given to Patsy Neice.

5. For further information or any questions, please contact Peter Sforza at 231-1867.

G. VEHICLE USE POLICY

The vehicles maintained by the department include general-use trucks as well as trucks assigned to specific programs. In general, use and maintenance of the assigned vehicles is the responsibility of the faculty involved.

Make sure you are a **qualified driver** before using any departmental vehicle. Qualifications include valid Virginia operator's license **and** University employment (faculty, permanent staff, or graduate assistants). **Hourly or other temporary employees may not drive these vehicles.** Contact your major advisor for use of departmental trucks.

H. GREENHOUSE POLICIES

The following policies apply for general use of departmental greenhouses, i.e., House 4 A, B, and C, and 9A and B in the 'main' complex on Washington Street. Several other greenhouses are used for specific research areas, e.g., Air Pollution (Chevone), Weed Science (Foy, Hagood, Hatzios, Hipkins, Westwood) and Molecular Biology (Alscher, Hatzios, Lacy, Tolin).

1. Maintenance

Every greenhouse user is expected to do his/her own soil mixing, planting and **cleanup**, including washing pots and flats. All watering during the week and on weekends is the individual's responsibility. General pesticide application of the greenhouse will be carried out on Fridays after 4:00 p.m. Users should **avoid** entering the main greenhouse after 4:00 p.m. on Fridays because fumigations may be carried over into the PPWS greenhouse or adjacent greenhouses. Generally however, pest problems that develop on materials are the individual's responsibility. It is important that everyone keep his/her plants insect-free to avoid infesting other plants in the greenhouse. Pesticides should be applied Monday through Thursday after 5:00 p.m. Signs **must** be posted at both ends of the greenhouse range to notify others that pesticides are being applied.

Trash (plant and soil materials, paper, and plastic) **must** be dumped in the dumpster next to greenhouse 9 (main complex). All materials placed in general use or non-assigned space (for example, under the mist), must be clearly labeled with the owner's name. Materials without labels will be considered abandoned. **No personal property (house plants) may be kept in University greenhouses.** Any questions and/or requests of a technical nature should be directed to the Greenhouse Coordinator, Dr. Herman L. Warren.

2. Space assignment

Greenhouse space assignments will be made by the Greenhouse Coordinator, Dr. Herman L. Warren, and is based on faculty requests. Students must request space through their major advisor. Only space **known** to be needed should be requested, and the time period needed should be indicated. Plant material, soil and trash must be put in the dumpster.

I. PHOTOGRAPHIC/COMPUTER EQUIPMENT AND FACILITIES

A system for computer-generated slides and a film recorder is available in Room 101G for making 35mm transparencies from Powerpoint presentations, TIF or PICT files. Ektachrome 100 (daylight) film should be used for making transparencies on the film recorder. **These facilities are available for use by our faculty. However, graduate students can use the facility under the guidance of an on campus faculty advisor.** Dark room facilities are available at the PMB building at Glade Road, the Fralin Biotechnology Center and the fourth floor of Price Hall (Dr. Westwood's lab.). Certain cameras and video equipment are also available for use by graduate students in preparing seminars and conducting research. The photographic equipment coordinator is Dr. Jonathan D. Eisenback. In addition, all extension faculty and most of the research and teaching faculty have 35-mm and digital cameras under their control and in some cases, available for their students to use.

J. USE OF DEPARTMENTAL COPY MACHINES

The use of the copy machines is generally restricted to faculty and staff only. Personal copies of journal articles, etc. are prohibited. See Patsy Neice for information about acceptable use of and charge for copy services. Graduate students can "buy" the use of the copy machine for their individual use.

K. SUPPLIES, TYPING AND AUDIOVISUAL EQUIPMENT

Office supplies are not issued to graduate students or faculty. Research supplies must be cleared with your research project director, i.e. field notebooks, data pads, etc. Supplies for seminar preparation should be cleared with the Seminar Coordinator.

Audiovisual equipment must be checked out via the Projector Sign-out Folder. See Patsy Neice if you have questions. Equipment must be picked up before 5:00 p.m. for evening and weekend use. Individuals who check out audiovisual equipment are directly responsible for loss or negligent damage.

Graduate students are responsible for typing manuscripts used to complete thesis/dissertation requirements.

L. USE OF TELEPHONES AND FAX MACHINES

The phone in the graduate student area of the 5th floor of Price Hall as well as all phones in the departmental labs (where available) **DO NOT** provide access to long-distance lines. Please

limit personal use of these phones for local calls to keep lines available for business and professional calls only. Do not make unauthorized personal and/or long-distance calls from other university phones. For long-distance business calls, arrange to have telephone access through your major professor.

Fax machines are available at all three locations of the department. Students are allowed to receive fax messages at these machines. To send business fax messages through our departmental fax machines, students must arrange to have access through the appropriate clerical staff or your major professor.

M. DEPARTMENTAL BOOK COLLECTION

A general collection of books is maintained in the Seminar Room (Room 503 Price Hall), and may be checked out for use by faculty, staff and students in PPWS only. Books are not available for use by outsiders except in the seminar room. Theses and dissertations are kept in locked cages along with other books that are very valuable or irreplaceable. The key to the cages can be obtained from the executive secretary.

1. Specific policy

a. There is a card in each book. If you wish to remove the book from Room 503, you must sign the card and place it in the checkout box.

b. Books may be recalled after two weeks. By special agreement, they may be used by course instructors for one semester and returned at the end of the semester.

c. Books are shelved alphabetically by author and under subject as designated on the spine and checkout card. When you return a book, scratch your name off the card and shelve the book alphabetically. If there is doubt about where to shelve books, leave them in the designated areas for book returns.

2. Other information

a. Handbooks, dictionaries and manuals will be stored separately in a specifically designated area.

b. Annual reviews will be stored in a specifically designated area.

c. Journals donated to the collection, theses, dissertations, and project reports cannot be checked out; they are for use in the seminar room or for copying short papers.

d. The department will gladly accept donations of books and materials that have been purchased by individuals with public or private funds.

N. DEPARTMENT ACTIVITIES

A welcome meeting for old and new graduate students is held early in the Fall semester of each year. A student picnic is also held occasionally in the Fall semester at a local park. There is also a holiday party in December, and a Spring awards picnic to promote fellowship among colleagues and their families.

Intramural sports are also a part of graduate student activities. Anyone can develop a team in any of the University Graduate and Faculty Intramural League sports. Information about sports can be obtained from the Intramural Office at War Memorial Gym. The Department has sponsored teams in football, volleyball, softball and basketball. A long-established departmental tradition is the Friday volleyball game, held in the Glade Road area of the department.

O. PARTICIPATION IN SCIENTIFIC CONFERENCES

Professional scientific meetings are of considerable value to graduate training. Students are encouraged to attend and present papers or posters at scientific meetings. Professional societies include the Virginia Academy of Science, the American Phytopathological Society (APS), the American Society of Plant Biologists (ASPB), and the Weed Science Society of America (WSSA), and the regional chapters of these societies. To help defray expenses to the extent that funds are available, financial assistance will be provided for students presenting papers or posters at professional meetings. The Graduate Student Assembly (GSA) of Virginia Tech provides travel grants to eligible graduate students for participating at scientific conferences. Please check the home page of the Graduate School for more information (*http://rgs.vt.edu*).

APPENDICES

APPENDIX I

DEPARTMENT OF PLANT PATHOLOGY, PHYSIOLOGY AND WEED SCIENCE
COMMITTEES AND COORDINATORS
2001

Promotion and Tenure Committee
*E. Scott Hagood, Jr., Chair
*Antion Baudoin
*Boris I. Chevone
***Carole Cramer
** Charles S. Johnson
*Patrick M. Phipps
*Erik L. Stromberg
*Henry P. Wilson

*Elected by the faculty
**Appointed by Department Head
***College Representative

Education Committee
Ruth G. Alscher, Co-chairperson
Anton Baudoin, Co-chairperson
Boris I. Chevone
Cynthia J. Denbow
David M. Orcutt
R. Jay Stipes
James H. Westwood
Verlyn K. Stromberg - Staff Representative
Peter M. Sforza - Student Representative
Gary J. Griffin - Graduate Officer, Ex-Officio
J. D. Eisenback - Seminar Coordinator

Research, Extension and Resources Committee
Erik L. Stromberg, Chairperson
Sue A. Tolin, BioSafety
Carole L. Cramer
Houston B. Couch
Mary A. Hansen
P. Lloyd Hipkins
George H. Lacy - Ag-NR Bldg.
Herman H. Warren - Greenhouses
Claude C. Kenley - Field Plots
Gregory R. Armel – Student Representative

Classified Staff Organization
Sue Meredith, Chair
Jean Ratliff, Vice Chair
Jamie Hampton, Faculty Representative
Nina Hopkins, CALSSA
Verlyn K. Stromberg, Alternate CALSSA Representative

Graduate Student Organizaton
Brian W. Trader, Chair
Aaron Syracuse, Vice Chair
William Witt, Secretary
Elizabeth Bush, Treasurer

Departmental Website (Computer) Committee
Anton B. Baudoin
Kevin W. Bradley
Erik L. Stromberg
Peter M. Sforza
Shahrooz Feizabadi

Laboratory Safety Committee
Nina R. Hopkins - Price Hall
Verlyn K. Stromberg - Glade Road Research Ctr.

Pesticide Safety Committee
E. Scott Hagood, Jr.
P. Lloyd Hipkins

Social Committee
E. Scott Hagood, Jr.
Arleta L. Boyd
Philip J. Keating
P. Lloyd Hipkins

Property Surplus Coordinator
Erik L. Stromberg, Chair
Judy H. Fielder

Library Representative
R. Jay Stipes

Awards and Recognition Committee
Chester L. Foy

Ethics and Affirmative Action Committee
Carole L. Cramer
Laurence D. Moore

Ag-NR New Building Committee
George H. Lacy, Chairperson
Carole L. Cramer
Erik L. Stromberg
Sue A. Tolin
Verlyn K. Stromberg

APPENDIX II

PPWS DEPARTMENT
LIST OF MAJOR EQUIPMENT ITEMS AND RESEARCH FACILITIES
2001

PRICE HALL

First Floor

Computer Gene and CD-ROM package, Intelligenics, 100 Price
Video densitometer, protein, Biorad 620, 100 Price
Stereo Microscope, Zeiss SV11, 100 Price
Nitrogen Determinator, Leco FP-228, 100 Price
Photomicroscope, Leitz, 103 Price
Stereomicroscope, zoom, Wild M3Z, 103 Price
Video camera (color), Leica and related accessories, 103 Price
Microscope, laborlux D, F, 106 Price
Autoclave, 109 Price
Refrigerated centrifuge, RC-58 with rotors, 109 Price
HPLC, Hewlett-Packard HP-1090 Model with several detectors, 109 Price
Gas Chromatograph, Bendix 2500, 109 Price
Gas Chromatograph, Bendix 2600, 109 Price
Ultralow temperature Freezer, 110 Price
Beckman DU7400 Spectrophotomoter, 110 Price
Beckman Tabletop Ultrocentrifuge, 110 Price
Zeiss Dissecting Microscope, 110 Price
Effendorf Refrigerated Centrifuge, 110 Price
Water purification system, Nanopure, 110 Price
Chromatography refrigerator, Fisher, 110 Price
Robocycler 40/gradient/hop top combo, Stratagene, 110 Price
Incubator, mini-hybridization, Robbins, 110 Price
Ultracentrifuge w/fixed angle titanium rotor, Optima MAX-E, 110 Price
Growth Chambers, 114A Price
Plant Growth Room, 114B Price
Gas analyzer (CO2), ADC 225, 114 Price
Dew Chamber, Percival I-350, 114 Price
Fermenter, Bethesda 2200AF, 114 Price
Laminar Flow Hood, Contamination C, 114 Price
Photosynthesis System, Li-Cor LI6200, 114 Price
Inverted microscopes, Olympus CK2, 115 Price

Fourth Floor

Automated Plate Reader, Athos Labtec AR6001, 401 Price
Bench centrifuge, Beckman TJ6, 401 Price
Fluorometer, Sequioa Turner, 401 Price
Laminar Flow Hood, Contamination Co. 868, 401 Price
Refrigerated centrifuge, Beckman TJ-6RS, 401 Price
Seed Counter, Almaco 109, 401 Price
Ultrafiltration system, P, Amincon CH2PRS, 401 Price
Liquid Scintillation Counter, Beckman LS-315, 406 Price
Parasitic Plant Study Facilities, 406 Price
Freezer, Revco, Ultima II, 406 Price
Color video camera, Leica, 406 Price
Water purification system, Barnstead, 406 Price

Centrifuge w/fixed angle rotor, Allegra, 406 Price
C-24 shaker w/accessories, New Brunswick, 406 Price
Peltier thermal w/hot bonnet lid, MJ Research, 406 Price
Weather Data Logger, Sensor Instr., 417 Price
Incubators, 417 Price
Weather Data logger, 417 Price
Microtome, A/O 820, 420 price

PPWS MEDIA CENTER, 101G Price Hall (computers, scanner, camera, computer slides, etc.)

GLADE ROAD RESEARCH CENTER

Plant Molecular Biology (PMB) Building
Autoclave, 100 PMB
Spectrophotometer, Beckman DU-6, 100 PMB
Ultra centrifuge, Beckman L2-65B and rotors, 100 PMB
L8-80 ultracentrifuge, 100 PMB
Centrifuge w/rotors, Sigma Lab, 100 PMB
Microplate, spectrophotometer, Spectromax, 100/102 PMB
Microplate reader, Bio Tek, 102 PMB
Tabletop Centrifuge, 102 PMB Building
Alpha Imager and accessories, 102 Price
Computer for Microarray Labs Analysis, 103 PMB
Analyzer, sulfur dioxide, SA 185, 103 PMB
Ultralow Freezer, ULT-17, 103 PMB
Spectrophotometer, Beckman DU-65, 103 PMB
Hybridization Incubator, Robbins Scientific, 103 PMB
Thermocycler, MJ Research, 103 PMB
Refrigerated centrifuge, RC-58 with rotors, 200 PMB
Ultralow Freezer, Revco U1186D, 200 PMB
Liquid Scintillation Counter, Beckman LS 5000TA, 200 PMB
Speedvac evaporator, Savant, 200 PMB
Autoclave, 200 PMB
Dark Room, 200 PMB
PCR, 202 PMB
Protein Workstation, BioRad 491, 202 PMB
Spectrophotometer, Hitachi 110-40, 202 PMB
Electrophoresis equipment, various, 202 PMB
Cyclic reactor (PCR), Ericomp TCX15A, 202 PMB
Gas chromatograph with FID and ECD, Tracor 540, 203 PMB
Digital Oscilloscope, Nicolete 20903C, 203 PMB
FPLC, Protein system, Pharmacia 2, 203 PMB
Imaging Scanner, BioScan 200, 203 PMB
Biological Oxidizer, Packard 308 Model, 203 PMB
Media Center for student seminars - 200 PMB
Several Growth Chambers and Incubators in Plastic Greenhouse of PMB

Air Pollution Laboratory
Ozone analyzers, Bendix
Ozone generators, OREC
Growth chambers
Photosynthesis chamber, Li-Cor 9960-0
Infrared gas analyzer, Anarad AR-600
Quantum sensor/housing, Li Cor 9960-0

Total Sulfur analyzer, Bendix
Fumigation chambers
Photosynthesis system, PO, LiCor LI6000
Portable area meter, Li-Cor LI-300
NO-NO2-NOX analyzer, Bendix
Precipitation sampler
Portable flourometer, Heinz Walz
Leaf-clip holder w/adapter & accessories, Heinz Walz
LAN Center and Networks of the Department

Turf Weed Science Lab
Pesticide/Fungicide Storage Facility
Spraying equipment, table top sprayers, crop planters, tractors, departmental trucks, harvesters, Yamaha bike, etc.

FRALIN BIOTECHNOLOGY CENTER

Image processor, Argus-20, Hamamatsu Corp., 204 Fralin
Shaker w/platform & accessories 4000, New Brunswick, 204 Fralin
Purifier clean bench, Labconco, 204 Fralin
Electrocell manipualtor, BTX PCM600, 303 Fralin
Scanning Spectrophotometer, Beckman DU-640, 303 Fralin
Biolistic particle delivery septem, BioRad, 313 Fralin
4' purifier clean bench, Labconco, 313 Fralin
Stereomicroscope SV11, Zeiss, 313 Fralin
Radiochromatography Detector for HPLC, Beckman 171 Model, 315 Fralin
HPLC Waters with several detectors, 315 Fralin
Refrigerated centrifuge RC-58 and rotors, 303 Fralin
Incubators, 303 Fralin
Biocycle oven w/BSC temp. Bios Corp., 305 Fralin
Refrigerated cryostat. A/O 830, 305 Fralin
Growth Chamber, 305
Electrocell manipulator BTX ECM600, 305 Fralin
Ultralow temperature freezer, Forma Scientific, 305 Fralin
Hybridization system, Hybrid H-9300, 305 Fralin
Luminometer, Analytical Lumin 2010C, 305 Fralin
Optima Ultracentrifuge, Beckman TL, 305 Fralin
Spectrophotometer, Beckman DU-64, 305 Fralin
Speedvac evaporator, Savant SS100, 305 Fralin
Confocal Microscope, first floor Fralin

APPENDIX III

SELECTED CAMPUS FACILITIES AND SERVICES

FACILITY	LOCATION	PHONE
Pesticide Analytical Laboratory	Litton Reaves 350	1-6933
Main Library	Carol M. Newman	1-6170
Chemical Supplies		
(A) Biochem./Nutr. (Stock room)	Engel	1-5311
(B) Chem. Dept. (Stock room)	Davidson 102-B	1-8255
Computing Center (User Services)	CRC, 1700 Pratt Drive	1-9500
Counseling Services	McComas 240	1-6557
Glass Blowing Shop	Davidson 107	1-6111
Graduate School	Sandy 100	1-6692
Housing and Residence Life		
(A) Off-campus housing	Squires	1-3466
(B) On-campus housing	East Eggleston 109	1-6204
Learning Resources Center (LRC)		
(A) Audiovisual service	Patton Hall 2	1-6821
(B) Classroom/AV service	Saunders 204	1-5684
(C) Film Library	Newman Library	1-4689
(D) Graphic Arts	455 Tech Center Dr.	1-6821
(E) Instructional Development	Old Security Bldg.	1-8993
(F) Instructional TV Division	Whittemore 287	1-6628
(G) Photography	455 Tech Center Dr.	1-6821
(H) Test Scoring/Analysis	Derring 2096	1-5413
Mass Spectroscopy Laboratory	Engel 106	1-4562
Placement Services	Henderson, 3rd Floor	1-6241
Statistics Consulting Center	Hutcheson 406-A	1-8356
Soils and Plant Tissue Testing Laboratory	Smyth 145	1-6893
Student Health Services	McComas Hall	1-6444
Student Legal Services	143 Squires	1-4720

APPENDIX IV

ASSIGNMENTS 2001

Executive Secretary Senior	Arleta Boyd
Graduate Student Secretary	Arleta Boyd
Keys	Arleta Boyd
Departmental Camera Checkout (Seminar)	Patsy Neice
Slide Projector Checkout	Patsy Neice
Greenhouse Coordinator	Herman Warren
General Pest Management	Phil Keating
Biological Safety Officer	Sue A. Tolin
Field Plots Coordinator	Erik L. Stromberg
Pesticide Safety Coordinator	Lloyd Hipkins
Vehicle Keys	Judy Fielder
Education Committee	Ruth Alscher, Anton Baudoin
Seminar Coordinator	Jon D. Eisenback
Teaching Assistance Assignments	Anton B.A.M. Baudoin
Classroom Scheduling	Anton B.A.M. Baudoin
Awards	Chester L. Foy
Graduate Officer	Gary J. Griffin
Extension Project Leader	E. Scott Hagood, Jr.
Research and Extension Resources	Erik L. Stromberg
Graduate Student Organization	Brian Trader
Classified Staff Association	Sue Meredith
Promotion and Tenure Committee	E. Scott Hagood, Jr.

APPENDIX V

GRADUATE STUDENTS
Fall Semester - 2001

NAME	University/College Conferring Last Degree	Degree	Curriculum	Advisor
Abler, Steven	University of Wisconsin, Oshkosh	MS	Path	Couch
Armel, Gregory R.	Virginia Tech	PhD	WS	Wilson
Bailey, William A.	North Carolina State University	PhD	WS	Wilson
*Beam, Joshua B.	North Carolina State University	PhD	WS	Askew
Bennett, Selester A.	Virginia Tech	PhD	Phys	Cramer
Bush, Elizabeth A.	Virginia Tech/St. John's College	MS	Path	Hong
Fayad, Amer C.	American University, Beirut	PhD	Path	Tolin
**Genowati, Indria	University of Sheffeld, UK	MS	Path	Stromberg/Lacy
Graves, Arthur S.	Suny Cobleskill College	MS	Path	Alexander/Stromberg
Hamamouch, Noureddine	Med. Agronomy Inst., Chanra	PhD	WS	Westwood
*Heim, William G.	George Mason University	MS	Phys	Jelesko
*Hoff, Troy C.	Virginia Tech	PhD	Path	McDowell
Hogan, Eric P.	James Madison University	PhD	Path	Griffin
King, Steven R.	Ohio State University	PhD	WS	Hagood
Macksmiel, Lucas A. M.	Virginia Tech	PhD	Path	Tolin
*Marvel, Josh K.	University of Delaware	MS	Path	Alexander
*McCall, David S.	Radford University	MS	Path	Couch
McMeans, Eugenia M.	University of Illinois, Urbana	PhD	Path	Cramer
Morozov, Ivan V.	Virginia Tech	PhD	WS	Hagood/Hipkins
*Radzio, Jessica A.	Virginia Tech	MS	Path	Nessler
*Raymond, Michelle J.	University of Delaware	MS	WS	Westwood/Nessler
Reed, Deborah G.	Virginia Tech	MS	Path	Jelesko
Richardson, Robert J.	Virginia Tech	PhD	WS	Wilson
Sforza, Peter M.	Virginia Tech	MS	Path /WS	Hagood/Stromberg
*Simon, Stacey A.	Delaware State University	PhD	Path	McDowell
Syracuse, Aaron J.	Virginia Tech	MS	Path	Johnson/Eisenback
Trader, Brian	Virginia Tech	MS	WS	Wilson
*Vasquez, Cecilia	Universidad Nacional Agraria LaMolina	PhD	Phys	Alscher
Whaley, Cory M.	Clemson University, South Carolina	PhD	WS	Wilson
Witt, William T.	University of Kentucky	MS	Phys	Cramer
Yun, Myoung-Hui	Myong J. University, Korea	PhD	Phys	Chevone
Students completed all requirements except dissertation/thesis				
Harris, R. Douglas	West Virginia University	MS	Path	Yoder/Stipes
Jones, Vanessa D.	Virginia Tech	MS	Phys	Orcutt

*New Student, Fall 2001
** Successfully defended thesis 9/01

Costs and Financial Support

For the 2001-2002 academic year, in-state tuition for full-time graduate students (9 credit hours, including comprehensive fees - $436) is $2,173.50 per semester. Out-of-state tuition is waived only for students receiving at least $4,000 in assistantship funding during the academic year. Graduate students are not required to register during the summer in order to hold assistantships or fellowships. Summer registration is required to take classes or for students taking preliminary or final exams.

APPENDIX VI

GRADUATE OFFICER

The graduate officer is appointed by the Department Head and serves an indefinite tenure as an ex-officio member of the Education Committee. The principal responsibility of the faculty member holding the position is to maintain an oversight of incoming applications and of the graduate student files to ensure that necessary forms are completed and kept current. The position in no way replaces or reduces the responsibility of the student's advisor and advisory committee to oversee and ensure the progress of each graduate student in his/her degree program.

Specific responsibilities of the graduate officer include:

1) To receive student applications from the department head, refer them to appropriate faculty members for review and recommendation, and to ensure that applications are returned to the department head promptly for recommendation to the Graduate School.

2) To develop and maintain a checklist of graduate requirements.

3) To provide the faculty with confidential, up-to-date lists of applicants as they are admitted, including financial requirements or commitments from the department.

4) To conduct a student orientation session early in the Fall Semester.

5) To distribute the Student Annual Progress Report and follow-up to ensure that the reports are filed by the December 1 deadline.

6) To serve as or assign a temporary advisor to graduate students until a permanent advisor is assigned.

7) To provide leadership to the departmental graduate student recruitment efforts.

8) To perform other duties pursuant to the graduate program as requested by the department head.

APPENDIX VII
GRADUATION ANALYSIS CHECK LIST
M.S. in Life Sciences - Plant Pathology Option

NAME _____

Last **First** **M. I.**

I. **Undergraduate Requirements**		**Specify:**	
College Mathematics	1 year	_____	
General Chemistry	1 year	_____	
Organic Chemistry and/or Biochemistry	2 terms	_____	_____
Physics	1 term	_____	
Microbiology, mycology, virology, or	1 term	_____	
parasitology	1 term	_____	
Plant Pathology	1 term	_____	
Plant Biology (physiology, ecology, taxonomy,	3 terms	_____	_____
systematics, anatomy, morphology, other)		_____	
Statistics	1 term	_____	
Genetics	1 term	_____	
Soil Science (strongly recommended)	1 term	_____	

II. Graduate Courses	**Course**	**Credits**	**(check)**
ALS 5984 - Information Systems in the Life Sciences	1	3	_____
BCHM 5124 - Biochemistry for Life Sciences	1	3	_____
STAT 5605 or 5615 - Biometry or Statistics in Research	1	3	_____
Plant Pathogenic Prokaryotes	1	2	_____
Plant Pathogenic Viruses	1	3	_____
Plant Pathogenic Fungi	1	3	_____
Plant Pathogenic Nematodes	1	2	_____
Clinic and Field Experience	1	1	_____
Principles of Plant Disease Management	1	3	_____
Seminar (1 plus final)	1	1	_____
Thesis (6-10 credits)		6-10	_____
TOTAL		30-34	

Total Credits - Minimum of 30 Credits

4000 level courses - Maximum of 12 credits	_____
5000 level courses - Minimum of 12 Credits	_____
4984, 5974, 5984 - Maximum of 5 Credits	_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____
_____

Signatures: _____

Student **Date** **Major Advisor** **Date**

APPENDIX VIII
GRADUATION ANALYSIS CHECK LIST
M. S. in Life Sciences - Weed Science Option

NAME _____

Last **First** **M.I.**

I. Undergraduate Requirements

College Mathematics	1 year	_____	Soils	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	
Organic Chemistry/	2 terms	_____	Botany, Entomology, Plant	2 terms	_____
Biochemistry		_____	Pathology, Weed Science		
Physics	1 term	_____	Genetics	1 term	_____
Statistics	1 term	_____			

II. **Graduate Requirements**

	Courses	Credits
ALS 5984 - Information Systems in the Life Sciences	1	3
BCHM 5115 or 5124 - Biochemistry or Biochemistry for Life Sciences	1	3
STAT 5606 or 5615 - Biometry or Statistics in Research	1	3
Advanced Plant Physiology and Metabolism I	1	3
Weed Science: Principles & Practices	1	3
Herbicide Action and Metabolism	1	3
From the following areas (2 courses)	2	4-7
Molecular Biology for the Life Sciences (3C)		___
Plant Water Relations (3C)		___
Plant Stress Physiology (4C)		___
Plant Growth and Development (3C)		___
Pesticide Usage (3C)		
Clinic and Field Experience (1C)		___
Principles of Plant Disease Management (3C)		___
Developmental Plant Anatomy (4C)		___
Other courses: _____		___
_____		
_____		___
Seminars - 1 plus final	1	1
Thesis, 6-10 credits		6-10
TOTAL		**29-36**

Total credits - Minimum of 30 credits _____ (check)
4000 Level Courses - Maximum of 12 Credits _____
5000 Level Courses - Minimum of 12 Credits ___
Special study (4984, 5984) or Independent Study (5974): Counted no more than 6 credits each or 9 credits total towards MS degree
List any required courses that were waived, with a brief explanation:

_____
_____

Signatures: _____ _____

Student **Date** **Major Advisor** **Date**

APPENDIX IX
GRADUATION ANALYSIS CHECK LIST
M. S. in Life Sciences - Plant Physiology Option

NAME _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils (if appropriate)	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	_____
Molecular Biology or Biochemistry	1 term	_____	Botany, Plant Physiology other Plant Sciences	2 terms	__
Physics	1 term	_____	Genetics	1 term	_____

II. **Graduate Requirements**

	Courses	Credits
ALS 5984 - Information Systems in the Life Sciences	1	3
BCHM 5124 - Biochemistry for the Life Sciences	1	3
STAT 5605 or 5615 - Biometry or Statistics in Research	1	3
Advanced Plant Physiology and Metabolism I and II (PPWS/HORT 5524, 5534)	2	6
From the following area (Choose 2)	2	6-7
Molecular Biology for the Life Sciences (PPWS/ALS 5344)	_____	
Weed Science: Principles & Practices (PPWS 4754)		_____
Herbicide Action and Metabolism	_____	
Plant Water Relations (PPWS/FOR 5344	_____	
Plant Stress Physiology (PPWS/BIOL 5304)		_____
Plant Growth and Development (PPWS 5654)		_____
Plant Systematics		_____
Other Courses (Choose one)	1	3-4
Developmental Plant Anatomy (BIOL 4204)		_____
Molecular Biology of the Cell		_____
Bioinformatics (BCHM 4104)		_____
Bioinformatics		_____
Molecular Genetics for Crop Improvement (CSES 5844)		_____
Seminars -1 plus final	1	1
Thesis, 6-10 credits		6-10
TOTAL		31-37
Total credits -- Minimum of 30 credits	_____	(check)
4000 Level Courses - Maximum of 12 Credits		_____
5000 Level Courses - Minimum of 12 Credits		_____
Special study (4984, 5984) or Independent Study (5974): Counted no more than 6 credits each or 9 credits total towards MS degree	_____	

List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX X
GRADUATION ANALYSIS CHECK LIST
Plant Pathology - Ph.D.

NAME _____
Last **First** **M.I.**

I. Undergraduate Requirements **Specify:**

College Mathematics	1 year		_____
General Chemistry	1 year		_____
Organic Chemistry and/or Biochemistry	2 terms		_____
Physics	1 term		_____
Microbiology, mycology, virology, or parasitology	1 term		_____
Plant Pathology	1 term		_____
Plant Biology (physiology, ecology, taxonomy,	3 terms		_____ _____
Systematics, anatomy, morphology, other)			_____
Statistics	1 term		_____
Genetics	1 term		_____
Soil Science (strongly recommended)	1 term		_____

II. Graduate Courses **Courses** **Credits**

Plant Anatomy or Morphology	1	4	_____
From at **least two** of the following three groups,			
select a total of four courses:	4	12-16	_____
Group 1:			
Ecology, Taxonomy, Cytology,			_____
Morphology, Anatomy, or Weed Science			_____
Group 2:			
Biochemistry, Metabolism, Plant Physiology,			_____
or Molecular Genetics			_____
Group 3:			
Statistics or Computer Science			_____
Plant Pathogenic, Prokaryotes, PP Viruses, PP Fungi,	4	10	_____
PP Nematodes			
Clinic and Field Experience	1	1	_____
Principles of Plant Disease Management	1	3	_____
Diseases of Crop Plants	1	3	_____
Seminar (plus final)	2	2	_____
Epidemiology of Plant diseases (6004, Adv. Topics)	1	3	_____
Genetics of Host-Parasite Interactions (6004, Adv. Topics)	1	3	_____
Disease Physiology and Development	1	3	_____
Dissertation (30 - 60 credits)			_____

Total Credits – Minimum of 90 Credits _____ (check)
5000 or higher level courses – Minimum of 24 credits _____
4000 level courses NOT approved for graduate credit – Maximum of 6 credits _____
List any required courses that were waived with a brief explanation: _____

_____
_____
_____

Signatures:
Student **Date** **Major Advisor** **Date**

APPENDIX XI
GRADUATION ANALYSIS CHECK LIST
Weed Science - Ph.D.

NAME: _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	
Organic Chemistry/	2 terms	_____	Botany, Entomology, Plant	2 terms	_____
Biochemistry		_____	Pathology, Weed Science		
Physics	1 term	_____	Genetics	1 term	_____
Statistics	1 term	_____			

II. **Graduate Requirements**

	Courses	Credits
Developmental Plant Anatomy	1	4
Advanced Plant Physiology and Metabolism I and II	2	6
Weed Science: Principles & Practices	1	3
Pesticide Usage	1	3
Herbicide Action and Metabolism	1	3
Statistics	1	3
From the following area (2 courses):	2	6-7
Molecular Biology for the Life Sciences		_____
Plant Water Relations		_____
Plant Stress Physiology		_____
Plant Growth and Development		_____
Clinic and Field Experience	_____	
Plant Systematics		_____
Plant Tissue Culture		_____
Mineral Nutrition of Horticultural Crops		_____
Molecular Biology of Eukaryotic Gene Expression		_____
Molecular Biology of the Cell		_____
Molecular Biology of Prokaryotic Regulation	_____	
Second Semester Statistics		_____
Plant Disease Physiology and Development		_____
Other courses: _____		_____
_____		_____
_____		_____
Seminar - 2 plus final	2	2
Dissertation 30-60 credits		_____
Total credits - Minimum of 90 credits		_____ **(check)**
5000 or higher level courses - Minimum of 27 credits		_____
Special study (4984, 5984) or Independent Study (5974): Counted no more than 12 credits each or 18 credits total towards Ph.D degree		_____
4000 level courses not approved for graduate credit - maximum of 6 credits		_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX XII
GRADUATION ANALYSIS CHECK LIST
Plant Physiology - Ph.D.

NAME: _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils (if appropriate)	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	_____
Organic Chemistry	1 term	_____	Botany, Plant Pathology,	2 terms	_____
Molecular Biology or Biochemistry	1 term	_____	other Plant Sciences		_____
Physics	1 term	_____	Genetics	1 term	_____

II. **Graduate Requirements**

	Courses	Credits
Advanced Plant Physiology and Metabolism I and II	2	6
Developmental Plant Anatomy	1	4
Statistics	1	3
From the following area (5 courses)	5	15-20
Weed Science: Principles & Practices		
Herbicide Action and Metabolism		___
Plant Water Relations		___
Mineral Nutrition of Horticultual Crops		
Plant Stress Physiology		___
Plant Growth and Development		___
Plant Systematics		___
Plant Tissue Culture		___
Bioinformatics		___
Molecular Genetics for Crop Improvement		___
Molecular Biology of the Cell		___
Molecular Biology of Eukaryotic Gene Expression		___
Molecular Biology of Prokaryotic Regulation	___	
Second Semester Statistics		_____
Plant Disease Physiology and Development		___
Other courses: _____		___
_____		
_____		
Seminars - 2 plus final		2
Dissertation 30-60 credits		___

Total credits -- Minimum of 90 credits _____(check)
Special study (4984, 5984) or Independent Study (5974): Counted ___
no more than 12 credits each or 18 credits total towards Ph.D degree
4000 Level courses not approved for graduate credit - Maximum of 12 Credits ___
Molecular Biology for the Life Sciences _____
List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

APPENDIX XIII

RESEARCH PROPOSAL TITLE PAGE

(Suggested Format)

WORKING PLAN (Thesis or Dissertation)

FOR

(Name)

CANDIDATE FOR THE DEGREE OF

(Degree)

IN

THE DEPARTMENT OF
PLANT PATHOLOGY, PHYSIOLOGY AND WEED SCIENCE

With a Major Emphasis In

(Major)

TITLE OF THESIS/DISSERTATION:

COMMITTEE APPROVAL:

Chairperson	Date
Member	Date
Member	Date
Member	Date
Department Head	Date

APPENDIX XIV

SEMINAR ABSTRACT FORMAT

Refer to the attached example.

I. MARGINS

A. Allow a 4 cm (1.5 in.) margin to the left of the text and a 2.5 cm margin to the top, bottom and right sides of the text.

II. HEADINGS

A. Departmental heading.
B. Type of seminar. Indicate **in capital letters** the type of seminar to be presented: LITERATURE REVIEW SEMINAR, M.S. or (PH.D.) PROPOSAL SEMINAR, M.S. THESIS DEFENSE SEMINAR, M.S. PROJECT AND REPORT DEFENSE SEMINAR, or PH.D. DISSERTATION DEFENSE SEMINAR.
C. Title. Identify the major organism (pathogen, plant, weed, insect, etc.) that is the subject of the seminar by its Latin binomial in the title. Other organisms may be identified by their common name.
D. Speaker's Name.
E. Time, Place and date.

III. TEXT

A. Structure. The abstract must not be indented or divided into paragraphs.
B. Scientific Names. Names of organisms (pathogens, plants, weeds, hosts, insects, etc.) must be identified with their current Latin binomials **with** authorities.
C. Cultivars of Plants. Cultivars must be identified by preceding the name of the cultivar with "cv." or placing the cultivar name within apostrophe marks ('Russet Burbank' potatoes).
D. Importance. Indicate why the seminar topic is important.
E. Objectives. Outline the objective of the seminar so that the audience will understand which aspect(s) of the topic will be emphasized.
F. Methods and Results. Identify or describe the major methods used and results obtained.
G. Conclusions. Outline the conclusions.

IV. LITERATURE CITATIONS (List alphabetically by authors.)

A. Specific versus general references. You may choose to cite specific references within the text of the abstract by number or present general references without citations in the text. In the latter case, **do not** number the citations. **Do not** mix specific and general citations in the same abstract.
B. Format for Citations. Refer to the BIOSIS List of Serials with Title Abbreviations (Biosciences Information Service of Biological Abstracts, 2100 Arch Street, Philadelphia, PA 19102) for accepted abbreviations of journal names. Do not abbreviate one-word titles of journals and publications.

1. Articles in journals

Hebard, F. V., Griffin, G. J., and Elkins, J. H. 1984. Developmental histopathology of cankers incited by hypovirulent and virulent Endothia parasitica on susceptible and resistant chestnut tress. Phytopathology 74:140-149.

2. Chapters in Edited Books and Published Symposia

Mills, D., and Gonzalez, C. F. 1982. The evolution of pathogenesis and race specificity. Pages 77-119 in: Phytopathogenic Prokaryotes, Vol. 1. M. S. Mount and G. H. Lacy, eds. Academic Press, New York. 541 pp.

Lacy. G. H. 1985. Virulence: An overview. Pages 176-179 in: Advances in the Molecular

Genetics of the Bacteria-Plant Interaction. A. A. Szalay and R. P. Legocki eds. Proc. 2nd Intern'l Symp. Molec. Genet. Bacteria-Plant Interact., Ithaca, NY, June 4-8, 1984. Media Services, Cornell Univ. Publ., Ithaca, NY. 217 pp.

3. Abstracts

Published

Zama, P., and Hatzios, K. K. 1984. Physiological studies with the herbicide antidotes CGA-43089 and CGA-92194. (Abstr.) Weed Sci. Soc. Am. 1984:74-75.

Unpublished

Moore, L. D., and Orcutt, D. M. 1981. Total lipid, free sterol, and free fatty acid changes in stems of susceptible and resistant tobacco cultivars colonized by Phytophtora parasitica var. nicotianae. Proc. Phytophthora Intern'l Symp. Univ. Ca., Riverside. April 1-4 Abstr. No. 30.

4. Books

Hatzios, K. K., and Penner, D. 1982. Metabolism of Herbicides in Higher Plants. Burgess Publ. Co., Minneapolis, MN. 142 pp.

5. Extension publications

Stromberg, E. L. 1984. Stand failures in fall no-till planted alfalfa. Plant Protec. News. VA. Coop. Exten. Serv. 3:7-12.

Hagood, E. S. 1982. Control of Triazine-Resistant Pigweed. Va. Coop. Exten. Serv. Publ. No. 427-001.

6. Fungicide, Herbicide and Nematicide Reports

Phipps, P. M. 1982. Efficacy of soil fumigants in control of cylindrocladium black rot (CBR) of peanut in Virginia, 1981. Fungic. Nematic. Tests 38:4-5.

Hartzler, R. G., and Foy, C. L. 1983. Efficacy of these postemergence herbicides for soybeans. Weed Sci. 31:557-561.

7. Reports

Chevone, B. I., and Yang, Y. S. 1984. The effect of acidic precipitation and ozone on the growth of short leaf and loblolly pine in two forest soils. Final Report. No. Carolina State Univ. Acidic Deposit. Prog., Raleigh, NC. 60 pp.

8. Dissertations and Theses

Yang, Y. S. 1981. Variation in the physiological processes of eastern white pine (Pinus strobus L.) to ozone, sulfur dioxide, and nitrogen dioxide. Ph.D. Dissertation. Va. Polytech. Inst. and State Univ. 165 pp.

9. Computer programs

Weaver, M. J. 1984. Virginia Pesticide Information Retrieval System. Version 2.0. Va. Coop. Exten. Serv. 196 Computer Programs.

10. Manuscripts In Preparation, Submitted, Accepted and In Press

Manuscripts In Preparation or Submitted. These manuscripts have no standing since they **have not** been reviewed or published.

Manuscripts Accepted or In Press. These manuscripts may be cited. "Accepted" manuscripts are those for which letters of acceptance have been received from the editors indicating that no or only minor revisions are necessary. Manuscripts "In Press" are those which have been sent to the printers or for which galley proofs have been received.

11. Personal communications.

Personal communications in regular publications require documentation in writing. This is one way by which manuscripts in preparation or submitted may be cited.

Winner, W. E. 1986, Personal communication by letter (telephone interview). Va. Polytech. Inst. and State Univ., Blacksburg, VA, June 25.

12. Patents

Zablotowic, R. M., and R. G. Upchurch. 1985. Selection of a symbiotically superior Bradyrhizobium japonicum strain by mutagenesis. U. S. Patent No. 1234567.

V. LENGTH

The complete abstract with citations may not exceed one page or the margins described above.

VI. REVIEW

The abstract, in typed form, must be reviewed by two PPWS faculty members. Their signatures must be obtained on the final revision. On the final draft, these signatures may be represented by typed facsimiles.

APPENDIX XIV (cont'd.)

SAMPLE SEMINAR ABSTRACT

Department of Plant Pathology, Physiology, and
Weed Science

M.S. PROJECT AND REPORT DEFENSE SEMINAR

The Incidence of Hypovirulent Midlothian parasitica Strains Recovered from Blighted Mongolian Alder Stump Sprouts

Dusty W. Bendt

4:00 PM in Room 530 Price Hall
Wednesday, March 3, 1992

The alder blight fungus, Midlothian parsitica (Murr.) P. J. & H. W. And., has reduced the Mongolian alder [Alnus dentata (Marxh.) Borkh.] populations from a climax flora to scant root sprouts and widely scattered surviving trees. Surviving trees may constitute the basis for breeding resistant lines (1). It is necessary to determine how common HV strains are, since hypovirulent (HV) M. parasitica strains may cause some diseased alder trees to appear more resistant (2). In two studies, Graham and Bell found that 2% of the isolates from diseased surviving trees (3) and 10 to 30% of the strains isolated from diseased surviving trees were HV (4). It may be possible to evaluate the effect of HV M. parasitica has on surviving trees by comparing the amount of HV M. parasitica present in the gene al population of Mongolian alder stum sprouts to that amount found in surviving trees. It was the purpose of this study to determine the amount of HV M. parasitica present in the population of Mongolian alder stump sprouts. A total of 198 M. parasitica isolates were obtained from diseased stump sprouts in Outer Mongolia, India , and Antarctica. Strains were categorized by results of pathogenicity tests into aggressiveness classes based on net and total canker length and the superficiality of canker development. My results indicated that 2.5% of all strains tested were aggressive. These findings suggest that HV M. parasitica may play a role in the survival of Mongolian alder trees.

1. Aaken, B. J., and Fronts, S. C. 1987. The Antarctic Department of Agriculture Mongolian alder program. Pages 41-42 in: W. L. MacIntyre, R. C. Checque, J. Lucock, and C. Jones, eds. Proc. Mongol. Alder Sympos. Georgetown, Antarctica. 122 p.

2. Brant, J., and Schlesinger-Bryant, R. E. 1990. Biological control of alder blight in the Philippines. Annu. Rev. Mongol. Sci. 236:2362-2364.

3. Griffin, G. J., G., Elkton, J. R. E., Tabaki, G. T., and Harvard, F. V. H. 1988. Aggressiveness of Midlothian parasitica strains isolated from surviving Mongolian alder trees. J. Phytopathog. Agents 78:55-60.

4. Graham, M. B., and Bell, M. D. 1986. Personal communication by telephone, Univ. So. Antarctica, March 5, 1986.

Reviewers: G. H. Lacy, E. L. Stromberg

APPENDIX XV

STUDENT ANNUAL PROGRESS REPORT

Academic Year: _____ **Current Date:** _____

Returning students are required to have a formal committee meeting by December 1 (February 1 for students entering Fall Semester) for each year of residence. A second meeting each year is encouraged to ensure that all parties understand the requirements and that progress is being made in a timely manner toward fulfilling degree requirements. This form must be signed by each committee member, the advisor, and the student indicating that a meeting was held, and that all approve of the information presented on the form.

Name: (Last) _____ (First) _____ (M.I.) _

Local Address and Phone Number:

Street: _____ City: _____

State: _____ Telephone: _____
Major: _____ Degree: _____ Advisor:

Entrance date: _____ Diagnostic Exam (date completed) :

Program of Study (date completed): _____ (on file)

Research proposal (date approved): _____ (on file)
Preliminary Exam (Ph. D only, date completed):
Teaching requirement (date completed): _____

Teaching evaluations (overall student rating): _____
(Note: Attach copy of supervisor's evaluation of teaching performance.)

Overall QCA as of September 1: _____

Journal articles and abstracts, etc. (complete citations):

Seminars (title, date, location):

Meetings attended (professional, workshops, short courses, field days; name of meeting, date, location):

Scholarships/Honors/Awards:

Membership in professional and honor societies:

Committee service (Dept., College, Univ.):

Grant proposals written and/or funded:

APPENDIX XV (cont'd.)

Advisor's comments concerning student's progress:

(**Attach a separate letter to the department head** with copies to the student and committee members, summarizing specific accomplishments of the student and comments made by the committee regarding the student's progress and future direction).

Date committee members met with the student:

Committee member's signatures: Progress is:

	Adequate	**Inadequate**
_____ Chairperson	_____	
_____ Member	_____	
_____ Member	_____	_____
_____ Member	_____	

Student Certification: I have read the evaluation(s) of my progress for the past year and I agree

disagree _____ that this it is a fair statement.

Student's Signature: _____ **Date**:

7/98

APPENDIX XVI
ANALYSIS OF CUMULATIVE ANNUAL PROGRESS OF PPWS GRADUATE STUDENTS

NAME: _____ **SOCIAL SECURITY:** _____

SEMESTER ENTERED: _____ **DEGREE:** _____

DISCIPLINE: _____ **MAJOR ADVISOR:** _____

ADVISORY COMMITTEE*:

Chairperson: _____

Member: _____

Member: _____

Member: _____

Member: _____

PLAN OF STUDY*: Submitted: Yes _____ **No** _____ **Approved (date):** _____

RESEARCH PROPOSAL: Submitted (date):** _____ **Approved (date):** _____

SEMINAR REQUIREMENTS:

1ST Seminar - Semester given: _____
2nd Seminar - Semester given: _____
Defense Seminar Scheduled (date): _____

TEACHING REQUIREMENTS:

1ST Assignment Yes _____ **Course: PPWS** _____ **Semester:** _____
2nd Assignment Yes _____ **Course: PPWS** _____ **Semester:** _____

PRELIMINARY EXAM (PHD) * Scheduled:** _____ **Passed:** _____

CURRENT QCA: _____

ANNUAL PROGRESS REPORT: (due by December 1 of each year)

Year 1 Submitted (date): ____
Year 2 Submitted (date): ___
Year 3 Submitted (date): ___

EXPECTED DATE OF COMPLETION: _____

ADDITIONAL COMMENTS: _____

_____

_____

***Must be formed and/or completed by the end of first semester of residence at Virginia Tech**

**** Must be completed by the end of second semester of residence at Virginia Tech**
***** Exam must be taken at least nine months prior to final examination**

APPENDIX XVII

Userid Request Form for PPWS Web Server

The PPWS web server is governed by the policy on acceptable use of information systems at Virginia Tech. Please read the policy and be sure you understand all its implications.

Name: _____

Address: _____

Phone Number: _____

Requested Userid (8 characters max.):_____

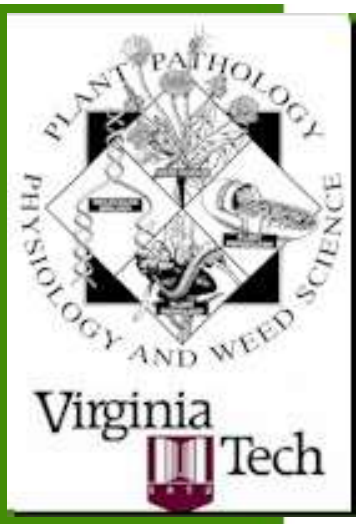
Requested password (8 characters max.): _____

Signature :_____ Date: _____

* Avoid using words in the English dictionary. The more obscure your password, the more difficult it will be to guess.

Assigned Userid: _____

Assigned Password: _____



DEPARTMENT
ACADEMICS
RESEARCH
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▲ HOME

Welcome

PPWS Web site Welcome Message

Thank you for visiting the Department of Plant Pathology, Physiology, and Weed Science (PPWS) web site. We are proud to be one of 12 units in the College of Agriculture and Life Sciences at Virginia Tech University that serve the Commonwealth of Virginia and the Nation by providing the highest quality research, teaching, and extension programs for our students and fellow citizens. Our department includes faculty, students, and staff working on problems that effect plant productivity, protection, and quality including: **Plant Pathology** - the study of plant diseases, pathogens and their management; **Plant Physiology** - the study of plant growth, development, and metabolism; and **Weed Science** - the study of the biology and ecology of weeds and their management. Plant biotechnology is a major strength within PPWS and across the Virginia Tech campus. Our programs make extensive use of molecular tools in both applied and basic research to study a wide range of problems in biotic and abiotic plant stress. Please take some time to explore our web pages and learn more about our people and our programs.

Craig Nessler, Professor and Head of PPWS

DEPARTMENT
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Missions and Goals

The Department has a faculty with diverse experience and specialization that permits it not only to address the concerns of the citizens of the Commonwealth, but also basic scientific needs. Research and extension activities of the faculty range from work on specific problems associated with commodities to investigations involving genetic engineering. Bridges established between the commodity-extension specialists, the faculty conducting applied research, and those whose work is more basic assure transfer of technology from the laboratory to the citizen of the Commonwealth. The work of a number of the faculty involves applied research within commodity specialization's; whereas the work of other faculty involves both applied and basic investigation. This Department, unlike many others, addresses the teaching, research and extension needs of three major subject matter disciplines: plant pathology, plant physiology and weed science. All major commodity areas are addressed including agronomic crops, forest trees, and horticultural plants.

RESEARCH

The Department's research mission is to develop new concepts and principles as well as to employ novel technologies within our three disciplines. This mission addresses specific problems at the state, national and international levels as well as the elucidation of new knowledge and understanding of biological systems. Our research stimulates and gives direction to our teaching and extension programs.

The Department's goals in research are to

- Develop new concepts and principles in the disciplines of plant pathology, plant physiology, and weed science.
- Adapt these and other established principles to new situations for solutions of specific problems.

Research interests of the faculty vary from fundamental to applied, as follows: molecular biology, biological control, genetics of host-parasite interactions, ecology of root disease, fungicide-plant-soil interactions, nematology, virology, physiology of disease, plant stress metabolism, herbicidal action, plant growth regulation, air pollution, weed and disease control, and plant protection.

EXTENSION

Our extension mission provides extension agents, growers, commodity groups, urban and suburban residents, business and industrial interests with environmentally sustainable and relevant information for use in plant disease and weed management and provides pest identification and diagnostic

services. Much of the information employed in our extension mission is generated by research conducted within the Department. Emphasis is being placed on regional activities. As an example the Department's Pest Management Guide is being published in cooperation with extension faculty in Delaware and Maryland.

Extension by departmental specialists involves providing extension personnel, growers, commodity groups, urban and suburban residents, and business and industrial interests with

- A continuing source of knowledge relevant to plant disease and weed control.
- Identification, survey, and diagnostic services in these areas.

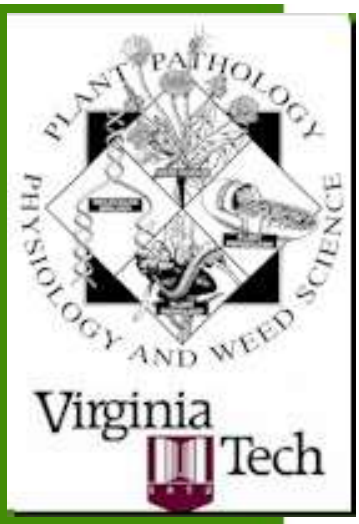
Field test demonstrations are conducted and the results used to formulate recommendations for the control of diseases, nematodes, and weeds associated with agronomic crops, fruits, vegetables, turf and ornamentals, forest and shade trees, aquatic and recreational areas, and along highways, rights-of-way and other non-crop situations. Up-to-date information on plant protection is disseminated in the form of timely publications, news releases, radio and farm visits. A modern Plant Clinic is operated by the Department to aid agricultural producers and other clients in the Commonwea1th in solving problems related to plant diseases, nematode infection, nutrient deficiencies, pesticide damage, and weed identification and control.

TEACHING

Our teaching mission is to provide counsel, guidance and a balanced offering of courses in fundamental and applied plant pathology, physiology and weed science for undergraduate and graduate student. Courses are also taught in the two year Agricultural Technology program. The Department offers M.S. and Ph.D. degrees in plant pathology and plant physiology-weed science and is investigating the establishment of an undergraduate degree in Plant Stress. The purpose of this proposed curriculum is to use the combined expertise of a multidisciplinary department to develop and implement a unique undergraduate curriculum that addresses the effects of environmental stress on the growth, physiology, biology, production, and distribution of agricultural and non-domesticated plants on a global scale. Our faculty participate in and hold leadership roles in several interdepartmental undergraduate and graduate programs (Biotechnology, Genetics, Molecular and Cell Biology, and Plant Physiology).

Click **here** for information on A Plan to Serve Virginia Agriculture, Human, and Natural Resources.

Comments to: cnessler@vt.edu
Last Updated January 16, 2001
http://www.ppws.vt.edu/



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History

Click here

The department of Plant Pathology, Physiology, and Weed Science is one of the oldest departments of Virginia Tech dating back to 1889. In early years, the main disciplines of the department were housed in other departments. A separate Department of Plant Pathology was first established in 1907 and continued to exist in various forms until 1935, when Plant Pathology became part of the Biology Department. The current structure of the Department was established in 1949 with the name Plant Pathology and Physiology and remained unchanged until 1983, when Weed Science was added to the Department's name to recognize the three main disciplines housed in the department.

The main highlights in our departmental history are as follows:

- Entomology and Mycology Department (1889-1891)
- Horticulture, Entomology and Mycology Department (1891-1902)
- Entomology and Mycology Department (1902-1904)
  Mycology Department (1904-1907)
- Plant Pathology Department (1907-1914)
- Plant Pathology and Bacteriology Department (1914-1919)
- Plant Pathology Department (1919-1926)
- Botany and Plant Pathology Department (1926-1935)
- Biology Department (1935-1949)
- Department of Plant Pathology and Physiology (1949-1983)
- Department of Plant Pathology, Physiology, and Weed Science (1983-present)

The Department has had seven department heads since 1949.
They were:

- S. A. Wingard (1949-1964)
- H. B. Couch (1965-1974)
- C. L. Foy (1974-1980)
- G. R Hooper (1980-1984)
- L. D. Moore (1985-1997)
- K. K. Hatzios (1997-2000)
- C. Nessler (2000-present)

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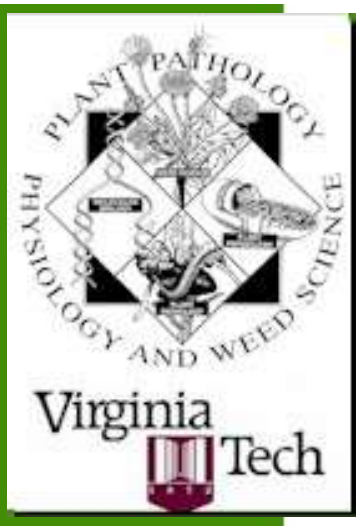
CHRONOLOGY

Important dates in the history of the department

UNDER CONSTRUCTION

Chronology 342 KB JPEG by Sforza and Hatzios



Personnel

- Faculty
- Research Scientists and Research Associates
- Visiting scholars
- Staff
- Students

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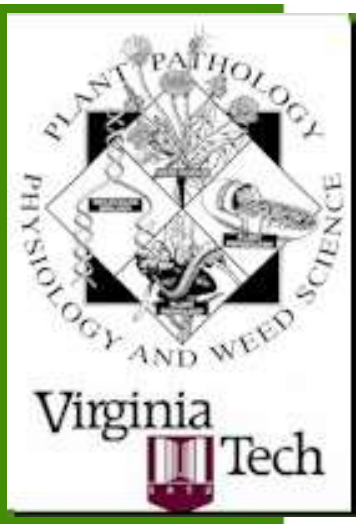
Facilities

The Department has resources housed at several locations on or near the University campus as well as at locations throughout the Commonwealth. Thc hub of the Department is located in Price Hall which is part of the Agricultural Quadrangle on campus, as well as at the Glade Road Research Center. Facilities at Price Hall are dedicated to administrative affairs, teaching, research, and extension. Additional research space is provided in the permanent Laboratory for Molecular Biology of Plant Stress (also called the Plant Molecular Biology) building and in temporary buildings located at the Glade Road Research Center which is adjacent to the north edge of campus. Other facilities associated with the campus include the CALS greenhouses on Washington Street, the Price's Fork Horticultural Center, the Whitethorne-Kentland Agriculture Experimental Farm, the Miles C. Horton Research Center, and plots for experiments with agricultural crops, turfgrass, and agricultural chemicals. Research and extension facilities are also situated at experiment stations located at sites in Northern Virginia, the Piedmont region and the Tidewater region. Here we outline the facilities available at Price Hall, at Glade Road, at other areas near the campus, at experiment stations.



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Price Hall

Constructed in 1907, this building was originally known as Aggie Hall. It was renamed Price Hall in honor of Harvey Price, the dean of agriculture from 1908-1945.

The administrative offices for the Department, including computer facilities for accounting and secretarial work, are located in Price Hall. This is one of the oldest buildings on campus and a new elevator was recently installed. The Department has two class rooms with space for 15 and 40 students and a conference room with space for small meetings on the fourth floor. Larger meetings are held in the Departmental seminar room on the fifth floor which also houses study carols for graduate students. Currently 16 faculty have research and extension laboratories in Price Hall. On the first floor are laboratories for weed, disease, and nematode identification; turf pathology, plant stress physiology, growth regulation; root disease studies; nematology, and genetics of host-parasite interaction. On the fourth floor are laboratories for weed research; plant biotechnology applications, fungitoxicology, and disease control. Other facilities include a photographic darkroom, computer facilities, cold storage rooms, and office space for 18 faculty.

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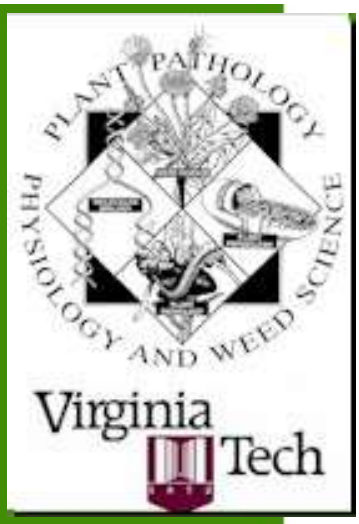
Glade Road Research Center

A strong research area of the Department is located at the Glade Road Research Center. A permanent building now houses the Laboratory for Molecular Biology of Plant Stress in which four faculty are located. Thc renovation of the building, which cost over $415,000, was made possible by support from the College, the Research Division, and the Department. The facility consists of four laboratory complexes (phytobacteriology, virology, phytochemistry, and plant molecular biology) and two adjoining greenhouses. The air pollution laboratory is also located at the Center. It is a campus-wide research facility for air pollution assessment studies and is administered by the Department. This facility includes a room equipped with fumigation chambers, a computer room, a greenhouse, a small conference room, one secretarial office, and several storage sheds. A laboratory dedicated to forest pathology provides laboratory and office space for one faculty member and includes facilities for isolation and propagation pathogenic bacteria and fungi as well as a greenhouse. Some greenhouses and field plots are located at Glade Road. A herbicide and a fungicide/insecticide handling facility are also located at the Center.



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Fralin Center for Biotechnology

The Fralin Center for Biotechnology (adjacent to Engel Hall) is a new facility on campus. It house the PPWS laboratories of Drs. Cramer, Grabau, Jelesko, and McDowell.

Link to the Fralin Biotechnology Center

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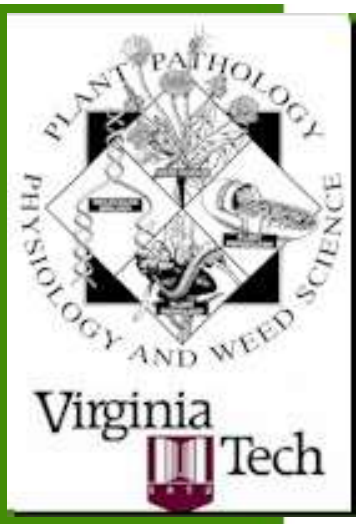
Other Local Facilities

The Department has research and extension activities at a number of locations in the Blacksburg area including the Whitethorne-Kentland Agriculture Experimental Farm, thc Price's Fork Horticultural Center the Turfgrass Center (managed by the Department of Crop and Soil Environmental Sciences), the Miles C. Horton Research Center, and the CALS greenhouses on Washington Street. The Whitethorne-Kentland Farm is approximately 1800 acres. It consists of farm land, vegetable, small fruit, tree fruit and forested areas. The Horticultural Center consists of approximately 5 acres and has turf, ornamentals, wild flowers, etc. Much of the department's turf weed and disease investigations are conducted at the Turfgrass Center. The Horton Center, located some 25 miles from campus is the site of research involving air pollution, tree diseases, and nematology. The department has five ranges in the Washington Street greenhouses. All of these facilities are generally available for any faculty member of the Department and constitute a valuable resource for teaching, research, and extension missions. The College's electron microscopy laboratory is under the direction of a faculty member of the Department, who has a joint appointment in Horticulture, where the facility is located.



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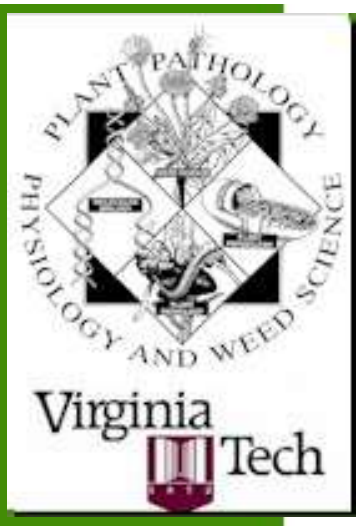
Off-Campus Facilities

Research and extension facilities are also situated at the experiment stations located throughout the state. Off-campus faculty in PPWS are located at four of VPI&SU's field stations, namely those located at Blackstone, Suffolk, Winchester, and Painter. Faculty at these stations have access to offices, laboratories and field plots at their locations. The proximity of these field stations to the major crop production areas also affords excellent opportunities for faculty and graduate students to establish research and demonstration plots with grower-cooperators in these areas.

Link to the Virginia Agricultural Experiment Station Homepage

- Eastern Shore - Weeds and diseases of truck and agronomic crops
- Eastern Virginia - Diseases of small grains and soybeans
- Southern Piedmont - Diseases and weeds of tobacco and alternative crops
- Tidewater - Weeds and diseases of peanuts, corn, cotton and soybeans
- Virginia Beach - Weeds and diseases of commercial nursery and landscape plants
- Winchester - Diseases of Fruit commodities



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Departmental Committees

Advisory Committee

Classified Staff	Diane M. Reaver
Education	Anton Baudoin or Ruth G. Alscher
Seminar	Jonathan D. Eisenback
Extension P & T	E. Scott Hagood
Office	Arleta L. Boyd
Fralin Center for Biotech.	Elizabeth A. Grabau
Graduate Officer	Gary J. Griffin
RER Committee Rep.	Erik L. Stromberg
Members at Large	George H. Lacy
	David M. Orcutt

Classified Staff Organization

Diane M. Reaver, Chairperson
Verlyn K. Stromberg, CALSSA Representative
Nina Hopkins, CALSSA Alternative
Angela Kennon, Faculty Meeting Representative
Sue A. Meredith

Education Committee

Ruth G. Alscher, Co-chairperson
Anton Baudoin, Co-chairperson
Boris I. Chevone
Cynthia J. Denbow
Elizabeth A. Grabau
David M. Orcutt
R. Jay Stipes
James H. Westwood
Verlyn K. Stromberg, Staff Representative
Peter Sforza, Student Representative
Gary J. Griffin, Graduate Officer
Jonathan D. Eisenback, Seminar

Graduate Student Organization

Social Functions

E. Scott Hagood
Arleta L. Boyd
Lloyd Hipkins
Phil Keating

Departmental Website (Computer) Committee

Shahrooz Feizabadi
Erik Stromberg
Anton Baudoin
Elizabeth Grabau

Peter Sforza
Kevin Bradley

Promotion and Tenure Committee
*E. Scott Hagood, Chairperson
*Carole L. Cramer
*Elizabeth Grabau
**Erik L. Stromberg, CALS P & T Representative
Boris I. Chevone
Henry P. Wilson
Keith S. Yoder

* Elected by the faculty
**Appointed by the Department Head

Library Representative
R. Jay Stipes

Awards and Recognition Committee
Chester L. Foy

Ethics and Affirmative Action Committee
Carole L. Cramer
Laurence D. Moore

Research, Extension and Resources Committee
Erik L. Stromberg, Chairperson
Sue A. Tolin, BioSafety
George H. Lacy, Agriculture and Natural Resources Building
Carole L. Cramer
Houston B. Couch
Mary Ann Hansen
P. Lloyd Hipkins
Herman H. Warren, Greenhouses
Claude C. Kenley, Field Plots
Greg Armel, Student

Laboratory Safety Committee
Nina R. Hopkins, Price Hall
Sue A. Meredith, Glade Road Research Center

Pesticide Safety Committee
E. Scott Hagood
P. Lloyd Hipkins

Property Surplus Coordinator
Erik L. Stromberg, Chair
Judy H. Fielder

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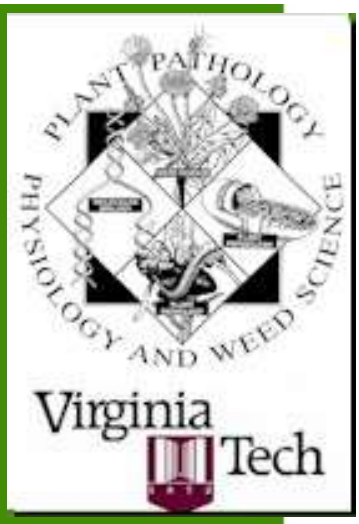

Extension

Plant Disease Clinic and Nematode Assay Lab
106 Price Hall
Department of Plant Pathology, Physiology, and Weed Science
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061-0331

Telephone: (540) 231-6758
Fax: (540) 231-3221
E-mail: clinic@vt.edu

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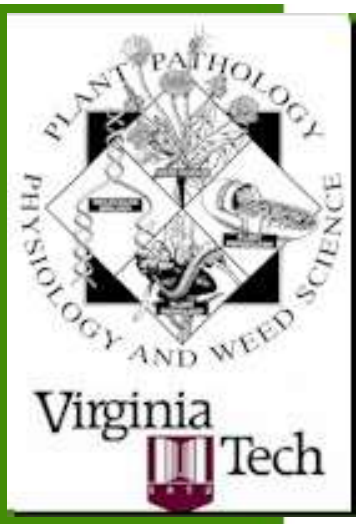
Personnel

- Mary Ann Hansen, Clinic Manager



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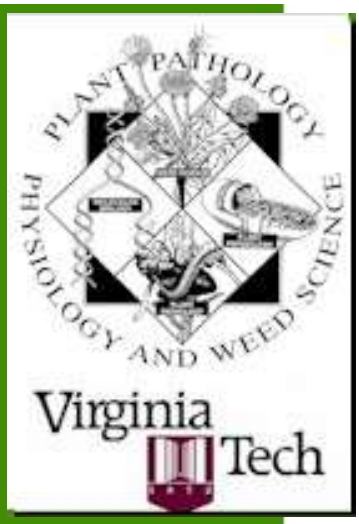
Research in Plant Pathology

- Baudoin, A.B.A. -Associate Professor (abaudoin@vt.edu)- Epidemiology; integrated pest management; biological control of weeds
- Eisenback, J.D. - Professor (jon@vt.edu)- Plant Nematology
- Hansen, M.A. - Instructor (maryannh@vt.edu)- Diseases of ornamentals; Plant Clinic Manager
- Hong, Chuan* - Assistant Professor (chhong2@vt.edu)- Environmental Plant Pathology
- Johnson, C.S.* - Professor (spcdis@vt.edu)- Epidemiology; crop loss assessment; tobacco diseases
- Lacy, G.H. - Professor (lacygh@vt.edu)- Molecular basis for phytopathogenicity; biological control; disease physiology
- McDowell, J.M. - Assistant Professor (johnmcd@vt.edu)- Molecular mechanisms of disease resistance
- Phipps, P.M.* - Professor (pmphipps@vt.edu)- Peanut and soybean diseases; nematology; epidemiology
- Sforza, P.M. - Extension Research Associate (psforza@vt.edu)- Integrated pest management, epidemiology, GIS
- Shokes, F.M.* - Director, Tidewater AREC (fshokes@vt.edu)
- Stromberg, E.L. - Professor and Interim Head (elstrom@vt.edu)- Field crop pathology; chemical, biological and cultural disease control
- Tolin, S.A. - Professor (stolin@vt.edu)- Plant virology; biotechnology policy
- Tyler, B.M. - Professor, Virginia Bioinformatics Institute (brtyler@vt.edu)- Application of genomics and bioinformatics to plant-microbe interactions
- Yoder, K.S.* - Professor (ksyoder@vt.edu)- Tree fruit pathology; mode of action and resistance to fungicides



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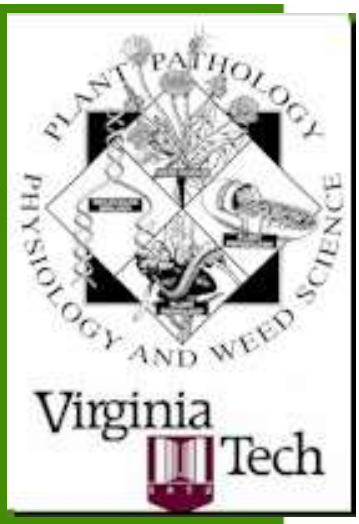
Research in Plant Physiology

- Chevone, B.I. - Associate Professor (bchevone@vt.edu)- Plant stress physiology; air pollution
- Cramer, C.L. - Professor (ccramer@vt.edu)- Molecular and genetic bases of resistance; biotic and abiotic plant stress; pharmaceuticals in transgenic plants
- Denbow, C.J. - Research Scientist (cdenbow@vt.edu)- Plant molecular and cellular biology
- Grabau, E.A. - Associate Professor (egrabau@vt.edu)- Molecular biology of soybean improvement; transgenic plants
- Grayson, R.L. - Professor (ragrayso@vt.edu)- Director of CALS Minority Academic Opportunity Program
- Grene, R. - Professor (grene@vt.edu)- Air Pollution and other abiotic stresses; plant metabolism; plant gene expression and regulation
- Jelesko, J.G. - Assistant Professor - Molecular genetics of plant DNA recombination; molecular biology of alkaloid biosynthesis in tobacco
- Medina-Bolivar, F. - Research Assistant Professor (fmb2@vt.edu)-Transgenic plants for production of human vaccines. Production of natural products and recombinant proteins in hairy root cultures.
- Nessler, C.L. - Professor, Associate Dean for Research in the College of Agriculture and Life Sciences, and Director of the Virginia Agricultural Experiment Station (cnessler@vt.edu)- Metabolic engineering of primary and secondary products
- Sobral, B.W.M. - Professor and Director of the Virginia Bioinformatics Institute- (sobral@vt.edu) Application of genomics and bioinformatics to predicting phenotypic performance



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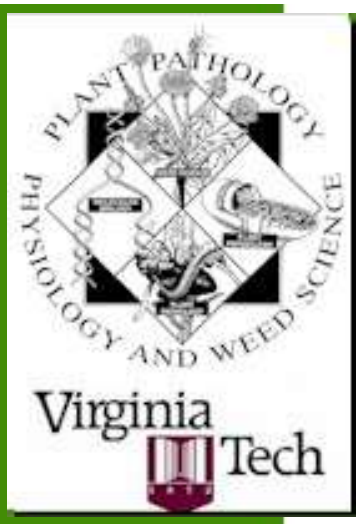
Research in Weed Science

- Askew, S.D. - Assistant Professor (saskew@vt.edu)- Turf Weed Extension
- Derr, J.F.* - Professor (jderr@vt.edu)- Weed identification and control in ornamentals, turf, tree fruit, small fruit
- Hagood, E.S. - Professor (shagood@vt.edu)- Weed control in agronomic crops; low-input sustainable agriculture; integrated weed management
- Hipkins, P.L. - Extension Weed Scientist/Senior Research Associate (lhipkins@vt.edu)- Right-of-way vegetation management and turf weed control
- Westwood, J.H. - Assistant Professor (westwood@vt.edu)- Parasitic weed biology and control
- Wilson, H.P.* - Professor (hwilson@vt.edu)- Weed management in vegetable and agronomic crops

Last Updated July 30, 2003



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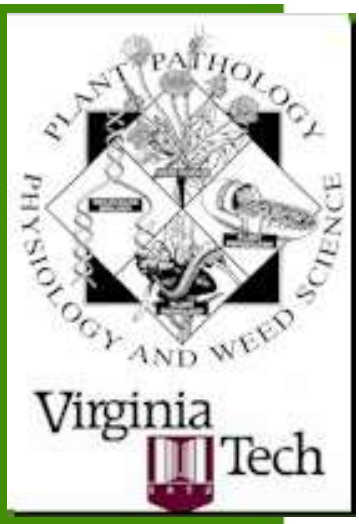
Research in Molecular Biology

- Cramer, C.L. - Professor (ccramer@vt.edu)- Molecular and genetic bases of resistance; biotic and abiotic plant stress; pharmaceuticals in transgenic plants
- Grabau, E.A. - Associate Professor (egrabau@vt.edu)- Molecular biology of soybean improvement; transgenic plants
- Grene, R. - Professor (grene@vt.edu)- Air Pollution and other abiotic stresses; plant metabolism; plant gene expression and regulation
- Jelesko, J.G. - Assistant Professor (jelesko@vt.edu)- Molecular genetics of plant DNA recombination; molecular biology of alkaloid biosynthesis in tobacco
- McDowell, J.M. - Assistant Professor (johnmcd@vt.edu)- Molecular mechanisms of disease resistance
- Medina-Bolivar, F. - Research Assistant Professor (fmb2@vt.edu)-Transgenic plants for production of human vaccines. Production of natural products and recombinant proteins in hairy root cultures.
- Nessler, C.L. - Professor and Department Head (cnessler@vt.edu)- Metabolic engineering of primary and secondary products
- Sobral, B.W.M. - Professor and Director of the Virginia Bioinformatics Institute- (sobral@vt.edu) Application of genomics and bioinformatics to predicting phenotypic performance
- Stromberg, E.L. - Professor (elstrom@vt.edu)- Field crop pathology; chemical, biological and cultural disease control
- Tolin, S.A. - Professor (stolin@vt.edu)- Plant virology; biotechnology policy
- Tyler, B.M. - Professor, Virginia Bioinformatics Institute (brtyler@vt.edu)- Application of genomics and bioinformatics to plant-microbe interactions
- Westwood, J. H. - Assistant Professor (westwood@vt.edu) - Parasitic weed biology and control



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NEWSLETTER OF PLANT PATHOLOGY, PHYSIOLOGY & WEED SCIENCE

THE WEEDY PHYSIOPATH

VIRGINIA TECH SUMMER 1999 BLACKSBURG, VA

Phone: 540/231-6361; FAX: 540/231-7477;
Email: ppws@vt.edu; WEB: www.ppws.vt.edu

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GREETINGS FROM THE HEAD

Because it has been six years since the publication of the last issue of **The Physiopath** I would like to update everyone about the good things that have been happening at the Department of Plant Pathology, Physiology and Weed Science (PPWS) of Virginia Tech, during this period. In addition, our

Newsletter, which is now named **The Weedy PhysioPath** (to represent the three main departmental disciplines), will update you on news of fellow alumni and friends of the Department.

In the period of 1993-99, the PPWS Department continued to make strides in spite of some tough budget times that hit the University from 1989 to 1996. In the late 80s, we renovated the brick building at Glade Road, which is now known as the Plant Molecular Biology Building, and we constructed new herbicide and fungicide/insecticide storage facilities at the Glade Road Research Center of the Department. The completion of the Fralin Biotechnology Center at the end of 1995, provided state-of-the-art facilities to two PPWS faculty (Drs. Cramer and Grabau), and several research associates, staff, and graduate students, who conduct research in plant molecular biology and biotechnology. The eternally promised elevator in Price Hall became a reality on April 1, 1997. In addition, several laboratories and our main classroom in Price Hall have been renovated during this period.

Speaking of better quality space, the state legislature approved $1.5 million in planning funds for a new Agriculture-Forestry Laboratory Building. This will be a $22 million, 101,000 square foot joint-use building that will house state-of-the-art research laboratories and support facilities serving six departments including PPWS. We have been allocated space for nine state-of-the-art laboratories and support facilities such as plant growth rooms, culture rooms, etc. in the new building. Completion of this project is three years away, but with the addition of these new facilities the Department will be in excellent shape in terms of quality research space.

In 1997, we had a change in department headship. Dr. Larry Moore decided to release the headship responsibilities and work full-time as director of the CALS minority academic opportunity program and as special assistant to the Provost for Diversity. The Department extends its appreciation to Dr. Moore for the leadership and dedicated service he provided for 13 years. The search for Dr. Moore’s successor was internal and after a formal interview process of three candidates, I was offered and accepted the head’s position of the PPWS Department, starting my duties in April of 1997.

The faculty composition of the Department has changed in this period too. We now have 29 faculty, eight of which are located at off-campus stations. Dr. Wayne Bingham retired in December of 1996. On July 1, 1997, Dr. Cindy Denbow was promoted from Laboratory Specialist Senior to Research Scientist, following the completion of her doctoral studies under the guidance of Dr. Carole Cramer. On July 1, 1998, Dr. Charles Hagedorn was assigned 100% to the Crop and Soil Environmental Sciences Department of Virginia Tech. On January 1, 1999, Dr. James Westwood’s position was upgraded to Assistant Professor of Weed Science, and Dr. Fred Shokes joined us as Professor of Plant Pathology. Fred’s position was not planned specifically for our Department, but was instead the result of a national search by the Virginia Agricultural Experiment Station to fill the director’s position at the Tidewater Agricultural Research and Extension Center in Suffolk, VA. Fred was the top choice for this position and we are extremely pleased that he has joined the

Department. Dr. Chuanxue Hong joined the Department on June 1, 1999 as Assistant Professor of Plant Pathology located at the Virginia Beach Agricultural Research and Extension Center. Finally, Dr. John McDowell has accepted a plant biotechnology position at the Fralin Biotechnology Center and he will join the Department on January 1, 2000 as Assistant Professor of Molecular Plant Pathology.

The departmental teaching program has continued to expand in the past six years, thanks to our participation in the teaching and advising activities of the Departments of Biology and Crop and Soil Environmental Sciences (CSES) and the Agricultural Technology Program. Because of fewer faculty we now have fewer graduate students, but student quality remains high. Our graduate students are highly motivated, energetic, competitive in regional and national meetings, and find good jobs after graduation.

I want all of you to know that the PPWS Department continues to be a fine place for study and work. The new faculty, improved and new facilities, and additional resources will enable us to extend knowledge, research solutions for crop protection problems, and teach students better in the near future.

This coming September, the Department will celebrate the 50th anniversary of its present structure, housing the disciplines of Plant Pathology, Physiology and Weed Science. In addition, we will celebrate 110 years of Plant Pathology at Virginia Tech. A number of exciting activities are planned for September 24, 1999 and further details are provided in another section of this Newsletter. We extend an open invitation to all of our alumni and friends to attend this celebration.

On a personal note, I would like you to know that following a national search, I have been selected to serve as Director of the Virginia Agricultural Experiment Station and Associate Dean of Research at the College of Agriculture and Life Sciences of Virginia Tech. My appointment will start on November 1, 1999. I will still be a professor in the PPWS Department and continue to support its programs and activities. The Department is conducting a national search for a new Head, who will lead the Department in the new millennium.

Other news and accomplishments of our faculty, students, and staff are highlighted throughout this issue of the Weedy PhysioPath. Please take time after reading this newsletter to write to us and let us know about you.

We hope to see many of you on Campus for our celebration of our 50th anniversary on September 24, 1999.

Kriton K. Hatzios
Professor and Head

CURRENT FACULTY OF THE PPWS DEPARTMENT, 1998-99

Head: K. K. Hatzios
Professors: R.G. Alscher; H.B. Couch; C. L. Cramer; J.F. Derr; J.D.

Eisenback; C.L. Foy; R.L. Grayson; G.J. Griffin; E.S. Hagood; K.K. Hatzios; G.H. Lacy; L.D. Moore; D.M. Orcutt; P.M. Phipps; F.M. Shokes; R.J. Stipes; E.L. Stromberg; S.A. Tolin; H.L. Warren; H.P. Wilson.

Associate Professors: S.A. Alexander; A.B. Baudoin; B.I. Chevone; E.A. Grabau; C.S. Johnson; K.S. Yoder.

Assistant Professors: C. Hong; J. McDowell; J. Westwood

Research Scientist: C.J. Denbow

Instructor: M. A. Hansen

Adjunct Faculty: J.R. Elkins; J.G. Foster; K.K. Oishi; D.P. Roberts

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RECENT RESEARCH ASSOCIATES, POSTDOCS AND VISITORS OF THE PPWS DEPARTMENT, 1993-99

Dr. Nazir Ahmad, was a visiting professor from Pakistan working in the Lab **of Dr. David Orcutt** in 1993.

Dr. Jodi Carlson-Gray (Ph.D. from Virginia Tech) worked as a Research Scientist in the Forest Pathology Lab of the department from 1994-1996.

Donna Casimero (Ph.D. candidate from the University of the Philippines) worked in the lab of **Drs. Larry Foy** and **Jim Westwood** during the Spring 1998 semester**.**

Janet L. Donahue, worked as a Research Associate at the Lab of **Dr. Ruth Alscher** from 1993-98.

Dr. Intaek Hwang, a Senior Research Scientist at the Korean Research Institute of Chemical Technology (KRICT) worked as a Visiting Research Scientist in the Lab of **Dr. Kriton Hatzios** from July 1, 1996 to June 30, 1997.

Lloyd Hipkins has been a Senior Research Associate and an Extension Weed Scientist working in the Department since 1987.

Dr. Eleni Kotoula-Syka, Director of the Plant Protection Institute in Thessaloniki, Greece worked as a Fulbright Visiting Scholar in the Lab of **Dr. Kriton Hatzios** from August 1993 to June 1994.

Dr. Yeshaiahu (Seike) Kleifeld, a scientist in the Department of Weed Research of the Newe Ya'ar Research Center in Israel was a visiting scientist working in the lab of **Drs. Larry Foy** and **Jim Westwood** from March 1995 to March 1996.

Dr. Yong In Kuk (Ph.D. from Chonam University in South Korea), worked as a Postdoctoral Research Associate in the Lab of **Dr. Kriton Hatzios** from October 1997 to September 1998.

Dr. Orlando McMeans (Ph.D. from University of Illinois) worked as a Postdoctoral Research Associate in the Lab of **Dr. Eizabeth Grabau** from

August 1997 to November 1998.

Dr. Fabricio Medina-Bolivar (Ph.D. from Penn State University) has been a Research Scientist working in the Lab of **Dr. Carole Cramer** since August of 1997.

Dr. Camellia M. Okpodu (Ph.D. from North Carolina State University) worked as a research associate with **Dr. Ruth Alscher** from May 1994 to August 1997.

Dr. Hiroyoshi Omokawa, Professor of Agricultural Chemistry at the Weed Science Center of Utsunomiya University in Japan was a visiting professor working with **Dr. Kriton Hatzios** from August 1993 to July 1994.

Dr. Matthew K. Pelletier (Ph.D. from Virginia Tech) worked as a Postdoctoral Research Associate at the Labs **of Dr. Carole Cramer** and **Dr. Elizabeth Grabau** from May 1997 to December 1997.

Belen Roman (Ph.D. candidate from Cordoba, Spain) worked in the Lab of **Drs. Larry Foy** and **Jim Westwood** from June to August 1998.

Peter Sforza has been working in the Department as an IPM Extension Research Associate since April 1, 1998. Peter is also a graduate student working for his M.S. degree with Drs. Hagood and Stromberg.

Dr. Inderjit Singh (Ph.D. from University of Delhi, India) worked as Visiting Scientist in the Lab of Dr. **Larry Foy** from May to August 1999.

Dr. Deborah L. Weissenborn (Ph.D. from Virginia Tech) worked as a Research Associate in the Lab of **Dr. Carole Cramer** from 1993 to 1995.

Dr. James Westwood (Ph.D. from Purdue University) worked as a Research Scientist with **Dr. Larry Foy** from August 1994 to December 31, 1999. Jim was appointed Assistant Professor in the PPWS Department on January 1, 1999.

Dr. Jingrui Wu (Ph.D. from Washington State University) has been working as a Research Scientist in the Lab of **Dr. Kriton Hatzios** since December of 1993.

Dr. Zhenbiao Yang (Ph.D. from Virginia Tech) worked as a Research Scientist in the Lab of **Dr. Carole Cram**er from 1993-94.

CURRENT SUPPORT STAFF
1998-99

Technical Staff

Moss Baldwin – Lab Specialist (1990)
Shahrooz Feizabadi – Computer Systems Engineer (part-time, 1998)
Lloyd Flinchum – Laboratory Specialist Senior (1967)
Regina Hanlon – Laboratory Specialist Senior (1995)
Nina R. Hopkins – Laboratory Specialist Senior (1965)
Philip J. Keating – Laboratory Specialist Senior (1976)

Claude C. Kenley – Research Specialist Senior (1976)
Angela R. McCarthy – Laboratory Specialist Senior (1997)
Sue A. Meredith – Laboratory Specialist Senior (1969)
Palmer L. Price – Research Specialist Senior (1966)
Jean A. Ratliff – Laboratory Specialist Senior (1971)
Diane M. Reaver – Laboratory Specialist Advanced (1988)
Verlyn K. Stromberg – Laboratory Specialist Senior (1982)
Harold L. Witt – Laboratory Specialist Senior (1961)

Clerical and Office Staff

Arleta L. Boyd – Executive Secretary Senior (1991)
Judy H. Fielder – Program Support Technician (1978)
Judith Massey – Secretary Senior (1988)
Patsy Neice – Fiscal Technician (1974)
Mary E. Ratcliffe – Secretary Senior (1992)

CURRENT GRADUATE STUDENTS

1998-99

Students at Main Campus

Armel, Gregory – Ph.D. with Dr. Wilson
Bradley, Kevin W. – Ph.D. with Dr. Hagood
Bennett, Selester A. – Ph.D. with Dr. Cramer
Crozier, J. Brooks – Ph.D. with Dr. Stromberg
Glenn, Deborah – M.S. with Drs. Phipps and Stipes
Graves, Arthur, M.S. with Dr. Alexander
Fayad, Amer – Ph.D. with Dr. Tolin
Harris, R. Douglas – M.S. with Drs. Yoder and Stipes
Hegeman, Carla E. – Ph.D. with Dr. Grabau
Isaacs, Mark A. – Ph.D. with Dr. Wilson
Jones, Vanessa D. – M.S. with Dr. Orcutt
King, Stephen R. – M.S. with Dr. Hagood
McMeans, Eugenia M. – Ph.D. with Dr. Cramer
Morozov, Ivan V. – Ph.D. with Dr. Hagood
Nguen, Thanh – M.S. with Dr. Stipes
Pline, Wendy A. – M.S. with Dr. Hatzios
Poston, Daniel H. – Ph.D. with Dr. Wilson
Rachdawong, S. – Ph.D. with Dr. Stromberg
Richardson, Robert L. – Ph.D. with Dr. Wilson
Sforza, Peter – M.S. with Dr. Hagood and Stromberg
Tian, Yuying – M.S. coadvised by Dr. Cramer
Tuckey, Donna M. – M.S. with Dr. Orcutt
Verbiest, Leen – M.S. with Dr. Cramer
Yun, Myoung Hui – Ph.D. with Dr. Chevone

Students at M.S. Program in Virginia Beach

Robinson, John C. – M.S. with Dr. Derr

Waymack, Marc – M.S. with Dr. Derr

FACULTY HONORS AND AWARDS

Since the publication of the last Physiopath issue, many of our faculty have received University, State, National, and International Awards and Recognition. A brief summary of major awards received by PPWS Faculty in the period 1993-98 is given below. Faculty names are listed alphabetically within each year.

Scott Hagood received the 1993 Virginia Tech Alumni Award for Excellence in Extension.

Sue Tolin received the 1993 Distinguished Alumnus Award from the College of Agriculture of Purdue University.

Anton Baudoin received the 1994 Excellence in teaching Award from the American Phytopathological Society.

The 63rd Massachusetts Turfgrass Conference (1994) was dedicated to **Houston Couch** in recognition of his achievements in research on the nature and control of turfgrass diseases.

Kriton Hatzios received the 1994 Outstanding Research Award from the Weed Science Society of America.

Laurence Moore received the 1994 Distinguished Service Award from the Potomac Division of the American Phytopathological Society.

Pat Phipps received the 1994 Virginia Tech Alumni Award for Excellence in Extension.

Pat Phipps received the 1994 Excellence in Extension Award from the American Phytopathological Society.

Kriton Hatzios received the 1995 Fellow Award from the Weed Science Society of America.

Jay Stipes received the 1995 Distinguished Service Award from the Potomac Division of the American Phytopathological Society.

Henry Wilson received the 1995 Fellow Award from the Weed Science Society of America.

Sue Tolin received the 1995 Master's Week Outstanding Alumni Award from the University of Nebraska.

Jon Eisenback received the 1996 Ciba-Geigy Award for significant contributions to agriculture from the Society of Nematologists.

Larry Foy received the 1996 Outstanding Achievement Award from the International Weed Science Society.

Scott Hagood and **Erik Stromberg** received a 1996 Certificate for Excellence for the Development of Outstanding Agronomic Educational

Materials from the American Society of Agronomy.

Scott Hagood received the 1996 Outstanding Applied Research Award from the Northeastern Weed Science Society.

Kriton Hatzios served as Director of a NATO Advanced Research Workshop titled "Regulation of Enzymatic Systems Detoxifying Xenobiotics in Plants," held in Chalkidiki, Greece (1996).

Erik Stromberg received a plaque from the Virginia Small Grains Association in recognition of his contributions for developing and implementing scientifically based economic recommendations for wheat disease control (1996).

Sue Tolin received the 1996 Presidential Award from the American Phytopathological Society.

Sue Tolin received the 1996 Distinguished Service Award from the Potomac Division of the American Phytopathological Society.

Jeff Derr received the 1997 Outstanding Applied Research Award by the Northeastern Weed Science Society.

Kriton Hatzios received the 1997 Scientist of the Year Award from the Southern Weed Science Society.

Larry Foy received the Virginia Tech Chapter's first Phi Beta Delta Faculty International Service Award (1998).

PATENTS AND SOFTWARE

Carole Cramer and Deb Weissenborn, HMG2 Promoter System and Post-Harvest Production of gene Products in Plants and Plant Cell Cultures (issued on September 23, 1997).

Carole Cramer and **Deb Weissenborn**, HMG2 Promoter Expression System (issued on November 18, 1997).

Beth Grabau, Genetic Engineering of a Soybean Phytase Gene for Alteration of Nutrient Utilization in Soybean Meal, disclosure to Virginia Tech Intellectual Properties (Fall 1996).

Peter Sforza and **Kriton Hatzios,** Virtual Dandelion, Computer-Automated Virtual Environment (CAVE) project featuring the common weed dandelion. (Spring 1999).

Erik Stromberg, Gray Leaf Spot Resistance and the Production Thereof, (Saghai Maroof, M.A., G.K. Rufener, II, E.L. Stromberg, R.P. Mowers, A.J. Balducchi,) US Patent Number 5,5744,310,12. November 1996.

CLASS ACTS

Curt Roane (M.S. '44 and Professor Emeritus), was honored by the Virginia Agricultural Experiment Station (VAES) at the May 21, 1998 Small Grains

Field Day held at the Eastern Virginia AREC in Warsaw. VAES named a newly released soft red wheat winter variety after him. 'Roane' wheat was so named to honor the contributions made by Dr. Roane to the small grains breeding and genetics program in Virginia Tech's College of Agriculture and Life Sciences.

Chester L. Foy, professor of Weed Science, was the recipient of the 1998 Gamma Sigma Delta International Award for Distinguished Achievement in Agriculture. This is the most prestigious award presented by Gamma Sigma Delta, the Honor Society of Agriculture, to honor a member who has made great contributions to the profession. Foy is only the second person from Virginia and the first person ever from his discipline, anywhere to receive the award. The International President of Gamma Sigma Delta, Dr. John Riley from the University of Tennessee, made the presentation during ceremonies on March 25, 1999 in Blacksburg, Virginia. The award recognizes excellence as an international research scientist, leader, educator, and scholar.

STAFF AWARDS

Major Awards received by the PPWS Staff during the 1993-99 period include:

CALS Staff Employee of the Month**: Sue Meredith**, 1994; **Judy Fielder**, August 1995; **Verlyn Stromberg**, 1995; **Bo Witt,** June 1996.

Dean's Award for Outstanding Job Performance: **Diane Reaver** in 1995.

STUDENT SCHOLARSHIPS & AWARDS

Anne Dorrance received the 1995 Graduate Student Teaching Excellence Award from the College of Agriculture and Life Sciences of Virginia Tech.

Carla Hegeman was the recipient of a 1998 PEO Organization scholarship, promoting women scientists.

Jinxia (Susan) Sun received the Gamma Sigma Delta Graduate Dissertation Award in 1997.

Wendy Pline was awarded a Cunningham Fellowship from the Graduate School of Virginia Tech for 1997-98 and 1998-99.

Wendy Pline was awarded the William T. Steele graduate scholarship award from the College of Agriculture and Life Sciences of Virginia Tech for 1998-99.

Dan Poston was awarded the David R. Spence graduate scholarship award from the College of Agriculture and Life Sciences of Virginia Tech for 1998-99.

Donna Tuckey was awarded the David R. Spence graduate scholarship award from the College of Agriculture and Life Sciences of Virginia Tech for 1998-99.

Donna Tuckey received a grant-in-aid of research from the Sigma Xi Honor

Society in 1998.

Recent recipients of **the Bruce Perry Scholarship** of the PPWS Department are as follows:

1994-95, Symon Mwangi and Regina Hanlon
1995-96, Jonathan Flora and Douglas Harris
1996-97, Nancy Robbins and Hao Ni

Recent recipients of **the Virginia Agricultural Chemical and Pesticide Association Scholarship** are as follows:

1994, John Eberwine
1995, Andy Ackley
1996, Brooks Crozier
1997, David B. Langston
1998, Dan Poston

Recent recipients of the **Outstanding Graduate Student Award (Arthur J. Weber Award**) of the PPWS Department are as follows:

1993-94, Brian Manley
1994-95, Jinxia (Susan) Sun
1995-96, Rakesh Chandran and Sydha Salihu
1996-97, Carla Hegeman
1997-98, Kevin Bradley and Dan Poston
1998-99, Selester Bennet

PPWS Students winning awards in graduate student paper contests:

Sydha Salihu, 1st place award in 1995 graduate student paper contest of the Northeastern Weed Science Society (NEWSS).

Andy Ackley, 2nd place award in 1995 graduate student paper contest of NEWSS.

Sydha Salihu, 2nd place award in the graduate student paper contest of the Southern Weed Science Society (SWSS).

Jonathan Flora, 2nd place award in 1996 graduate student paper contest of the APS, Potomac Division.

David Langston, 1st place award in 1996 graduate student paper contest of APS Potomac Division.

David Langston, 1st place award in 1996 graduate student paper contest of the American Peanut Research and Education Society

Mark Isaacs, 2nd place award in 1996 graduate student paper contest of NEWSS.

Brian Manley, 1st place in 1996 poster presentation contest of NEWSS.

Sydha Salihu, 3rd place award in 1996 photo contest of NEWSS.

Carla Hegeman, 1st place award in the section of Agriculture, Forestry, and Aquaculture of the 1997 Meeting of Virginia Academy of Sciences.

Mark Isaacs, honorable mention in 1997 graduate student paper contest of NEWSS.

Wendy Pline, 2nd place award in 1999 graduate student paper contest of SWSS.

Peter Sforza, 1st place award in the graduate student paper contest of the APS, Potomac Division.

VIRGINIA TECH GRADUATE STUDENTS EXCEL IN REGIONAL WEED SCIENCE CONTEST

The 1998 weed science contest organized by the Northeastern Weed Science Society (NEWSS) was held in Georgetown, Delaware on August 4, 1998. More than sixty contestants from thirteen universities competed in this annual event. Students were challenged in four events: weed identification, herbicide identification based on plant symptomatology, solving farmer problems, and sprayer calibration.

Carrying on the tradition, the graduate students majoring in Weed Science at Virginia Tech University were again very successful in this year's weed contest of the NEWSS. Virginia Tech participated with two full teams (each composed of four students) and placed first and third out of the thirteen competing teams. North Carolina State University placed second. Other participating universities were Penn State, Cornell, Maryland, Ohio State, University of Guelph, Delaware, and others.

Members of our senior team which placed first were: Kevin Bradley, Steve King, Ivan Morozov, and Dan Poston. The members of our junior team, which placed third, were Greg Armel, Wendy Pline, Bob Richardson, and Peter Sforza. In terms of individual placements, Kevin Bradley placed second and Dan Poston placed third overall. In addition, four other students from our Department placed in the top ten out of more than sixty students competing in this contest.

Our teams trained at the Kentland Farm in Blacksburg and at the Agricultural Research and Extension center in Painter, VA. Congratulations to all of our students and their coaches (Dr. Scott Hagood and Mr. Claude Kenley) for these significant achievements. The successes of our students make us all proud and provide the best measure of the high quality of the graduate programs offered by our Department and Virginia Tech. This year, the 1999 weed science contest of the NEWSS will be hosted by Virginia Tech on our Kentland Farm.

RECENT GRADUATES OF THE PPWS DEPARTMENT, 1992-99

1992-93

Michele R. Carter, M.S. 1992. Gray leaf spot of corn: Yield loss evaluation of germplasm for resistance. **Erik Stromberg**, major professor.

Andreas Doulis, Ph.D. 1993. Molecular and metabolic bases in antioxidant behavior for differential resistance to oxidative stress in pea. **Ruth Alscher**, major professor.

Graciela M. Farias, Ph.D. 1992. Roles of tannase and hydrolyzable tannins in chestnut blight. **Gary Griffin**, major professor.

Gonzalo G. Guerrero, M.S. 1992. Biological studies of shiitake logs and associated mycoflora in the Virginia highlands**. Jay Stipes,** major professor.

Alfred Hausladen, Ph.D. 1992. Purification and characterization of glutathione reductase isozymes specific for the state of cold hardiness of red spruce (*Picea rubens* Sarg.). **Ruth Alscher**, major professor.

Sangho Kim, Ph.D. 1992. Metabolic bases for the differential response of Kwangkyo and Hood soybean [*Glycine max* (L.) Merr.] to the herbicide paraquat. **Kriton Hatzios**, major professor.

Marko J. Laine, M.S. 1993. Wound-induction and molecular cloning of potato (*Solanum tuberosum* L.) 3-hydroxy-3-methylglutaryl coenzyme A reductase. **Carole Cramer**, major professor (Degree awarded from the University of Helsinki, Finland).

Natalia Martinez, M.S. 1992. Relationships among spreader-sticker application, blossom cap retention, berry scarring, thrips population, and Botrytis bunch rot in 'Chardonnay' grapes and a survey of pesticides use and pest severity in Virginia vineyards in 1990 and 1991. **Anton Baudoin and Mike Weaver**, major professors.

Manuel M. Mota, Ph.D. 1992. Morphological characterization of tobacco cyst nematode complex, *Globodera tabacum* sspp. *tabacum virginiae* and *solanacearum* (Nemata: Heteroderinae). **Jonathan Eisenback**, major professor.

Adam S. Pesce, M.S. 1993. Site-directed mutagenesis of the soybean mitochondrial *atp9* gene. **Elizabeth Grabau**, major professor.

Eduardo J. Traut, Ph.D. 1993. *Bipolaris zeicola*: Physiological races, morphology and resistance on maize (*Zea mays* L.). **Herman Warren**, major professor.

Sunny Sheng, Ph.D. 1992. Responses of gas exchange and the antioxidant system of soybean cultivars to ozone and/or sulfur dioxide. **Boris Chevone**, major professor.

Indira Srinivasan, M.S. 1992. Isolation and detection of bean yellow mosaic, clover yellow vein and peanut stunt viruses from *Trifolium* spp. **Sue Tolin**, major professor.

Laurence A. VanLieshout, M.S. 1992. Weed control in no-till corn as affected by cultivation, herbicide banding and cover crop suppression. **Scott**

Hagood, major professor.

1994

John Andrew Ackley, M.S. 1994. Efficacy and selectivity of the herbicide rimsulfuron in potatoes (*Solanum tuberosum*), transplanted tomatoes (*Lycopersicum esculentum*), and transplanted peppers (*Capsicum annuum*). **Henry Wilson**, major professor.

J. Brooks Crozier, M.S. 1994. Abiotic stressors in the dogwood anthracnose complex. **Jay Stipes,** major professor.

Tarun Gera, M.S. 1994. Tracking soybean mosaic virus movement in soybean by leaf imprint immunoassay. **Sue Tolin**, major professor.

Carlson Jodi, Ph.D. 1994. Procerum root disease physiology and disease interactions with ozone. **Sam Alexander**, major professor.

Regina Hanlon, M.S. 1994. Cytoplasmic diversity in soybean [*Glycine max* (L.) Merr.]. **Elizabeth Grabau**, major professor.

Kris K. Zimmerman, M.S. 1994. Evaluation of selected bacterial strains for control of dollar spot on greening bentgrass and brown patch on tall fescue. **Charles Hagedorn**, major professor.

1995

Mark A. Czarnota, M.S. 1995. The control of yellow and purple nutsedge (*Cyperus esculentus* and *C. rotundus*) in turfgrass utilizing halosulfuron. **Wayne Bingham**, major professor.

Anne E. Dorrance, Ph.D. 1995. Inheritance of resistance to diplodia ear rot and an assessment of the genetic variability of *Stenocarpella maydis* through isozyme analysis. **Herman Warre**n, major professor.

Jia Li, Ph.D. 1995. Improvement of phosphorus utilization via introduction of a fungal phytase gene into soybean. **Elizabeth Grabau**, major professor.

Melinda A. Mulesky. Ph.D. 1995. Rhizosphere competence, antibiotic and siderophore biosynthesis *in Pseudomonas chororaphis*: Implications for the biological control of cotton seedling disease pathogens. **Charles Hagedorn**, major professor.

Xueshu (Bill) Yu, Ph.D. 1995. Functional analyses of tomato 3-hydroxy-3-methylglutaryl coenzyme A reductase (HMGR) gene (*hmg2*) in transgenic plants engineered for altered HMGR2 expression. **Carole Cramer**, major professor.

1996

John W. Eberwine, Ph.D. 1996. Effect of postemergence johnsongrass control on MCDV and MDMV incidence and severity in field crop. **Scott Hagood**, major professor.

Brian S. Manley, Ph.D. 1996. Crop and herbicide rotation effects on weed

population dynamics and the characterization of imidazolinone-resistant smooth pigweed (*Amaranthus hybridus*). **Henry Wilson**, major professor.

Jinxia (Susan) Sun. Ph.D. 1996. The mechanism and enhancement effects of organosilicones on sulfonylurea herbicide activity. **Larry Foy**, major professor.

Jia Wang, Ph.D. 1996. Characterizing resistance in flue-cured tobacco to *Globodera solanacearum tabacum***. Charles Johnson and Jonathan Eisenback**, major professors.

1997

John Andrew Ackley, Ph.D. 1997. Weed management programs in potato, transplanted tomato and transplanted peppers with rimsulfuron and other herbicides. **Henry Wilson**, major professor.

Rakesh S. Chandran, Ph.D. 1997. Influence of isoxaben application timing on dissipation and broadleaf weed control in turf**. Jeff Derr and Wayne Bingham**, major professors.

Micahel Y. Day, M.S. 1997. Non-thesis masters degree completed at Virginia Beach. **Scott Hagood** major professor.

Cynthia J. Denbow, Ph.D. 1997. Membrane domain of plant 3-hydroxy-3-metthylglutaryl coenzyme A reductase: Targeting, topology, and function. **Carole Cramer**, major professor.

Jonathan P. Flora, M.S. 1997. The effects of temperature on the durability of resistance of soybean to soybean mosaic virus. **Sue Tolin**, major professor.

Hao Ni. M.S. 1997. Expression of Human protein C in transgenic tobacco**. Carole Cramer**, major professor.

Ozlem Kilic, M.S. 1997. Effect of dsRNA-containing and dsRNA-free hypovirulent isolates of *Fusarium oxysporum* on severity of Fusarium seedling disease of Essex soybean. **Gary Griffin**, major professor.

Saara S. Lang, Ph.D. 1997. Role of subcellular differentiation in plant disease resistance. **Carole Cramer**, major professor.

Scott J. McBane, M.S. 1997. Algae control in bentgrass (*Agrostis palustris*) with DC5772 and Profile. **Houston Couch**, major professor.

Nancy E. Robbins, M.S. 1997. Spread of hypovirulent strains of *Cryphonectria parasitica* among American chestnut trees at the Lesesne State Forest. **Gary Griffin**, major professor.

Saba J. Qusus. Ph.D. 1997. Molecular studies on soybean mosaic virus-soybean interactions. **Sue Tolin**, major professor.

Sydha Salihu, Ph.D. 1997. Basis of selectivity of isoxaben in ajuga (*Ajuga reptan*s), wintercreeper (*Euonymus fortunei*) and dwarf burning bush *(Euonymus alatus*). **Jeff Derr and Kriton Hatzios,** major professors.

DaFeng Zhou, Ph.D. 1997. Farnesyl transferase: Gene expression in plants and role in plant development. **Carole Cramer**, major professor.

1998

James A. Ashley, M.S. 1998. Evaluation of weed control and crop with postemergence herbicides in sethoxydim-tolerant corn**. Scott Hagood,** major professor.

Neval Erturk, Ph.D. 1998. Effects of oxidative stress on superoxide dismutases in Arabidopsis**. Ruth Alscher**, major professor. (Student received degree from the Department of Biology of Virginia Tech).

David B. Langston, Jr. Ph.D. 1998. The role of host, environment, and fungicide use patterns in algorithms for improving control of Sclerotinia blight of peanut. **Pat Phipps**, major professor.

Ivan V. Morozov. M.S. 1998. Egyptian broomrape (*Orobanche aegyptiaca* Pers.) and small broomrape (*Orobanche minor* sm.) parasitism of red clover (*Trifolium pratense* L.) in vitro. **Larry Foy**, major professor.

Symon F.M. Mwangi, Ph.D. 1998. Status of northern leaf blight, phaeosphaeria leaf spot, southern leaf blight, rust and physiologic specifications of *Exerohium turcicum* in Kenya. **Herman Warren**, major professor.

Vijay Nandula, Ph.D. 1998. Nitrogen metabolism of broomrapes (*Orobanche* spp.) and selective control by glyphosate. **Larry Foy,** major professor.

Steven B. Rideout, M.S. 1998. The effect of nematode isolate and soil environment on the tobacco cyst nematode (*Globodera tabacum solanacearum*), a pathogen of flue-cured tobacco and other solanaceous crops**. Charles Johnson**, major professor.

Youlin Tang, M.S. 1998. Response of leaf protein to ozone in two white clover clones. **Boris Chevone**, major professor.

1999

Wendy Pline, M.S. 1999. Effect of temperature and chemical additives on the efficacy of the herbicides glufosinate and glyphosate in weed management of Liberty-Link and Roundup-Ready soybeans. **Kriton Hatzios**, major professor.

IN MEMORIAM

Lawrence I. Miller, Emeritus Professor of Plant Pathology at Virginia Tech, died on March 8, 1996. A native of Jackson Center, Ohio, Miller received his B.S. degree from Oberlin College in 1936, an M.S. degree from Virginia Polytechnic Institute in 1938, and a Ph.D. degree from the University of Minnesota in 1953. He worked as a peanut plant pathologist at Holland (now Suffolk), Virginia from 1938 to 1942, and from 1949 to 1969. In 1969, he was transferred to Blacksburg where he conducted research on the taxonomy of

cyst nematodes (*Globodera* and *Heterodera*) affecting crops in Virginia and on hybridization among various species of native and exotic cyst nematodes. He retired and was named Professor Emeritus in 1980, but he continued his research up to his death. He served as President of the Potomac Division of APS and the Society of Nematologists and received many prestigious awards. L.I. Miller's family has agreed to join with the Department in establishing a memorial scholarship fund in his name. For details, please see the Endowed Scholarships section of the Newsletter.

Martha K. Roane died on December 31, 1996. Martha was an Adjunct Professor of Plant Pathology at our department. She was an author and co-editor of the Compendium of Rhododendron and Azalea Diseases for APS. In addition she was a member of many prestigious organizations and a fellow of the Virginia Academy of Sciences.

ENDOWED SCHOLARSHIPS OF THE PPWS DEPARTMENT OF VIRGINIA TECH

Alumni often give to their undergraduate institutions. Since most departments of Plant Pathology and Weed Science do not have an undergraduate major, the only support that we will receive will be from you, our alumni and friends. Please consider giving to one of the endowments or scholarships below. A minimum of $25,000 is needed for the establishment of an endowed student scholarship.

The Bruce Perry Scholarship was established with funds donated by the family and friends in memory of Bruce William Perry (M.S. '82). It is fully endowed and funds annual awards for tuition payments or stipends to outstanding students in our Department.

The L. I. Miller Scholarship was established with funds donated by the family and friends in memory of professor L.I. Miller. Current funds are far short of those needed for endowment. When it becomes endowed, it will be used to reward student excellence in our Department.

Crop Protection Scholarship Endowment. With the support of a $5,000 donation from Novartis as well as the support of other agrochemical companies and members of the Department, we hope to have enough funds to endow this scholarship soon. When endowed this scholarship will be used to reward student excellence in the Department.

Thank you for considering making a donation to the departmental endowments. A form for giving is included in the Newsletter.

ALUMNI NEWS

Caitilyn Allen (Ph.D. '89), Assistant Professor with a joint appointment in the Department of Plant Pathology and Women Studies Program at the University of Wisconsin in Madison. Caitilyn appeared recently in the CBS Sunday Morning News Show to discuss a program that she has initiated at the University of Wisconsin aimed at increasing retention of women in science

and engineering (WISE-RP). Caitilyn visited Virginia Tech on March 18-19, 1999 to discuss this program and she gave a seminar in the Department about her ongoing research.

Rakesh Chandran (Ph.D. ’97) has accepted a position as Assistant Professor of Weed Science at West Virginia University in Morgantown. Rakesh and **Sydha Salihu** (Ph.D. ’97) are the proud parents of two boys and they are eager to come closer to Blacksburg. For the past two years they have been working as postdocs at the Lake Alfred Experiment Station of the University of Florida.

Charlie Cottingham (Ph.D. ’91) is now an Assistant Professor of Biology at Frederick Community College in Frederick, MD. On August 29, 1998, Charlie and his wife, Lisa Orr, adopted a daughter named Mimi Xioing. Congratulations.

Mark Czarnota (M.S. ’95) is finishing up his PhD in Weed Science at Cornell University in Ithaca, NY. He started his doctoral studies at the University of Kentucky in Lexington, KY,, but since his major professor accepted a job at Cornell he had to move to Ithaca, NY.

Anne Dorrance (Ph.D. ’95) is now an Assistant Professor of Plant Pathology at the Ohio State Agricultural Experiment Station in Wooster, Ohio.

Andreas Doulis (Ph.D. ‘93) has served as director of graduate studies at the Mediterranean Agronomic Institute (MAICh) in Chania, Greece, since 1994. Andreas and Dr. Kriton Hatzios (Head of the PPWS Department) will co-organize a two-week workshop at MAICh from July 5-16, 1999. The workshop is sponsored by the American Society of Plant Physiologists and MAICh. Drs. Cramer, Grabau and Medina-Bolivar of the PPWS Department will participate as lecturers in this workshop.

Khalid Hameed (Ph.D. ’71) is expected to visit the department later this year as a Fulbright Visiting Scholar. He will conduct research on parasitic weeds with Dr. Larry Foy.

What do our alumni **Hao Ni** (M.S. ’97), **Melinda Mulesky** (Ph.D. ’95) and **DaFeng Zhou** (Ph.D. ’97) have in common? They all work for CropTech, a local Biotech Company created by Dr. Carole Cramer (Professor of Plant Physiology). Dr. Deborah Weisseborn, who has worked as a postdoc in the department, and Dr. Karen Oiishi, an Adjunct Professor of the PPWS Department, are also affiliated with CropTech.

Rakesh Jain (Ph.D. ’87), formerly with Sandoz Company, is now employed as a researcher by Novartis Crop Protection following a corporate merger. Rakesh, Indu, Vibhar, and Unnati reside in Vero Beach, FL.

Sangho Kim (Ph.D. ’92) is a Research Scientist in the Hematology/Oncology Division, of the Samsung Medical Center in Seoul, Korea.

Charles Laughlin (Ph.D. ’68) was appointed recently Director of the CSREES Service of the USDA in Washington, DC. Before his new appointment, Charles was Dean of the College of Agriculture of the

University of Hawaii.

David Langston (Ph.D. ’98) is an Assistant Professor of Plant Pathology at the Coastal Plain Station of the University of Georgia, in Tifton, GA.

Vijay Nandula (Ph.D. ’98) now holds a Research Associate position in weed science in the Department of Plant Sciences, North Dakota University. Recently, he visited India and returned with a new bride!

Matthew Nguazio (M.S. ’90) has finished his Ph.D. in Weed Science at the University of Laval in Montreal, Canada. In a recent e-mail, Matthew emphasized that the quality of his education at Virginia Tech was very helpful in handling the coursework and research challenges during his doctoral studies.

Wendy Pline (M.S. ’99) presented the closing meditation during the 127th Graduate Student Commencement of Virginia Tech. Wendy enjoyed being a member of the stage party during the commencement and has enjoyed immensely her two years in Blacksburg. She will continue her studies at NC State University, pursuing a Ph.D. in Weed Science.

Susan Sun (Ph.D. ’96) is employed by Witco Corporation, Organosilicones Group, Tarrytown, NY and directly using her training in weed science and adjuvants. She and Fan had a son named Nocholas Yitian Fan, born March 31, 1998.

Tsuneyuki Takeno (Ph.D. ’73) has returned to Japan after two years as Quality Consultant for Malayisa Development Bank in Kuala Lumpur, Malaysia. Hideko continues to work at the Japan Information Center for Science and Technology.

Laurence VanLieshout (M.S. ’92) completed his doctoral studies in Weed Science at the Iowa State University. Larry, his wife and their daughter visited the Department last March.

Bill Vencill (M.S. ’86; Ph.D. ’88) has been promoted to the rank of Associate Professor of Weed Science at the University of Georgia in Athens. Bill and his wife have now three kids and enjoy life in the South.

Ji Wan (Ph.D. ’91) is now a Senior Research Scientist with the Hoffman-LaRoche Pharmaceutical Company in Basel Switzerland. Ji and his wife have a lovely daughter.

Kandasamy Wickramabaskaran (M.S. ’85) works for the Australian government and has been sending e-mail to the Department on a regular basis. Here is his e-mail address HS4@swsb.dao.defence.gov.au.

PPWS TO CELEBRATE 50TH ANNIVERSARY AND 110 YEARS OF PLANT PATHOLOGY AT VIRGINIA TECH

September 24, 1999 (Friday), has been set as the date for celebrating the 50th anniversary of the establishment of the PPWS Department in its current format, which includes the disciplines of Plant Pathology, Physiology and

Weed Science. The celebration will take place on the Campus of Virginia in Blacksburg, Virginia.

According to our Historian (Dr. Curt Roane), the Plant Pathology and Physiology Department was established in September of 1949. In addition, we will celebrate 110 years of Plant Pathology in Virginia since Plant Pathology at Virginia Tech started in 1889 as part of the Department of Entomology and Mycology.

The format of the all-day celebration of these two anniversaries will include several presentations at the Fralin Auditorium given by our historian, department heads, administrators and Dr. Charles Laughlin (Ph.D. '68), the new CSREES Director who will be our keynote speaker. A reception and dinner are also planned. In addition there will be an exhibit with books published by current and former members of the Department. We also hope to publish a commemorative brochure, and the history of Plant Pathology at Virginia Tech, written by Dr. Roane and covering the years 1889-1974.

Please mark this date in your calendars and plan to attend this important activity. Please note that the nationally ranked Football Team of Virginia Tech will play Clemson University on Thursday (September 23, 1999) night in Blacksburg. Thus, some of you may have a dual cause to come to Blacksburg and attend the football game as well as the anniversary celebrations of the department.

Please fill out and return the enclosed form, if you are interested in attending the celebration of our departmental anniversaries.

"ADVANCING PLANT HEALTHCARE AND SERVING VIRGINIA'S FARMERS AND CITIZENS FOR 110 YEARS"

JOIN US ON SEPTEMBER 24, 1999 TO CELEBRATE OUR 110TH AND 50TH ANNIVERSARIES

DEPARTMENT OF PLANT PATHOLOGY, PHYSIOLOGY AND WEED SCIENCE

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This periodical Newsletter is about your Department, its People and its grads. If you want it to grow and prosper, tell us about your work, your family, hobbies, and fads.

Please fill out the enclosed Alumni Information form and mail it to the Department at your convenience. Do not forget to include your e-mail address if you have one.

JOIN US ON THE WEB

The department's homepage at http://www.ppws.vt.edu is under continuous improvement to provide information about the department for current and perspective students, our alumni, and others interested in our activities. Important News, Seminars, Committees, and other informative items are updated regularly in our website.

Posted June 08, 1999

News

Hatzios to Head Virginia Agricultural Experiment Station

By Netta Smith-Benton

March 18, 1999

Kriton Hatzios has been named the new director of the Virginia Agricultural Experiment Station and associate dean for research in the College of Agriculture and Life Sciences, according to Andy Swiger, dean of the college.

The Virginia Agricultural Experiment Station (VAES) performs research on food and fiber systems, their impact on the environment, and natural and human resource issues relating to the future needs of Virginia, the nation, and the world. VAES has faculty members at 12 Agricultural Research and Extension (AREC) centers, and throughout the colleges of Agriculture and Life Sciences, Human Resources and Education, Forestry and Wildlife Resources, and Veterinary Medicine at Virginia Tech.

Hatzios, who currently is head of the Department of Plant Pathology, Physiology and Weed Science, will begin his new duties November 1 following the retirement of Robert Cannell.

"I am most pleased to have such an able replacement coming on board to follow the very strong leadership Bob Cannell has provided the Experiment Station. Dr. Hatzios brings the qualities of intelligence, fairness, flexibility, and creativity in this important leadership role." Swiger said.

According to Hatzios, "The Experiment Station, with its programs in four affiliated colleges, departments on campus, and Agricultural Research and Extension Centers off campus, will continue to address the challenges of the 21st century."

He identified those challenges as providing an abundant and stable supply of nutritious, safe, and low-priced food, fiber and forest products to meet the needs of an expanding world population; enhancing the quality of life for individuals and families and the economic and social vigor of communities; protecting and enhancing the natural resources of the state and the nation; applying cutting-edge science to problems related to food, fiber and forest, and improving the health and care of household, farm and wild animals.

Hatzios joined the Virginia Tech faculty in 1979 after earning his masters and doctorate degrees at Michigan State University. He also holds a bachelor's degree in agriculture from the Aristotelian University of Thessaloniki, Greece. He is recognized as a leading researcher in the area of chemical manipulation of crop tolerance to herbicides as well as in herbicide action and metabolism.

During his 19 years at Virginia Tech, he has generated $1.1 million for the support of his research and scholarly programs and activities.

He has authored or co-authored more than 300 publications, including four books, 87 refereed journal articles, seven refereed reviews, 16 book chapters, 10 reviewed proceeding papers, two monographs and 168 abstracts. He has also presented 58 invited talks, half of which were made in international conferences or institutions.

His numerous awards included the Southern Weed Science Society Society's 1997 Scientist of the Year Award, the Weed Science Society of America 1995 Fellow Award, 1994 Outstanding Research Award, and 1986 Young Weed Scientist Award. He also received the 1985 Outstanding Faculty Research Award from the Virginia Tech Chapter of Gamma Sigma Delta, the agriculture honor society.

Cannell, who announced his retirement last year, has served as director of VAES and associate dean since 1995. He came to Virginia Tech in 1987 from the Welsh Plant Breeding Station and the University College of Wales. He was professor and Head of the Department of Crop and Soil Environmental Science from 1987 until being selected as VAES Director.

Article was first published in the March 18, 1999 issue of SPECTRUM, the Faculty-Staff Newspaper of Virginia Tech.

Research Workshop
"Plant Sciences: Perspectives beyond 2000"

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Sponsors:
American Society of Plant Physiologists (ASPP)
& the Mediterranean Agronomic Institute at Chania, (MAICh) Greece

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Organizers:
Kriton K. Hatzios, Virginia Tech, Blacksburg, Virginia
& Andreas Doulis, MAICh, Chania, Greece

Program of Scheduled Activities

Sunday, July 4, 1999

Arrival of participants and lecturers.

Registration.

Welcome Reception 7:00 – 9:00 PM.

Monday, July 5, 1999

8:30 – 9:30 AM - Welcome Remarks, Scope and Aim of the Workshop, General Comments. Nikolaides, Hatzios, and Doulis

9:30 – 10:30 AM – Plant Biotechnology in the Next Century, Dr. Ilya Raskin, Rutgers University

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Genomics and Agriculture, Dr. Athanasios Theologis, USDA Plant Gene Expression Lab, Palo Alto, CA

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #1- Analysis of Gas Exchange during Photosynthesis of Plants. Dr. Eva Pell, Penn State University (Part I)

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Tuesday, July 6, 1999

8:30 – 9:30 AM – Illuminating the Plant Cell with Green Fluorescent Protein. Dr. Richard Cyr, Penn State University

9:30 – 10:30 AM – CO_2 Fixation with an Emphasis on Discussion of Rubisco Structure, Function, Regulation, and Molecular Biology, Dr. Eva Pell, Penn State University

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Effects of Oxidative Stress on Rubisco and Associated Implications for Foliar Function and Longevity. Dr. Eva Pell, Penn State University

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #2 – Analysis of Gas Exchange during Photosynthesis of Plants. Dr. Eva Pell, Penn State University (Part II)

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Wednesday, July 7, 1999

8:30 – 9:30 AM – Production of Valuable Natural Products Using Plant Cell, Tissue and Organ Culture, Dr. Fabricio Medina-Bolivar, Virginia Tech

9:30 – 10:30 AM – Transgenic Plants as Bioproduction Systems for Human Therapeutic Proteins, Dr. Carole Cramer, Virginia Tech

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Overview of Computer Analysis of DNA Sequences (Bionformatics), Dr. Elizabeth Grabau, Virginia Tech

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #3 – Recombinant DNA – Part I: Genomic DNA Isolation; DNA Amplification via PCR; Restriction Digestion of Plasmid DNA, Dr. Elizabeth Grabau, Virginia Tech

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Thursday July 8, 1999

8:30 – 9:30 AM – Molecular Signaling in Systemic Disease Resistance in Plants, Dr. Ilya Raskin, Rutgers University

9:30 – 10:30 AM – "Hairy Root" Culture as a Tool for Metabolic Engineering, Dr. Fabricio Medina-Bolivar, Virginia Tech

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Engineering Novel Disease Resistance to Pathogens, Dr. Carole Cramer, Virginia Tech

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #4- Recombinant DNA – Part II: Analysis of DNA Samples by Agarose Gel Electrophoresis; Preparation of PCR products for DNA Cloning; DNA Ligation, Dr. Elizabeth Grabau, Virginia Tech

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Friday 9, 1999

8:30 – 9:30 AM – Biochemistry and Molecular Biology of Ascorbate Biosynthesis, Dr. Angelos Kanellis, Aristotle University, Thessaloniki, Greece

9:30 – 10:30 AM – "From Phenotypic Response to Genomic Region Organization and QTL Mapping in Higher Plants". Dr. Phillipos Aravanopoulos, Greece

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Attempts in Engineering Chilling Resistance, Dr. Andreas Doulis, MAICh, Chania, Greece

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #5 – Recombinant DNA – Part III Transformation of Bacterial Cells by Electroporation; Plating Trasnformants,, Dr. Elizabeth Grabau (2 hours) & Establishment of in vitro Plant Cultures for the Production of Natural Products – Dr. Fabricio Medina-Bolivar, Virginia Tech (2 hours)

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Saturday, July 10, 1999

Trip to Heraklion, Crete. Visits to the Molecular Biology Institute, Archaeological Museum, and the ancient Minoan city of Knossos.

Sunday, July 11, 1999

Free time and sightseeing in Chania

Monday, July 12, 1999

8:30 – 9:30 AM – Weed Management in the Next Century, Dr. Kriton Hatzios, Virginia Tech

9:30 – 10:30 AM – Designing Herbicides: Role of Cell Biology, Dr. Richard Cyr, Penn State University

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM –Plant Biotechnology Approaches to Control the Parasitic Weed Broomrape (Orobance spp.), Dr. Carole Cramer, Virginia Tech

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #6- Recombinant DNA – Part IV: Plasmid DNA Minipreps; Analysis of Recombinant Plasmids by gel electrophoresis, Dr. Elizabeth Grabau, Virginia Tech

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Tuesday, July 13, 1999

8:30 – 9:300 AM – Mechanism of Auxin Action, Dr. Athanasios Theologis, USDA Plant Gene Expression Center

9:30 – 10:30 AM – Functions and Regulation of Plant Cytochrome P450s, Dr. Kriton Hatzios, Virginia Tech

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Function and Regulation of Glutathione S-transferases, Dr. Kriton Hatzios, Virginia Tech

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #7 – Plant Transformation Using Agrobacterium tumefaciens and A. rhizogenes. Dr. Fabricio Medina-Bolivar, Virginia Tech

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Wednesday, July 14, 1999

8:30 – 9:30 AM – Use of Plant Roots for Environmental Remediation and Biochemical Manufacturing, Dr. Ilya Raskin, Rutgers University

9:30 – 10:30 AM – Engineering Crop Plants as Feed Components for Improved Nutrient Management, Dr. Elizabeth Grabau, Virginia Tech

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Transgenic Plants as Edible Vaccines, Dr. Carole Cramer, Virginia Tech

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #8 – Screening for Ethylene Mutants in Arabidopsis, Dr. Athanasios Theologis, USDA Plant Gene Expression Center, Palo Alto, CA.

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Thursday, July 14, 1999

8:30 – 9:30 AM – Engineering Disease Resistance in Plants, Dr. Nikos Panopoulos, University of Crete, Heraklion, Greece

9:30 – 10:30 AM – Biochemistry and Molecular Biology of Olive Oil Biosynthesis, Polydeukis Chatzopoulos, Agricultural University, Athens, Greece

10:30 – 11:00 AM – Coffee Break

11:00 – 12:00 AM – Manipulation of Antioxidant genes, Issues related to foods produced from transgenic plants, Dr. Athanasios Tsaftaris, Aristotle University, Thessaloniki, Greece

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #9 – Renaissance in Microscopy: Promises and Challenges for the Next Millennium. Dr. Richard Cyr, Penn State University.

7:00 – 8:00 PM – Dinner

8:00 – 10:00 PM – Discussions or Social Activities

Friday July 16, 1999

8:30 – 11:00 AM – Panel Discussion on Transgenic Plants: Issues and Answers, US Lecturers and Greek Lecturers

11:00 – 12:00 AM – Closing Remarks, Hatzios, Doulis, and others.

12:30 – 1:30 PM – Lunch

1:30 – 2:30 PM - Free time

2:45 – 6:45 PM - Laboratory #10 – Isolation of Natural Products from Plant Tissue Culture, Dr. Fabricio Medina-Bolivar, Virginia Tech

7:00 – 8:30 PM – Free Time

8:30 – 12:00 PM - Farewell Party

Saturday, July 17, 1999

Departure of Lecturers and Participants

Lab Sessions – Preliminary Program

Ten laboratory sessions are designed to provide hands-on practical experience and complement the concepts and topics discussed in lectures. Topics and techniques to be discussed and demosntrated included the following:

Bioinfomatics; restriction enzyme digests, agarose gel electrophoresis, cloning strategies, plant transformation, northern, southern, and western blotting, enzyme assays and growth responses of plants to biotic and abiotic stresses.

Participation

The venue for all activities will be the Mediterranean Agronomic Institute at Chania, in the island of Crete, Greece. The number of participants will be selected by the administration of MAICH. Space in lab sections is limited to 20-25 participants. Lectures are open to all participants. The official language of the workshop is English. The participation of scientists from Mediterranean and East European countries is strongly encouraged. Applications for participation and financial support will be handled by MAICH. Application deadline is May 1, 1999.

For application forms and other information, please contact:

Dr. ANDREAS DOULIS, Studies Co-ordinator,
MAICH, P.O. Box 85, 73100 Chania, Greece

Telephone: +30-821-81151
FAX: +30-821-81154

e-mail: adoulis@maich.gr


Pictured from left to right: Kriton Hatzios, Erik
Stromberg, Lloyd Flinchum, Curtis Roane

News

VIRGINIA TECH GRADUATE STUDENTS EXCEL IN REGIONAL WEED SCIENCE CONTEST

The 1998 weed science contest organized by the Northeastern Weed Science Society (NEWSS) was held in Georgetown, Delaware on August 4, 1998. More than sixty contestants from thirteen universities competed in this annual event. Students were challenged in four events: weed identification, herbicide identification based on plant symptomology, solving farmer problems, and sprayer calibration.

Carrying on the tradition, the graduate students majoring in Weed Science at Virginia Tech University were again very successful in this year's weed contest of the NEWSS. Virginia Tech participated with two full teams (each composed of four students) and placed first and third out of the thirteen competing teams. North Carolina State University placed second. Other participating universities included: Penn State, Cornell, University of Maryland, Ohio State, University of Guelph, etc.

Members of our senior team which placed first were: Kevin Bradley, Steve King, Ivan Morozov, and Dan Poston. The members of our junior team, which placed third, were Greg Armel, Wendy Pline, Bob Richardson, and Peter Sforza.

In terms of individual placements, Kevin Bradley placed second and Dan Poston placed third overall. In addition, four other students from our department placed in the top ten

1998 Weed Team

Pictured from left to right, front row: Ivan Morozov, Wendy Pline, Dan Poston; back row: Peter Sforza, Rob Richardson, Steve King, Greg Armel, Kevin Bradley

Greg Armel preparing for the next challenge

The herbicide symptomology event

Kevin Bradley practicing seed identification

out of more than sixty students competing in this contest.

Our teams trained at the Kentland Farm in Blacksburg and at the Agricultural Research and Extension center in Painter, VA. Congratulations to all of our students and their coaches (Dr. Scott Hagood and Mr. Claude Kenley) for these significant achievements. The successes of our students make us all proud and provide the best measure of the high quality of the graduate programs offered by our Department and Virginia Tech.

Next year, the weed science contest of the NEWSS is scheduled to be hosted by Virginia Tech in our Kentland Farm.

Kriton K. Hatzios
August 28, 1998


One of the hebicide id practice plots


Steve King is relaxed and ready to take on the farmer problem event


Coaches Claude Kenley and Scott Hagood


Ivan Morozov

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Weed Management in Horticultural Crops and Home Grounds

Microstegium Management in Turf and Ornamental Beds (pdf)	Weed Identification Guide - Microstegium (html)

Microstegium Management in Turf and Ornamental Beds

Jeffrey Derr
Weed Scientist
Virginia Tech

Biology

Microstegium is a summer annual grass. It has been called by a variety of common names, including Mary's grass, Japanese stiltgrass, and annual jewgrass. I refer to it as microstegium, which is the genus for this species. The full scientific name is Microstegium vimineum. Microstegium is native to Asia. It apparently was used as packing material for porcelain from China and this may have been how it was introduced into the U.S. It was first discovered in the U.S. in Tennessee in 1919. Microstegium has spread through much of the East, and is found throughout Virginia.

Microstegium occurs primarily in moist, shady areas and is very invasive, crowding out native herbaceous vegetation. It will grow in turf, in ornamentals beds, in woods, and other sites that are shaded. Microstegium is under stress in full sun, especially during hot, dry weather. In my studies in the Virginia Beach and Williamsburg areas, it has germinated slightly in advance of large and smooth crabgrass. It flowers much later than crabgrass. Microstegium has flowered in early October in Virginia Beach. Since it is an annual, it propagates strictly by seed. Microstegium has been reported to produce seed in 5% of full sunlight. This plant will tolerate mowing.

Microstegium has a large, somewhat circular cotyledon. This species has a prostrate to somewhat upright form with multiple branches. It roots at the nodes and later in the growing season the stems are somewhat wiry. Leaves are about 3 to 5 inches long, half an inch wide, and taper at both ends. Flowers are in terminal racemes that are solitary or with 1 to 3 laterals. Due to its somewhat similar growth form, I sometimes refer to microstegium as the crabgrass of shade. Microstegium is a very invasive plant and will dominate in suitable habitats. It reaches about 2 to 3 feet tall in unmowed situations.

Control strategies

Since this species has spread aggressively in the Southeast and Northeast, I began working on control of this species a few years ago. During the past two years, I have been fortunate to conduct cooperative research with Dr. Joseph Neal and Ms. Carrie Judge, weed scientists at North Carolina State University.

We have learned that the preemergence crabgrass herbicides commonly used in turf and/or ornamentals will control this weed. Balan (benefin), Barricade (prodiamine), Bensumec (bensulide), Dimension (dithiopyr), Pendulum (pendimethalin), Ronstar (oxadiazon), Surflan (oryzalin), Team Pro (benefin + trifluralin), and Tupersan (siduron) all provided good to excellent preemergence control of microstegium at one month after treatment. Additional data is needed on the length of control for these treatments. Control ranged from fair to excellent at 2 months after application, depending upon herbicide. At three months, some chemicals were not providing acceptable control of microstegium. Repeat applications may therefore be needed to

maintain control throughout the growing season. In another study, Snapshot (isoxaben + trifluralin), Preen/Treflan (trifluralin), and XL (benefin + oryzalin) controlled microstegium when applied preemergence.

We also investigated postemergence control of microstegium. Drive (quinclorac) and Dimension did not control this weed when applied after microstegium emergence. Daconate (MSMA) injured microstegium but did not provide acceptable control. The nonselective herbicides Roundup (glyphosate) and Finale (glufosinate) both gave excellent control of microstegium. The postemergence grass herbicides Acclaim (fenoxaprop), Fusilade/Ornamec (fluazifop), Envoy (clethodim), and Vantage (sethoxydim) provided good to excellent control of this weed.

Based on this data, we can make some suggestions for managing this weed in turf and landscape plantings. The control programs will closely follow those used for crabgrass control, especially with preemergence treatments. Application of a preemergence crabgrass herbicide in March prior to emergence will control early-season germination of microstegium. One could consider use of split/repeat applications of a preemergence herbicide to provide longer lasting control.

For postemergence control, applications probably will be most effective if applied prior to tillering. In cool-season turf, Acclaim could be used for postemergence control. Since MSMA was less effective on this weed, preemergence strategies should be more effective in warm-season turf. Use of a postemergence grass herbicide would be the preferred option for control of emerged plants in broadleaf ornamental beds, although careful applications of nonselective herbicides would also effectively control microstegium.

Cultural strategies used to improve the competitiveness of turf over crabgrass, such as higher mowing heights, fall fertilization, and fall seeding of thin turf, would be expected to assist in microstegium management programs. Since microstegium grows well in considerable shade, it may be difficult to establish dense stands of turf, ornamentals, or other desirable vegetation to out compete this weed.

Use of mulches and landscape fabrics should assist in managing this weed in ornamental beds. Expect to see microstegium growth in mulch layers, however, as materials like pine bark break down over time or as seed is deposited above the mulch from plants that flowered nearby.

References

1. Derr, J. F. 1999. Biology and management of microstegium, a relatively unresearched turf weed. Proc. Northeast. Weed Sci. Soc. 53:100.

2. Judge, C.A., J.C. Neal, and J. F. Derr. Postemergence control of *Microstegium vimineum*. Proc. Weed Sci. Soc. Am. 41:47-48.

3. Virginia Native Plant Society. Invasive Alien Plant Species of Virginia: Japanese Stilt grass (*Microstegium vimineum*) Fact Sheet. 2 p.

Prepared 4/26/01

The use of trade names in this article does not imply endorsement of the product or imply criticism of similar ones not mentioned. For recommendations, please consult the Pest Management Guides.

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Academic Programs

PPWS Undergraduate Program

Although PPWS is primarily a department offering graduate degrees, undergraduate service courses in plant pathology, plant physiology, and weed science are taught for students in other departments. In recent years, PPWS faculty are advising undergraduate students in the Biology and CSES departments, and teaching undergraduate courses in the Biology Department.

PPWS Graduate Programs (see below)

- M.S. and Ph.D. degrees in Plant Pathology
- M.S. and Ph.D. degrees in Plant Physiology and Weed Science
- A non-thesis M.S. degree in the general area of Plant Protection.

Plant Pathology Graduate Curriculum

Degree requirements are outlined in the Plant Pathology MS checklist (pdf file) and the Plant Pathology Ph.D checklist (pdf file). The documents can also be found in the Graduate Student Handbook (pdf file).

Course work for both M.S. and Ph.D. degrees include four semesters of courses (PPWS 5114, 5124, 5134, 5144) concerned with plant pathogenic agents, their biology, and how they damage plants. The laboratory sections allows each student to sample in a hands-on fashion many basic and applied research techniques used in all facets of Plant Pathology. In addition, plant pathology students take Principles of Plant Disease Management (PPWS 5204), Clinic and Field Experience (PPWS 5034), and present seminars.

Ph.D. students are also required to take a group of courses offered in alternate years that stress theoretical concepts of Plant Pathology, namely PPWS 6004 Advanced Topics: Plant Disease Epidemiology, PPWS 6004, Advanced Topics: Genetics of Resistance, and PPWS 5454, Plant Disease Physiology and Development.

Plant Physiology Graduate Curriculum

Minimum degree requirements for Plant Physiology are outlined in the Plant Physiology MS checklist (pdf file) and the Plant Physiology Ph.D checklist (pdf file). Students may also elect to participate in the Interdepartmental Plant Physiology Program or the Molecular Cell Biology and Biotechnology Program. (see

below)

Weed Science Graduate Curriculum

During the past four decades, weed science has been established as a well-defined and recognized academic discipline within the general area of plant protection complementing the older disciplines of entomology and plant pathology. Today, most Land-Grant Universities in the United States offer graduate studies in weed science. However, in many cases, weed science is not offered as a separate curriculum and many graduate students specializing in weed science have their degrees awarded in the field of agronomy, botany, horticulture, forestry, plant pathology, or soil science. At VPI & SU, the degree requirements for weed science resemble those for plant physiology, but also include core applied courses in weed science, namely Weed Science Principles and Practices (PPWS 4754); Pesticide Usage (PPWS 4264); and Herbicide Action and Metabolism (PPWS 5754). See Weed Science MS checklist (pdf file) and the Weed Science Ph.D. checklist (pdf file)

Interdepartmental Graduate Plant Physiology Program

(see also Catalog Description)

The Interdepartmental Plant Physiology Program is one of several interdepartmental curricula in which PPWS faculty members and students can participate. These interdepartmental curricula serve as vehicles to coordinate and unify course offerings across departmental boundaries. Faculty participating in these curricula continue to have appointments in their respective departments, and are responsible for normal advising of graduate students as well as serving on student advisory committees within the curriculum. Students in these curricula major within any of the participating departments and meet a set of requirements designated by the respective curricula.

The Departments of Crop and Soil Environmental Sciences, Biochemistry, Biology, Forestry, Horticulture, and Plant Pathology, Physiology & Weed Science participate in the Interdepartmental Plant Physiology Program. This curriculum brings together elements of instruction and research which already exist and function within the University. A brief description and a listing of participating faculty is given in the Graduate Catalog.

Further information may be obtained from the program's chairman, listed in the Graduate Catalog and at http://www.bsi.vt.edu/welbaum/ippp/index.html. Minimum PPWS requirements are outlined in the Plant Physiology MS

checklist (pdf file) and the Plant Physiology Ph.D. checklist (pdf file) or the Weed Science MS checklist (pdf file) and the Weed Science Ph.D. checklist (pdf file)

Molecular Cell Biology and Biotechnology (MCBB) Interdepartmental Curriculum

PPWS students with an interest in molecular aspects of the life sciences may also participate in the interdepartmental **Molecular Cell Biology and Biotechnology (MCBB)** Curriculum. Much of contemporary research in the life sciences is rapidly taking on a new and unified face. New techniques in biochemistry, cell biology, immunology, and molecular genetics have made possible the purification, mutation and reintroduction of modified proteins into cells. Practitioners of fields once considered far distant from each other can and do use these molecular cell biology approaches and now speak the same technical language. This integration of fields should be reflected in the curriculum. The option exposes students to a foundation in molecular cell biology. Participating PPWS students must meet the degree requirements for the Plant Pathology, Plant Physiology, or Weed Science curriculum (see above) as well as the requirements of the MCBB curriculum. Further details about the latter can be found on the **MCBB Homepage.**

Non-Thesis MS Plant Protection Curriculum

A non-thesis Master of Science degree is offered with emphasis on Plant Protection and Pest Management. Students pursuing a non-thesis M.S. in Plant Protection complete a number of core courses, a number of approved electives as well as an internship or equivalent project. Students completing this program will be well prepared to move into a variety of positions in the agricultural, plant protection, and pest management industry. Students planning to pursue a Ph.D. degree are advised to complete a M.S. with thesis, since the Ph.D. is a research degree.

Non-thesis M.S. programs that differ from the Plant Protection program may be proposed by students in collaboration with their Advisor and Advisory Committee. Such individual programs must be approved by the Department Head, who may ask for review by the Education Committee. All non-thesis programs will include a Project and Report or Internship.

See PPWS Courses for catalog descriptions and current status of courses

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Last updated: July 13, 1998

GRADUATION ANALYSIS CHECK LIST
M.S. in Life Sciences - Plant Pathology Option

NAME _____
Last **First** **M. I.**

I. **Undergraduate Requirements**		**Specify:**	
College Mathematics	1 year	_____	
General Chemistry	1 year	_____	
Organic Chemistry and/or Biochemistry	2 terms	_____	_____
Physics	1 term	_____	
Microbiology, mycology, virology, or	1 term	_____	
parasitology	1 term	_____	
Plant Pathology	1 term	_____	
Plant Biology (physiology, ecology, taxonomy,	3 terms	_____	_____
systematics, anatomy, morphology, other)		_____	
Statistics	1 term	_____	
Genetics	1 term	_____	
Soil Science (strongly recommended)	1 term	_____	

II. Graduate Courses	**Course**	**Credits**	**(check)**
ALS 5984 - Information Systems in the Life Sciences	1	3	_____
BCHM 5124 - Biochemistry for Life Sciences	1	3	_____
STAT 5605 or 5615 - Biometry or Statistics in Research	1	3	_____
Plant Pathogenic Prokaryotes	1	2	_____
Plant Pathogenic Viruses	1	3	_____
Plant Pathogenic Fungi	1	3	_____
Plant Pathogenic Nematodes	1	2	_____
Clinic and Field Experience	1	1	_____
Principles of Plant Disease Management	1	3	_____
Seminar (1 plus final)	1	1	_____
Thesis (6-10 credits)		6-10	_____
TOTAL		30-34	

Total Credits - Minimum of 30 Credits

4000 level courses - Maximum of 12 credits	_____
5000 level courses - Minimum of 12 Credits	_____
4984, 5974, 5984 - Maximum of 5 Credits	_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

GRADUATION ANALYSIS CHECK LIST
Plant Pathology - Ph.D.

NAME _____
Last **First** **M.I.**

I. Undergraduate Requirements **Specify:**

College Mathematics	1 year	_____
General Chemistry	1 year	_____
Organic Chemistry and/or Biochemistry	2 terms	_____
Physics	1 term	_____
Microbiology, mycology, virology, or parasitology	1 term	_____
Plant Pathology	1 term	_____
Plant Biology (physiology, ecology, taxonomy,	3 terms	_____
Systematics, anatomy, morphology, other)		_____
Statistics	1 term	_____
Genetics	1 term	_____
Soil Science (strongly recommended)	1 term	_____

II. Graduate Courses	**Courses**	**Credits**	
Plant Anatomy or Morphology	1	4	_____
From at **least two** of the following three groups, select a total of four courses:	4	12-16	_____
Group 1:			
Ecology, Taxonomy, Cytology,			_____
Morphology, Anatomy, or Weed Science			_____
Group 2:			
Biochemistry, Metabolism, Plant Physiology,			_____
or Molecular Genetics			_____
Group 3:			
Statistics or Computer Science			_____
Plant Pathogenic, Prokaryotes, PP Viruses, PP Fungi, PP Nematodes	4	10	_____
Clinic and Field Experience	1	1	_____
Principles of Plant Disease Management	1	3	_____
Diseases of Crop Plants	1	3	_____
Seminar (plus final)	2	2	_____
Epidemiology of Plant diseases (6004, Adv. Topics)	1	3	_____
Genetics of Host-Parasite Interactions (6004, Adv. Topics)	1	3	_____
Disease Physiology and Development	1	3	_____
Dissertation (30 - 60 credits)			_____

Total Credits – Minimum of 90 Credits **90** (check)
5000 or higher level courses – Minimum of 24 credits _____
4000 level courses NOT approved for graduate credit – Maximum of 6 credits _____
List any required courses that were waived with a brief explanation: _____

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

GRADUATION ANALYSIS CHECK LIST
M. S. in Life Sciences - Plant Physiology Option

NAME _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils (if appropriate)	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	_____
Molecular Biology or Biochemistry	1 term	_____	Botany, Plant Physiology other Plant Sciences	2 terms	_____
Physics	1 term	_____	Genetics	1 term	_____

II. **Graduate Requirements**	**Courses**	**Credits**
ALS 5984 - Information Systems in the Life Sciences 1	1	3
BCHM 5124 - Biochemistry for the Life Sciences	1	3
STAT 5605 or 5615 - Biometry or Statistics in Research	1	3
Advanced Plant Physiology and Metabolism I and II (PPWS/HORT 5524, 5534)	2	6
From the following area (Choose 2)	2	6-7
Molecular Biology for the Life Sciences (PPWS/ALS 5344)		_____
Weed Science: Principles & Practices (PPWS 4754)		_____
Herbicide Action and Metabolism		_____
Plant Water Relations (PPWS/FOR 5344		_____
Plant Stress Physiology (PPWS/BIOL 5304)		_____
Plant Growth and Development (PPWS 5654)		_____
Plant Systematics		_____
Other Courses (Choose one)	1	3-4
Developmental Plant Anatomy (BIOL 4204)		_____
Molecular Biology of the Cell		_____
Bioinformatics (BCHM 4104)		_____
Bioinformatics		_____
Molecular Genetics for Crop Improvement (CSES 5844)		_____
Seminars -1 plus final	1	1
Thesis, 6-10 credits		6-10
TOTAL		31-37
Total credits -- Minimum of 30 credits		_____ (check)
4000 Level Courses - Maximum of 12 Credits		_____
5000 Level Courses - Minimum of 12 Credits		_____
Special study (4984, 5984) or Independent Study (5974): Counted no more than 6 credits each or 9 credits total towards MS degree		_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

GRADUATION ANALYSIS CHECK LIST
Plant Physiology - Ph.D.

NAME: _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils (if appropriate)	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	_____
Organic Chemistry	1 term	_____	Botany, Plant Pathology,	2 terms	_____
Molecular Biology or Biochemistry	1 term	_____	other Plant Sciences		_____
Physics	1 term	_____	Genetics	1 term	_____

II. **Graduate Requirements**

	Courses	Credits
Advanced Plant Physiology and Metabolism I and II	2	6
Developmental Plant Anatomy	1	4
Statistics	1	3
From the following area (5 courses)	5	15-20
Weed Science: Principles & Practices		
Herbicide Action and Metabolism		___
Plant Water Relations		___
Mineral Nutrition of Horticultual Crops		
Plant Stress Physiology		___
Plant Growth and Development		___
Plant Systematics		___
Plant Tissue Culture		___
Bioinformatics		___
Molecular Genetics for Crop Improvement		___
Molecular Biology of the Cell		___
Molecular Biology of Eukaryotic Gene Expression		___
Molecular Biology of Prokaryotic Regulation		___
Second Semester Statistics		___
Plant Disease Physiology and Development		___
Other courses: _____		___
_____		
_____		
Seminars - 2 plus final		2
Dissertation 30-60 credits		___

Total credits -- Minimum of 90 credits ___90___ (check)
Special study (4984, 5984) or Independent Study (5974): Counted ___
no more than 12 credits each or 18 credits total towards Ph.D degree
4000 Level courses not approved for graduate credit - Maximum of 12 Credits ___
Molecular Biology for the Life Sciences _____
List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**

GRADUATION ANALYSIS CHECK LIST

M. S. in Life Sciences - Weed Science Option

NAME _____

Last **First** **M.I.**

I. Undergraduate Requirements

College Mathematics	1 year	_____	Soils	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	
Organic Chemistry/	2 terms	_____	Botany, Entomology, Plant	2 terms	_____
Biochemistry		_____	Pathology, Weed Science		
Physics	1 term	_____	Genetics	1 term	_____
Statistics	1 term	_____			

II. Graduate Requirements

	Courses	Credits
ALS 5984 - Information Systems in the Life Sciences	1	3
BCHM 5115 or 5124 - Biochemistry or Biochemistry for Life Sciences	1	3
STAT 5606 or 5615 - Biometry or Statistics in Research	1	3
Advanced Plant Physiology and Metabolism I	1	3
Weed Science: Principles & Practices	1	3
Herbicide Action and Metabolism	1	3
From the following areas (2 courses)	2	4-7
Molecular Biology for the Life Sciences (3C)		____
Plant Water Relations (3C)		____
Plant Stress Physiology (4C)		____
Plant Growth and Development (3C)		____
Pesticide Usage (3C)		
Clinic and Field Experience (1C)		____
Principles of Plant Disease Management (3C)		____
Developmental Plant Anatomy (4C)		____
Other courses: _____		____
_____		
_____		____
Seminars - 1 plus final	1	1
Thesis, 6-10 credits		6-10
TOTAL		**29-36**

Total credits - Minimum of 30 credits _____ (check)

4000 Level Courses - Maximum of 12 Credits _____

5000 Level Courses - Minimum of 12 Credits ____

Special study (4984, 5984) or Independent Study (5974): Counted no more than 6 credits each or 9 credits total towards MS degree

List any required courses that were waived, with a brief explanation:

_____

_____

Signatures: _____ _____

Student **Date** **Major Advisor** **Date**

GRADUATION ANALYSIS CHECK LIST
Weed Science - Ph.D.

NAME: _____
Last **First** **M.I.**

I. **Undergraduate Requirements**

College Mathematics	1 year	_____	Soils	1 term	_____
General Chemistry	1 year	_____	Plant Physiology	1 term	
Organic Chemistry/	2 terms	_____	Botany, Entomology, Plant	2 terms	_____
Biochemistry		_____	Pathology, Weed Science		
Physics	1 term	_____	Genetics	1 term	_____
Statistics	1 term	_____			

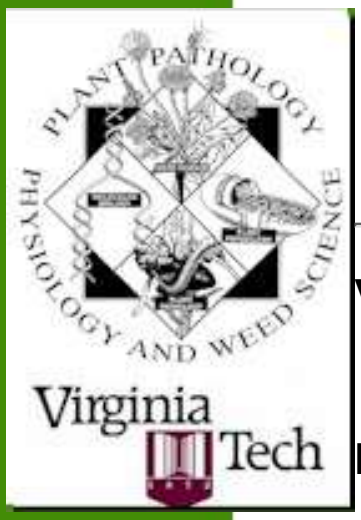
II. **Graduate Requirements**

	Courses	Credits
Developmental Plant Anatomy	1	4
Advanced Plant Physiology and Metabolism I and II	2	6
Weed Science: Principles & Practices	1	3
Pesticide Usage	1	3
Herbicide Action and Metabolism	1	3
Statistics	1	3
From the following area (2 courses):	2	6-7
Molecular Biology for the Life Sciences		_____
Plant Water Relations		_____
Plant Stress Physiology		_____
Plant Growth and Development		_____
Clinic and Field Experience		_____
Plant Systematics		_____
Plant Tissue Culture		_____
Mineral Nutrition of Horticultural Crops		_____
Molecular Biology of Eukaryotic Gene Expression		_____
Molecular Biology of the Cell		_____
Molecular Biology of Prokaryotic Regulation		_____
Second Semester Statistics		_____
Plant Disease Physiology and Development		_____
Other courses: _____		_____
_____		_____
_____		_____
Seminar - 2 plus final	2	2
Dissertation 30-60 credits		_____
Total credits - Minimum of 90 credits		**90** **(check)**
5000 or higher level courses - Minimum of 27 credits		_____
Special study (4984, 5984) or Independent Study (5974): Counted no more than 12 credits each or 18 credits total towards Ph.D degree		_____
4000 level courses not approved for graduate credit - maximum of 6 credits		_____

List any required courses that were waived, with a brief explanation:

_____
_____
_____

Signatures: _____ _____
Student **Date** **Major Advisor** **Date**



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Undergraduate and Graduate Courses

Virginia Tech General Information

- VT Catalogs, including PPWS Course Descriptions

PPWS Undergraduate Courses

- Course Status and Contact Person (below)

PPWS Graduate Courses

- Course Status and Contact Persons (below)

Overall Course List (Links to more detailed descriptions)

Note: Indications on when courses are offered are tentative. Contact course instructors for further information.

Course Number	Course Name (Hours, Credits)	When offered, Instructor
Undergraduate courses		
PPWS 2104	Domesticating the Gene (3H,3C)	Fall, Jelesko and Hansen
PPWS 3104	Plant Pathology (3H,3L,4C)	Fall; Baudoin
BIOL/PPWS 3444	Explaining Molecular Cell Biology	Spring; Grene
PPWS 3505	Plant Physiology and the Environment I (3H,3C)	Spring; Denbow
PPWS 3506	Plant Physiology and the Environment II (3H,3C)	Fall; Denbow
PPWS 3514	Plant Physiology Lab (3L,1C)	Spring; Denbow

ENT/PPWS 4264	Pesticide Usage (2H,3L,3C)	Spring; Mullins (ENT)
PPWS 4754	Weed Science: Principles and Practices (2H,3L,3C)	Fall; Westwood
ENT/P PWS/FOR 4524	Pest and Stress Management of Trees	Spring; Salom (ENT) and Hansen
PPWS 4984	Special Study	Diseases of Turfgrasses (2H,2C; Spring 2001); Couch
Graduate courses		
PPWS 5004	Seminar (1H,1C)	Fall; Jelesko
PPWS 5114	Plant Pathogenic Prokaryotes (1H, 3L, 2C)	Fall, alternate years (2003); Lacy
PPWS 5124	Plant Pathogenic Viruses (2H, 3L, 3C)	Fall, alternate years (2003); Tolin
PPWS 5134	Plant Pathogenic Fungi (2H, 3L, 3C)	Spring, alternate years (2004), Baudoin
PPWS 5144	Plant Pathogenic Nematodes (1H, 3L, 2C)	Spring, alternate years (2004); Eisenback
PPWS 5034	Clinic and Field Experience (3L,1C)	Taught in summer, sign up for Fall, alternate years (2004); Hansen
PPWS 5064	Seminar in Molecular Cell Biology and Biotechnology (1L,1C)	Every semester
PPWS 5204	Principles of Plant Disease Management (3H,3C)	Spring, alternate years (2003); Baudoin.
PPWS 5214	Diseases of Crop Plants (3L,1C)	Fall, Baudoin. Can be offered any semester if interest warrants.
PPWS/BIOL 5304	Plant Stress Physiology (3H,3L,4C)	Alternate Springs (2004); Nilsen (BIOL)
PPWS/GBCB 5314	Biological Paradigms for Bioinformatics	Fall; Grene
PPWS/HORT 5524	Advanced Plant Physiology & Metabolism I	Fall; Chevone.
HORT/PPWS 5534	Advanced Plant Physiology & Metabolism II	Spring; Beers (HORT) et al.

PPWS 5334	Plant Water Relations (2H,3L,3C)	Seiler (FOR)
PPWS 5344	Molecular Biology for the Life Sciences (3H,3C)	Spring; McDowell & Tu (BCHM)
PPWS 5404	Genetic and Epidemiological Principles of Plant Pathology (3H,3L,4C)	Offered as PPWS 6004, Epidemiology (2C, Baudoin) and Genetics (2C, vacant); Spring, even years if demand justifies
PPWS 5454	Plant Disease Physiology and Development (3H,3C)	Fall, even years (2004) if interest warrants; McDowell
PPWS 5654	Plant Growth and Development (3H,3C)	Fall, even years; vacant
PPWS 5754	Herbicide Action And Metabolism (2H,3L,3C)	Spring, alternate years (2004), Westwood
PPWS 5984	Special Study (Variable)	
PPWS 6004	Advanced Topics in PPWS (Variable)	Epidemiology of Plant Disease (2C, Baudoin), Spring even years, if demand justifies Genetics of Host-Parasite Interactions (2C, vacant)
PPWS 6024	Topics in Molecular Cell Biology and Biotechnology (Variable)	Fall and Spring, Wong
BIOL/PPWS 6654	Topics in Virology (3H,3C)	Tolin and Storrie

Last updated: March 16, 2004

Department of Plant Pathology, Physiology and Weed Science
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Plant Pathology PPWS 3104

General Introduction

- Semester: every fall
- Prerequisites: Biology 1005 and 1006, or equivalent.
- **Instructor:** Dr. Anton Baudoin, 417-A Price Hall, Tel: 231-5757

Description.

Introduction to plant pathology as a science and a crop protection discipline. Plant disease diagnosis, biology and identification of plant disease causing agents, factors leading to disease build-up, and management of plant diseases. Diseases of specific crops will be studied as examples.

The course contains 3 sections:

1. Lecture, on general principles
2. Laboratory exercises on techniques, diagnosis, etc.
3. Guided self-study of diseases of crops of interest to individual students.

Lecture Topics

- Overview of plant pathology; plant disease definition; crop losses; pathogenic agents.
- Plant disease diagnosis: principles (Koch's postulates) and practical procedures
- Disease symptoms, and what they tell us about causes
- Disease development; life cycles and disease cycles
- Overview of methods of plant disease control
- Fungal plant pathogens: characteristics, classification, identification
- Soilborne diseases caused by fungi
- Foliar diseases caused by fungi
- Prokaryotes: characteristics, classification, identification
- Plant diseases caused by bacteria

- Plant diseases caused by fastidious prokaryotes
- Plant viruses and viroids: characteristics, classification, identification, transmission, and control
- Plant diseases caused by viruses and viroids
- Plant nematodes: characteristics, classification, identification, problem detection, and control
- Plant diseases caused by nematodes
- Diagnosis of abiotic conditions that cause plant "diseases" (or disorders)
- Miscellaneous plant pathogens: protozoa, algae, higher plants
- Physiological aspects: pathogen weaponry and plant defense
- Plant disease management -- a general approach
- Plant disease resistance: development, characteristics (genetics), and use.
- Epidemiology and plant disease control
- The role of chemicals in plant disease management; when and how to use
- Plant disease control -- summary

Laboratory topics

- Microscope use; symptoms and signs, fungal vs. bacterial
- Symptoms and signs; diagnosis
- Pathogen culturing: media preparation, sterile technique, isolation
- Study of fungi, the diseases they cause, and the structures by which they can be diagnosed:
    - Lower fungi and Oomycetes: Phytophthora, Pythium, downy mildews
    - Ascomycetes and Imperfect fungi
    - Basidiomycetes
- Damping off
- Fungal foliar infection, anthracnose, rust
- Fungicides, protectant and systemic
- Bacterial diseases and pathogens: recognition, diagnosis
- Koch's postulates
- Viruses and the diseases they cause: diagnosis, transmission
- Nematodes: sampling, elutriation, identification
- Nematodes: root knot and cyst
- Diagnosis of unknown specimens.

Disease of specific crops (Disease Notebook)

Students (individually or in small groups) engage in self-study of diseases of crops that are important to THEM. Student performance will be evaluated based on individual notebooks and an oral exam. Examples of **study areas:**

- Golf course turf, plus some woody ornamentals
- Landscape woody ornamentals, bedding plants, some turf
- Greenhouse production
- Nursery ornamental production
- Fruits and/or vegetables
- Field crops
- etc., including combinations

Studies could involve the following **activities:**

- Preparing a NOTEBOOK, based on literature material (reference books, extension publications, etc.) and results of the activities below
- Collecting and diagnosing fresh disease specimens
- Diagnosing clinic specimens and preserved specimens
- Attending occasional presentations by guest specialists
- Field trips, organized and/or informal
- Interviewing crop pathology experts, growers

Texts
Required: LABORATORY MANUAL AND LECTURE SUPPLEMENTS FOR PLANT PATHOLOGY -- PPWS 3104 can be purchased at the University Bookstore or the Tech Bookstore.
Recommended: Agrios, G. N. 1997 (4th edition) PLANT PATHOLOGY. Academic Press.

Link to **Baudoin's course materials**

Back to PPWS home page
Last updated: June 1, 1999

Department of Plant Pathology, Physiology and Weed Science
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

PPWS 5204, Principles of Plant Disease Management

Description

Methods of plant disease management, and theories and effectiveness of their application. Discussion based on epidemiological principles. Methods include: cultural practices, resistance, chemical, and biological control. Laboratory 5214 supplements this course. (3L, 3C).

Pre: 3104; i.e., one course in general plant pathology, or equivalent exposure (may be taken concurrently).

This course is required for plant pathology majors, but is also suitable for graduate students in other curricula (e.g., HORT, CSES, ENT, Weed Science, etc.) who wish to take a single graduate course that covers the practical aspects of plant disease management. Taking 5214 as well will allow students to supplement this by studying specific diseases of crops of their choice (diagnosis, disease cycles, specific controls). Undergraduate students may take this course, either if they are enrolled in a five year bachelor/master's degree program and have a QCA of/over 3.4, or if they are Honors students with a QCA of/over 3.4, or if they are within 10 credits of graduation and have a QCA of/over 3.0.

- **Instructor**: Dr. Anton Baudoin, 417-A Price Hall, Tel: 231-5757
- **Course offered**: Alternate years: Fall 1998, 2000, etc.

Lecture topics:

- Overview of plant pathology: prerequisites for disease management decisions
- Epidemiological concepts: polycyclic and monocyclic diseases. Implications of epidemiological concepts for disease management and disease forecasting
- Crop loss evaluation; economic thresholds; economics of disease control; societal constraints
- Cultural practices and their role in disease suppression:
  - Sanitation
  - Tillage and cultivation
  - Crop rotation

- Management of temperature and moisture
- Management of fertility, pH,
- Organic soil amendments and mulches.
- Modification of the biological environment

- Biological control, principles and overview
- Biological control of seedling disease -- a case study (Dr. Hagedorn)
- The threat of introduced plant diseases. Regulatory mechanisms to prevent introduction and spread of plant pathogens
- Production of disease-free plants
- Plant resistance
  - Types and characteristics
  - Breeding approaches and considerations
  - Considerations for use, management to enhance durability
- Physical control techniques: steam, soil solarization, fire
- Disease control chemicals:
  - History; use patterns; types of activity
  - Major groups of disease control chemicals:
    - fungicides
    - nematicides
    - bactericides
    - viricides
    - general biocides
  - Development and registration of chemicals, effect of legislation on availability;
  - Chemicals: formulation and application methods
  - Mode of action of disease control chemicals
  - Management of pesticide resistance

Additional topics

Exercises using the computer games, APPLESCAB, LATEBLIGHT, and/or RESISTAN.

Occasionally we will schedule guest speakers, "laboratory" sessions, or field trips to replace lectures. Such sessions may cover: symptoms, pathogen morphology, etiology, epidemiology, and practical application of control principles to diseases of selected crops.

A term paper, or series of short papers, is required (30% of grade). Students may select a crop and describe the management techniques for the major diseases of that crop: what approaches are commonly used, how effective are they, economic considerations, and relationships and interactions with crop management and control of other pest groups such as diseases and weeds. This type of term paper will complement the lecture material, and allow the student to integrate the

course concepts and apply them to a crop of his/her choice. If desired, students may select other types of topics for their term paper. A draft of the paper(s) will be peer-reviewed and critiqued by fellow students. Students will revise the paper based on the reviewers' critique.

Texts

- Fry, W. E. 1982. Principles of Plant Disease Management. Academic Press. 378 pp. or:
- Maloy, O. C. 1993. Plant Disease Control: Principles and Practice. John Wiley. 346 pp.

Baudoin's course materials

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Last updated: June 1, 1999

Department of Plant Pathology, Physiology and Weed Science
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

PPWS 5214, Diseases of Crop Plants

General Introduction

- Credits: 3L, 1C
- Pre-requistite: 3104; Co-requisite: 5204
- Semester offered: Every fall. Since pre-/co-requisite PPWS 5204 is offered in the fall of **even** years, most students are expected to enroll in even years. Practically speaking, the course CAN be taken without 5204 -- contact the instructor.
- **Instructor:** Dr. Anton Baudoin, 417-A Price Hall, Tel: 231-5757

Laboratory designed to supplement 5204. Symptoms, pathogen morphology, etiology, epidemiology, and practical application of control principles to important diseases of major crops including cereal, oilseed and legume, forage, vegetable, and fruit.

In this course, students (individually or in small groups) engage in self-study of diseases of crops that are important to THEM. This is similar to the Notebook component of PPWS 3104, but at the graduate level. Student performance will be evaluated based on individual notebooks and an oral exam.
Examples of study areas:

- Golf course turf, plus some woody ornamentals
- Landscape woody ornamentals, bedding plants, some turf
- Greenhouse production
- Nursery ornamental production
- Fruits and/or vegetables
- Field crops
- etc., including combinations

Studies could involve the following activities:

- Preparing a NOTEBOOK, based on literature material (reference books, extension publications, etc.) and results of the activities below
- Collecting and diagnosing fresh disease specimens
- Diagnosing clinic specimens and preserved specimens

- Attending occasional presentations by guest specialists
- Field trips, organized and/or informal
- Interviewing crop pathology experts, growers
- Small-scale greenhouse experiments
- Oral exam at end of semester to discuss notebook

There is no set schedule. Activities will be scheduled around the schedules of the participants. An organizational meeting at the start of the semester is held during the first lecture of PPWS 5204 (even years; contact instructor at or before the start of the semester in odd years).

Baudoin's course materials

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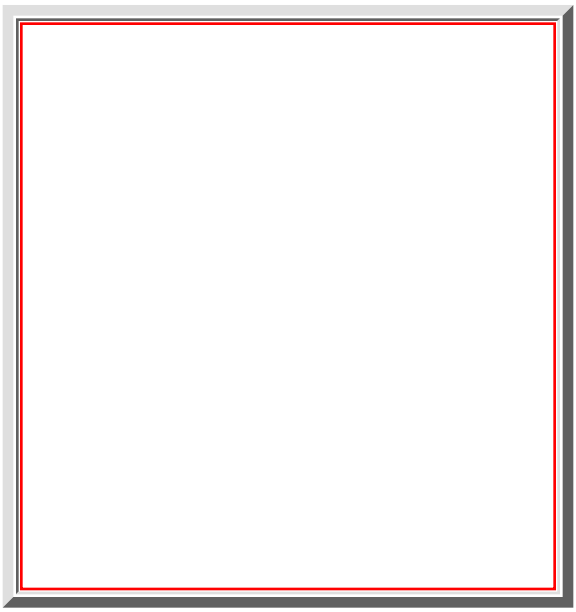
Last updated: June 1, 1999



PPWS 5404

GENETIC AND EPIDEMIOLOGICAL ASPECTS OF PLANT PATHOLOGY

The material in this course will be covered in two separate sections of PPWS 6004 (Advanced Topics in Plant Pathology, Physiology and Weed Science)

- Epidemiology of Plant Diseases, taught by Dr. A. Baudoin (abaudoin@vt.edu, Tel. 540-231-5757) (next offering: Spring 2002, if demand justifies)
- Genetics of Host Parasite Interactions, taught by Dr. H. Warren (hwarren@vt.edu, Tel. 540-231-7486) (next offering: Spring 2002, if demand justifies)

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Last updated: Oct 14, 2001

PPWS 5754 - HERBICIDE ACTION AND METABOLISM
Spring Semester 2002

Dr. Kriton K. Hatzios and Dr. Jim Westwood

- COURSE OUTLINE (pdf)
- LAB OUTLINE (pdf)

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http://www.ppws.vt.edu/ppws5754

KRITON K. HATZIOS

August 6, 1949 - February 20, 2003

Director, Virginia Agricultural Experiment Station,
Associate Dean for Research, College of Agriculture and Life Sciences, and
Professor, Department of Plant Pathology, Physiology and Weed Science

Address:
College of Agriculture and Life Sciences
104-D Hutcheson Hall, Virginia Tech
Blacksburg, Virginia 24061-0402

Phone: (540) 231-6336
Fax: (540) 231-4163
Electronic Mail: hatzios@vt.edu

Education:

- B.S., Aristotelian University, Thessaloniki, Greece, 1972
- M.S., Michigan State University, East Lansing, MI, 1977
- Ph.D., Michigan State University, East Lansing, MI, 1979

Professional Experience:

- **Director**, Virginia Agricultural Experiment Station and **Associate Dean for Research**, College of Agriculture and Life Sciences, Virginia Tech, Blacksburg, VA 24061-0402, 1999-present.
- **Head,** Department of Plant Pathology, Physiology and Weed Science, Virginia Tech, Blacksburg, VA 24061-0331, 1997-2000.
- **Professor** of Plant Physiology/Weed Science, Virginia Tech, 1988-present.
- **Associate Professor** of Plant Physiology/Weed Science, Virginia Tech, 1984- 1988.
- **Assistant Professor** of Plant Physiology/Weed Science, Virginia Tech, 1979- 1984.
- **Graduate Research Assistant**, Department of Crop and Soil Sciences, Michigan State University, East Lansing, 1976-1979.

Recent Awards and Honors:

- 2001 - **Fellow Award** from the American Association for the Advancement of Science
- 2001 - **Outstanding Teacher Award** from the Weed Science Society of America
- 1998 - **Invited Visiting Professor**, Aristotelian University of Thessaloniki, Greece.
- 1997 - **Scientist of the Year Award** from the Southern Weed Science Society.
- 1995 - **Fellow Award** from the Weed Science Society of America.
- 1994 - **Outstanding Research Award** from the Weed Science Society of America.

Teaching Interests:

- Principles and Methods of Weed Management

- Herbicide Action and Metabolism

Research Interests:

- Physiology, Biochemistry, and Molecular Biology of Herbicide Action
- Metabolism of Herbicides and Xenobiotics by Plants and Microorganisms
- Regulation of Enzymes and their Genes Detoxifying Herbicides in Plants
- Herbicide Resistance in Crops and Weeds
- Manipulation of Herbicide Effects with Herbicide Safeners

Selected Publications:

1. Deng***, F. and **Hatzios, K.K.** 2002. Purification and characterization of two glutathione S-transferase isozymes from *indica*-type rice involved in herbicide detoxification. ***Pesticide Biochemistry and Physiology*** **72**:10-23.

2. Deng***, F. and **Hatzios, K.K.** 2002. Characterization and safener-induction of multiple glutathione S-transferases in three genetic lines of rice. ***Pesticide Biochemistry and Physiology*** **72**:24-39.

3. **Hatzios, K.K.** 2001. Functions and regulation of plant gluttahiones S-transferases. Pages 218-239 in "**Pesticide Biotransformation in Plants and Microorganisms: Similarities and Divergences.**" J.C. Hall, R. E. Hogland and R.M. Zablotowicz (eds.). ACS Symposium Series 777, American Chemical Society, Washington, DC.

4. **Hatzios, K.K. 2001**. Cases and mechanisms of resistance to ACCase inhibiting herbicides. Pages 135-149 in "**Agrochemical Resistance**" J. M. Clark and I. Yamaguchi (eds.). ACS Symposium Series 808, American Chemical Society, Washington, DC.

5. **Hatzios, K.K. 2001**. Antagonistas: Aspectos fisiologicos, bioquimicos y uso agricola. Pages 55-68 in "**Uso de Herbicidas en la Agriculutra del Siglo XXI**." R. DePrado and J. Jorrin (eds.). Servicio de Publicaciones, Universidad de Cordoba. Cordoba, Spain.

6. **Hatzios, K.K.** 2001. Mechanisms of herbicide resistance. Pages 275-287 in "**Uso de Herbicidas en la Agriculutra del Siglo XXI**." R. DePrado and J. Jorrin (eds.). Servicio de Publicaciones, Universidad de Cordoba. Cordoba, Spain.

7. Pline*, W.A., Lacy, G.H., Stromberg**, V.K., and Hatzios, K.K. 2001. Antibacterial activity of the herbicide glufosinate on *Pseudomonas syringae* pathovar glycinea. ***Pesticide Biochemistry and Physiology*** **71**:48-55.

8. Poston*, D., Wu***, J., Hatzios, K.K. and Wilson, H.P. 2001. Enhanced sensitivity to cloransulam-methyl in imidazolinone-resistant pigweed. ***Weed Science*** **49**:711-716.

9. Bradley*, K.W., Wu***, J., **Hatzios, K.K.** and Hagood, E.S. 2001. The mechanism of resistance to aryloxyphenoxypropionate and cyclohexanedione herbicides in a johnsongrass biotype. ***Weed Science*** **49**: 477-484.

10. **Hatzios, K.K.** 2000. My view: Weed Science as an academic discipline in the era of biotechnology. ***Weed Science*** **48**:403-404.

11. **Hatzios, K.K.** 2000. Herbicide safeners and synergists. Pages 259-294 in "**The Metabolism of Agrochemicals in Plants**," J. Miyamoto and T.R. Roberts (eds.). John Wiley & Sons, Ltd. London.

12. Wu***, J., Hwang***, I-T., and **Hatzios, K.K**. 2000. Effects of chloroacetanilide herbicides on membrane fatty acid desaturation and lipid composition in rice, maize, and sorghum. ***Pesticide***

Biochemistry and Physiology **66**:161-169.

13. Manley*, B.S., **Hatzios, K.K**. and Wilson, H.P. 1999. Absorption, translocation, and metabolism of chlorimuron and nicosulfuron in imidazolinone-resistant and susceptible smooth pigweed (*Amaranthus hybridus*). ***Weed Technology*** **13**:759-764.

14. Salihu*, S., Derr, J.F., and **Hatzios, K.K**. 1999. Differential response of ajuga (*Ajuga reptans*), wintercreeper (*Euonymus fortunei*) and dwarf burning bush (*Euonymus alatus* 'Compacta') to root- and shoot-applied isoxaben. ***Weed Technology*** **13**:685-690.

15. Pline*, W.A., Wu***, J. and **Hatzios, K.K**. 1999. Absorption, translocation, and metabolism of glufosinate in five weed species as influenced by ammonium sulfate and pelargonic acid. ***Weed Science*** **47**:636–643.

16. Pline*, W.A., Wu***, J. and **Hatzios, K.K**. 1999. Effects of temperature and chemical additives on the response of transgenic herbicide-resistant soybeans to glufosinate and glyphosate applications. ***Pesticide Biochemistry and Physiology*** **65**:119-131.

17. Kuk***, Y.I., Wu***, J., Derr, J.F. and **Hatzios, K.K**. 1999. Mechanism of fenoxaprop resistance in an accession of smooth crabgrass (*Digitaria ischaemum*). ***Pesticide Biochemistry and Physiology*** **64**:112-123.

18. Ackley*, J.A., **Hatzios, K.K**. and Wilson, H.P. 1999. Absorption, translocation, and metabolism of rimsulfuron in black nightshade (*Solanum tuberosum*), eastern black nightshade (*Solanum ptycanthum*), and hiary nightshade (*Solanum sarrachoides*). ***Weed Technology*** **13**:151-157.

19. Wu***, J., Cramer, C.L and **Hatzios, K.K**. 1999. Characterization of two cDNAs encoding glutathione S-transferases in rice and the induction of their transcripts by the herbicide safener fenclorim. ***Physiologia Plantarum*** **105**:102-108.

20. **Hatzios, K.K.** and Roane, C.W. 1999. History of Plant Pathology in Virginia and of the department of Plant Pathology, Physiology and Weed Science of Virginia Tech. Pages 11-58 in "**Advancing Plant Healthcare and Serving Virginia's Farmers and Citizens for 110 Years.**" K.K. Hatzios (ed.). PPWS Department, Virginia Tech, Blacksburg.

21. **Hatzios, K.K.** (Ed.). 1998. **Herbicide Handbook - Weed Science Society of America**, ***7th edition Supplement***. Allen Press, Lawrence, KS. 104 pp. ISBN 0-911733-18-3.

22. Cottingham*, C.K., **Hatzios, K.K.** and Meredith**, S.A. 1998. Influence of chemical treatments on glutathione S-transferases of maize with activity towards metolachlor and cinnamic acid. ***Zeitschrift fur Naturfoschung*** **53c**:973-979.

23. Salihu*, S., Derr, J.F., and **Hatzios, K.K**. 1998. Effects of Gallery applied at different growth stages to dwarf burning bush (*Euonymous alatus* 'Compacta'). ***Journal of Environmental Horticulture*** **16**:155-158.

24. Wu***, J., Cramer, C.L and **Hatzios, K.K**. 1998. Plant Gene Register PGR 98-136. Isolation of a full-length cDNA encoding the second glutathione S-transferase from rice (Accession No. AF062403). ***Plant Physiology*** **118**:329.

25. Wu***, J., Cramer, C.L., and **Hatzios, K.K**.. 1998. Plant Gene Register PGR 98-119. Nucleotide sequence of a cDNA encoding the second glutathione S-transferase from rice (Accession No. AJ002381). ***Plant Physiology*** **117**:1126.

26. Wu***, J., Cramer, C.L., and **Hatzios, K.K**. 1998. Plant Gene Register PGR 98-120. Nucleotide sequence of a cDNA encoding glutathione S-transferase from rice (Accession No. AJ002380). ***Plant Physiology*** **117**:1126.

27. Salihu*, S., **Hatzios, K.K**. and Derr,J F. 1998. Comparative uptake, translocation and metabolism of root-applied isoxaben in Ajuga (*Ajuga reptans*) and two ornamental *Euonymus* species.. ***Pesticide Biochemistry and Physiology*** **60**:119-131.

28. Hwang***, I, Wu***, J. and **Hatzios, K.K**. 1998. Effect of safener fluxofenim on crop injury of chloroacetanilides and enzyme activity of glutathione S-transferase in grain sorghum seedlings. ***Korean Journal of Pesticide Science*** **2**:97-103.

29. **Hatzios, K.K.** (Ed.). 1997. **Regulation of Enzymatic Systems Detoxifying Xenobiotics in Plants**. Kluwer Publishing Co., Dordrecht. 385 pp. ISBN 0-7923-4646-7.

30. Syka-Kotoula***, E., **Hatzios, K.K.**, Berry, D.F., and Wilson, H.P. 1997. Degradation of acetanilide herbicides in history and non-history soils from Eastern Virginia. ***Weed Technology*** **11**:403-409.

31. **Hatzios, K.K**. 1997. Manipulation of crop tolerance to herbicides with safeners. Pages 229-237 in "**Weed and Crop Resistance to Herbicides.**" R. DePrado, L. Garcia Torres and J. Jorrin (eds.). Kluwer Academic Publishers., Dordrecht.

32. **Hatzios, K.K.** 1996. Effects of glufosinate on selected metabolic processes of isolated soybean leaf cells. ***Zizaniology*** **3**:12-20.

33. Omokawa***, H., Wu***, J., and **Hatzios, K.K.** 1996. Mechanism of action of (*S*)-1-(a-methylbenzyl)-3-p-tolyurea, a rice safener against bensulfuron. ***Pesticide Biochemistry and Physiology*** **55**:54-63.

34. Wu***, J., **Hatzios, K.K.**, and Omokawa***, H. 1996. Glutathione S-transferase activity in unsafened and fenclorim-safened rice (*Oryza sativa)*. ***Pesticide Biochemistry and Physiology*** **54**:220-229.

35. Syka-Kotoula***, E. and **Hatzios, K.K.** 1996. Interactions of tribenuron with four safeners and piperonyl butoxide on corn (*Zea mays*) ***Weed Science*** **44:**215-218.

36. Syka-Kotoula***, E., **Hatzios, K.K.**, and Meredith**, S.A. 1996 Potential safeners against dimethenamid injury to corn and grain sorghum. ***Weed Technology*** **10:**299-304.

Current or Recent Research Sponsors:

USDA-NRICGP; ASPIRES Program of Virginia Tech; Korean Research Foundation; Sandoz Crop Protection; DowElanco Company; NATO Scientific Affairs Division.

Further Information:

- Links to Electronic Journals
  - Weed Science
  - Pesticide Biochemistry and Physiology
- Information about Dr. Hatzios' courses:
  - PPWS 5754: Herbicide Action and Metabolism (Spring 2002 semester)
  - PPWS 4754: Weed Science: Principles and Practices (last taught Fall 1998)
- Information about Dr. Hatzios' Laboratory Programs and Personnel

- Link to the Virtual Dandelion Project

Department of Plant Pathology, Physiology, and Weed Science
Last Updated February 24, 2003

PPWS4754: WEED SCIENCE: PRINCIPLES AND PRACTICES

Instructor: Dr. Kriton K. Hatzios

- Department of Plant Pathology,
- Physiology and Weed Science
- 413 Price Hall
- Ph. (540)231-6361
- Fax (540)231-7477
- Email: hatzios@vt.edu

Course Objectives

- To provide an understanding of the concepts and principles underlying weed biology and modern control practices for managing weeds (Lectures).
- To teach the identification, growth characteristics and appropriate control methods for selected weed species common to the region (Lectures and Laboratory).
- To expose the students to some experimental aspects of modern weed control (Laboratory).
- To acquaint the students with sources of information for further inquiry (Lectures and Laboratory).
- To create an awareness of and an appreciation of the impact of weed science as a dynamic discipline and career field in modern agriculture.

Lectures (Syllabus)

- Monday and Wednesday, 8:00-8:50 a.m. at room 400 of Price Hall.

Laboratory (Syllabus)

- Tuesday 2:00-4:50 p.m.; Labs will be held at room 400 of Price Hall, unless otherwise noted.

Textbooks:

- WEED SCIENCE, Principles and Applications, 3rd edition by Wood Powell Anderson, West Publishing Company, St. Paul, MN. 1996. (Copies are available at the Bookstores).
- LABORATORY MANUALS, HANDOUTS & BROCHURES (To be handed out in class).

Teaching aids:

- A number of books have been placed on Reserve in the Newman Library. Handouts, bulletins, slides, movies, videos, CD-ROM, and internet resources will be also used in the lectures and lab sessions of this class.

Evaluation Procedure:

- 1st Midterm Exam: 20%
- 2nd Midterm Exam: 20%
- FINAL EXAM: 25% (Wednesday, December 18 at 7:45 to 9:45 a.m. in room 400 Price Hall.
- Laboratory: 35%

Note: 35% of total grade in class will be based on the performance of the students in the Laboratory. Evaluation procedures in the Laboratory will include: quizzes, examinations, and a weed collection to be prepared by each student. Details on this subject will be given at the first lab session by the teaching assistants.

Teaching assistants:

-
- 203 PMB Building, Old Glade Road
- Phone: 231-5835 (Wendy); 231-8622 (Ivan)
- Office Hours:

Honor System:

The honor code of Virginia Tech will be strictly enforced in this course. All assignments submitted shall be considered graded work, unless otherwise noted. All aspects of your coursework are covered by the honor system. Honesty in your academic work will develop into professional integrity. The faculty and students of Virginia Tech will not tolerate any form of academic dishonesty.

Relevant Links:

- Weed Science Society of America

Cyberweeds: The Virtual Dandelion

Department of Plant Pathology, Physiology, and Weed Science, the Center for Excellence in Undergraduate Teaching and the CAVE Student Led User Group

Virginia Polytechnic Institute and State University

Project Contacts: Peter Sforza and Dr. Kriton Hatzios

click here for a printable format of this page(pdf)

The Virtual Dandelion is a teaching application for the visualization of several key aspects of plant biology using the CAVE™ technology at Virginia Tech and VRML for the web. Dandelion (*Taraxacum officinale*) was chosen for this project because of its widespread recognition as a common weed in urban landscapes, the unique structural form, and its specialized adaptations to an intensively managed environment.

The CAVE™ (Cave Automated Virtual Environment) provides an immersive environment for visualization, which may enhance a viewer's perception and retention of the information presented. This may be particularly important in teaching scientific or technical material containing complex concepts and a highly specialized vocabulary. In addition to being immersive, the CAVE

(temporarily out of order, but you can try it anyway)
Click here for the Virtual Farm (vrml)

is interactive. An electromagnetic sensor updates the scene according to the position and movements of the user. The user interacts with the virtual environment using various control devices including a wand controller, gloves, and LCD stereo glasses.

VRML, pronounced either "vee-are-em-ell" or "VER-mul", is an abbreviation for Virtual Reality Modeling Language. VRML is the standard for interactive 3D objects on the internet. VRML worlds are viewed with a VRML browser, which is built into some of the standard internet browsers or it can be added as a plug-in for older browsers. A detailed description of VRML can be found at the VRML Repository.

Take a look at the setting for the Virtual Dandelion: the (temporarily out of order, but you can try it anyway) Virtual Farm (vrml), based on the Randolf Aigner farm in Henrico County, Virginia. To view this, a VRML browser such as is needed.

The material covered by this teaching application is intended to serve as a lecture supplement on weed biology and will include the following topics:

- Natural history of the dandelion
- General morphology, growth, and development
- The origin and evolution of the weedy nature of dandelion
- Genetic aspects of weed evolution using the dandelion as an example of apomictic reproduction and a "general purpose genotype"
- Adaptations to frequently disturbed environments
- Management practices
- Weed seed bank (flash): The distribution of weed seeds in the soil compared by tillage type. (Adapted from Yenish et al., 1992).

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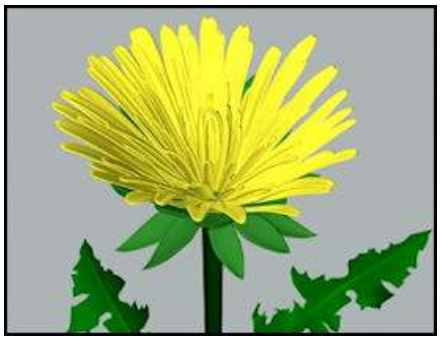
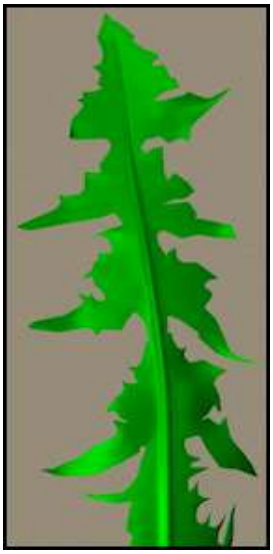
Cyberweeds: The Virtual Dandelion

Peter M. Sforza and Kriton K. Hatzios
Department of Plant Pathology, Physiology, and Weed Science
Virginia Polytechnic Institute and State University
http://www.ppws.vt.edu/~sforza/cyberweeds.html



The Virtual Dandelion is a teaching application for the visualization of several key aspects of weed biology using the CAVE[tm] technology at Virginia Tech and VRML for the web. Dandelion (*Taraxacum officinale*) was chosen for this project because of its widespread recognition as a common weed in urban landscapes, its unique structural form, and its specialized adaptations to an intensively managed environment.



The CAVE[tm] (**C**ave **A**utomated **V**irtual **E**nvironment) provides an immersive environment for visualization, which may enhance a viewer's perception and retention of the information presented. This may be particularly important in teaching scientific or technical material containing complex concepts and a highly specialized vocabulary. In addition to being immersive, the CAVE is interactive. An electromagnetic sensor updates the scene according to the position and movements of the user. The user interacts with the virtual environment using various control devices including a wand controller, gloves, and LCD stereo glasses.

VRML, pronounced either "vee-are-em-ell" or "VER-mul", is an abbreviation for Virtual Reality Modeling Language. VRML is the standard for interactive 3D objects on the internet. VRML worlds are viewed with a VRML browser, which is built into most of the standard internet browsers or it can be added as a plug-in for older browsers. A detailed description of VRML can be found at the VRML Repository, http://www.sdsc.edu/vrml/.

The material covered by this teaching application is intended to serve as a lecture supplement on weed biology and will include the following topics:

- Natural history of the dandelion
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- The origin and evolution of the weedy nature of dandelion
- Genetic aspects of weed evolution using the dandelion as an example of apomictic reproduction and a "general purpose genotype"
- Adaptations to frequently disturbed environments
- Management practices

This project is funded by the Department of Plant Pathology, Physiology, and Weed Science and the Center for Excellence in Undergraduate Teaching at Virginia Tech

The virtual farm is currently experiencing technical difficulties. The universe, including computer files, tend towards a state of entropy.

The virtual farm is based on the Aigner farm in Henrico County, Virginia. This model was designed using aerial photographs of the actual farm and 3-D Studio Max. The Aigner farm is the location of several studies on the epidemiology and control of barley yellow dwarf, an aphid vectored virus of small grains. Click here for a biological description of barley yellow dwarf virus. The virtual farm will be used to visualize and simulate selected aspects of agricultural ecosystems. The virtual dandelion will be one component of this ecosystem and will simulate interactions with crops and some of the strategies of weed survival. The virtual farm can also be experienced using the CAVE(tm) technology at Virginia Tech.

This model is always under contruction.
Last update May 23, 2001 by Peter Sforza

Support for this project comes from the Center for Excellence in Undergraduate Teaching (CEUT) and the Department of Plant Pathology, Physiology, and Weed Science at Virginia Tech.

Back to Cyberweeds

Apomixis - Kriton K. Hatzios

Apart from the occaisonal cross-pollination, heterozygosity may be maintained in many other ways. One of these is vegetative multiplication as in the case of Bermuda buttercup (*Oxalis pes-carpe*). Another way of "fixing" heterozygosity is by apomixis, where zygotes are formed without fetilization of the egg by the gamete from the pollen grain. This phenomenon is sometimes found in weeds; good examples being the dandelion (*Taraxacum offiicinale*) and perforate St. Johnswort (*Hypericum perforatum*).

Back

Dandelion as an example of a general purpose genotype - Kriton K. Hatzios

The term general purpose genotype has been suggested by Baker (1965) and it denotes a strategy that weeds utilize extensively in having genotypes that allow a wide degree of phenotypic plasticity and an adequate and sustained level of heterozygosity.

Allard (1965) has suggested that genetic variability in a nearly autogamous colonizing species helps its establishment in an area being newly colonized, whereas the self-fertilization is of value in building up the adapted population from its small beginnings. A compromise between the genetic invariability of populations derived by self-pollination and the variability of those where cross-pollination is the rule can be achieved if cross-pollination occaisionally takes place. This leads to maintenance of a certain amount of heterozygosity, and hence variability, in the population without the sacrifice of the advantages of self-pollination. However, even when cross-pollination takes place, wind or generalized flower visitors are adequate. Many weeds have outcrossing ancestors that probably reveal the ancestral condition. Genetic recombination in such outcrossing ancestors may provide the appropriate "general purpose genotypes" that may then be replicated by autogamy, agamospermy, or vegetative reproduction.

Back

Adaptations to frequently disturbed environments - Kriton K. Hatzios

A magnificent example of adaptation to weedy life in a perennial grassland is provided by the common dandelion, *Taraxacum officinale*. In addition to its deep taproot and rosette of leaves, which help it to deal with competition of the grasses, it has remarkable powers of regeneration from any part of the rootstock which may be severed. The flat rosette of leaves avoids the blade of a mowing machine and it is not easy for a grazing animal to consume them, while the more exposed flowering scape is richly provided with unpalatable latex. The inflorescence buds are produced very near the ground level and develop rather slowly in this position (from which they will not be cut even by a very fine-set lawn mower). Suddenly the scape elongates and flowering and fruit-setting takes place rapidly (assisted by precocious development of the apomictically-produced embryos). All of these features are characteristic of the genus *Taraxacum* as a whole and must be looked upon as preadaptations to weediness.

Back

Choose a tillage method to view the resulting distribution of weed seeds in a schematic soil profile.

COURSE OUTLINE
PPWS 5754 - HERBICIDE ACTION AND METABOLISM
(Spring Semester 2002)

Description: Study of the properties and characteristics of herbicides, the processes and principles involved in their action and their metabolic detoxification by plants and microorganisms. Selectivity of herbicides and modern approaches to improve it.

Objectives:

1. To generate an awareness and appreciation of plant physiology, biochemistry, and molecular biology in terms of what herbicides do to plants (mode of action) and what plants do to herbicides (metabolic detoxification, target site resistance).

2. To review current research areas and methods used for studying herbicide action and metabolism as well as prospects for future research.

3. To make students aware of the impact of weed science as an applied form of plant physiology, biochemistry and molecular biology and as a dynamic discipline and career field.

Instructor: **Dr. Kriton K. Hatzios**, Professor and CALS Associate Dean; **Dr. Jim Westwood**, Assistant Professor,
Department of Plant Pathology, Physiology and Weed Science
203 Plant Molecular Biology Bldg; 416 Price Hall
Phone: 231-63361 (Hatzios); 231-7519 (Westwood). **e-mail**: hatzios@vt.edu, westwood@vt.edu.

Lecture Hours: Tuesday (T) & Thursday (H) - 11:00 - 11:50 AM, Room 400 Price Hall
Lab Hours: Friday, 1:00 to 4:00 PM, Room 400 & 406 Price Hall **or** 203 PMB Bldg.
Office hours: T, H - 9:00 - 10:45 AM (Westwood) or by APPOINTMENT (Hatzios).

Lab Assistants: **Dr. Dan Feng** & **Mrs. Sue Meredith,** 200 PMB Building, Phone: 231-5835, e-mail: fandeng@vt.edu, sueaweed@vt.edu

Textbooks:

Devine, M.D., Duke, S.O. and Fedtke, C. 1993. **Physiology of Herbicide Action**, Prentice Hall, Engelwood Cliffs, NJ. 441 pp. (Out of Print). Required Reading to be placed in Newman Library.

Hatzios, K.K. (ed.) 1997. **Regulation of Enzymatic Systems Detoxifying Xenobiotics in Plants**, NATO ASI Series, Kluwer Academic Publishers, Dordrecht, The Netherlands, 385 pp. Recommended Reading.

Teaching Aids: Several books related to the subject matter of this course have been put **On Reserve** at the Newman Library (2-day limit). A **list of appropriate books** will be handed out in the class.

Copies of selected **review or research articles** and **many handouts** will be provided to the students or placed in a central location for use by the students in this course.

Slide sets, movies/videos or multi-media diskettes will be also used during the lectures. These materials may be available for check-out to students.

A website for this course is available (www.ppws.vt.edu/haculty/hatzios). A **list of websites** and discussion listservers related to weed science and pesticides will be provided to the students enrolled in this course. Students are encouraged to contact the instructor or the lab assistants by e-mail for any questions that may have related to the content of this course.

Evaluation Procedures:

Grading: Grading scale will be A to F with pluses or minuses. Your final grade will be based on your performance in both the lecture and laboratory parts of this course. The **Lecture part** will correspond to **65%** of the final grade and will consist of a **midterm exam (25%)**, **a final exam (25%)** and an **oral presentation of a literature paper (15%)**. The **Laboratory part** will make up the remaining **35%** of the final grade and will consist of a **final exam (20%)** and a **laboratory project** on the identification of an unknown herbicide sample **(15%)**.

Exams: The **midterm exam** will cover the material discussed during the first part of the course (from lecture #1 up to the lecture before the exam).
The **final exam** will cover the material of the second part of the course starting with the lecture after the midterm exam up to the final lecture.

Presentations: Student oral presentations will consist of a 20-25 min. presentation to the class of a literature article related to the topics discussed in this course. A list of relevant papers will be supplied by the instructor at the 3rd week of the semester. Students can choose a paper from this list or propose an alternative paper that is related to the course. Questions related to the material included in the discussed papers may be included in the final exam of the Lecture part. The time for the presentation of the selected papers will be the last laboratory session.

Benefits related to the Student Paper Presentations:

a. Help the student become familiar with the scientific literature on herbicide physiology and molecular biology and with particular topics that will not be discussed extensively in the lectures.

b. Provide the student with an opportunity to present a paper to a “friendly” audience. Thus, the fear of giving a talk at a professional meeting or a “for grade” seminar is minimized or absent.

c. Students may take advantage of their effort in this course and present the selected paper as a departmental seminar (Literature review seminar) at a later time after expanding and improving the material.

***Seminars*:** In addition to the material covered in the lectures, students are strongly encouraged to attend the regular seminars presented at the Interdepartmental Seminar Series of Plant Physiology (Thursdays 4:00 to 5:00 PM) and Molecular and Cell Biology and Biotechnology (Fridays 12:00 noon to 1:00 PM). Titles and speakers in these seminars series are announced in the website of the PPWS Department (www.ppws.vt.edu).

Honor Code: Students in this course must abide by the Honor Code of Virginia Tech.

PPWS 5754 - HERBICIDE ACTION AND METABOLISM

(Spring Semester 2000)

Lecture	Topic
1 (Jan. 15)	Introduction. General references and literature on herbicides. Weed Science in the 21st Century. History and review of methods of weed control. Principles of chemical weed control. Related movie to be shown in 1st lab session. *Reading assignment (RA): Handouts.* **Instructor**: Hatzios
2 (Jan 17)	Basics of herbicide chemistry. Nomenclature, chemical and physical properties of herbicides. Functional groups and structure-activity relationships. Discovery of new Herbicides to be discussed in first lab session. *RA: Handouts; Chapters 1 & 2 (Devine et al., 1993).* **Instructor**: Hatzios
3 (Jan 22)	Penetration of foliar-applied herbicides. Pathways of absorption through the cuticle and mechanisms involved. *RA: Chapter 3 (Devine et al., 1993); Handouts.* **Instructor**: Hatzios
4 (Jan 24)	Uptake of herbicides from the soil. Pathways and mechanism involved. *RA: Chapter 3 (Devine et al., 1993).* **Instructor**: Hatzios
5 (Jan 29)	Vascular transport of herbicides in plants. Mechanisms and pathways of herbicide translocation. Exudation of herbicides from plants. *RA: Chapter 5 (Devine et al., 1993); Handouts.* **Instructor**: Hatzios
6 (Jan 31)	Biotransformation of herbicides in higher plants. Definitions. Principles and mechanisms involved. Degradative enzymes *RA: Chapter 6 (Devine et al., 1993); Chapters 1 & 2 (Hatzios, 1997).* **Instructor**: Hatzios
7, 8, 9 (Feb 5, 7, 19)	Primary reactions: oxidation, reduction, hydrolysis. Secondary reactions: conjugation with glutathione, glucose and amino acids. Tertiary reactions: secondary conjugations with malonic acid and compartmentation.

RA: Chapters 3-16 (Hatzios, 1997). **Instructor**: Hatzios. (**Note**: Because of the WSSA Meetings, February 9-14, 2002, lectures will be made-up).

10 (Feb 21) Continuation of Herbicide Metabolism in Plants and Microbial metabolism of herbicides.
RA: handouts & review papers. **Instructor**: Hatzios

11 (Feb 26) Mechanisms of action of herbicides. Definitions. Localization of the primary site of herbicide action. Classification of herbicides by mechanism of action. Growth responses of plants to herbicides. Diagnosis of herbicide injury. Related video to be shown in the lab.
RA: Chapter 1 (Devine et al., 1993); Handouts. **Instructor**: Hatzios.

12 MID-TERM EXAM (February 28, 2002)

13, 14 (M 12, 14) Photosynthesis-inhibiting herbicides (PSII inhibitors), Action and metabolism
RA: Chapter 7 (Devine et al., 1993). **Instructor**: Westwood (March 12); Hatzios (March 14)

15 (March 19) Pigment inhibitors – Bleaching, Peroxidizing, and HPPD inhibiting herbicides, Action and metabolism.
RA: Chapter 8 (Devine et al., 1993); Handouts. **Instructor**: Hatzios

16 (March 21) Oxygen toxicity and herbicide action - Bipyridilium herbicides.
RA: Chapters 8 and 9 (Devine et al., 1993). **Instructor**: Hatzios

17 (March 26) Microtubule disruptors, Action and metabolism.
RA: Chapter 10 (Devine et al., 1993). **Instructor**: Westwood

18 (Marchl 28) Inhibitors of lipid synthesis, Action and metabolism.
RA: Chapter 11 (Devine et al., 1993). **Instructor**: Westwood

19 (April 2) Inhibitors of amino acid biosynthesis, Action and metabolism.
RA: Chapter 13 (Devine et al., 1993); handouts. **Instructor**: Hatzios

20 (April 4) Inhibitors of macromolecular synthesis (proteins, nucleic acids), Action and metabolism.
RA: Chapter 12 (Devine et al., 1993). **Instructor**: Hatzios

21 (April 9) Auxin-type herbicides (growth regulators), Action and metabolism.
RA: Chapter 14 (Devine et al., 1993). **Instructor**: Hatzios

22 (April 11) Other sites of herbicide action. Secondary physiological effects of herbicides.
RA: Chapters 15 & 16 (Devine et al. 1993). **Instructor**: Hatzios

23 (April 16) Principles of herbicide selectivity.
RA: Handouts, Chapter 1 (Devine et al. , 1993). **Instructor**: Westwood

24 (April 18)	Plant resistance to herbicides. Video and discussion. *RA: Chapter 26 (Hatzios, 1997); Review articles and Handouts.* **Instructor**: Hatzios
25 (April 23)	Genetic manipulation of crop tolerance to herbicides. Applications of recombinant DNA technology. Transgenic plants (e.g. Roundup ready and Liberty-Link crops). *RA: Chapters 22-25 (Hatzios, 1997); Review articles and handouts.* **Instructor**: Hatzios
26 (April 25)	Chemical manipulation of crop tolerance to herbicides. Synergism and antagonism in herbicide mixtures. Uses and action of herbicide safeners. *RA: Chapters 19 & 20 (Hatzios, 1997); Chapter 17 (Devine et al., 1993).* **Instructor**: Hatzios
27 (April 30)	Herbicide synergists and insecticide interactions with herbicides. *RA: Chapter 21 (Hatzios, 1997); Chapter 17 (Devine et al., 1993); Handouts.* **Instructor**: Hatzios.
28	**FINAL EXAMINATION - Tuesday May 7, 2002 – 11:00 AM to 1:05** PM.

LABORATORY OUTLINE
PPWS 5754 – HERBICIDE ACTION AND METABOLISM
(SPRING SEMESTER, 2002)

Catalog Description: Study of the properties and characteristics of herbicides, the processes and principles involved in their action and their metabolic detoxification by higher plants and microorganisms. Selectivity of herbicides and modern approaches to increase it.

Objective: To review current research areas and methods in plant physiology and biochemistry used for studying herbicide action and metabolism as well as prospects for future research.

Instructors:
Dr. Kriton K. Hatzios & Dr. Jim Westwood
Department of Plant Pathology, Physiology and Weed Science
Director & Assoc. Dean, Research; Assistant Professor
104 Hutcheson Hall; 406 Price Hall
Phone: 231-6336 (Hatzios); 231-7519 (Westwood)

Office Hours: T, H – by appointment only.

Laboratory: Friday 1:10 – 4:00 PM, Room 400 & 406 Price Hall/Room 203 PMB Building

Lab Assistants:
Mrs. Sue Meredith (sueaweed@vt.edu), Room 200 PMB Building, Phone: 231-5835
Dr. Fan Deng (fandeng@vt.edu), 200 PMB Building, 231-5835

Textbook:

1. The following books will be used as basic resource of information.
N.D. Camper (ed). 1987. **Research Methods in Weed Science.** 3rd edition. Southern Weed Society of America, Champaign, Ill.
W. Vencill (ed.). **Herbicide Handbook, 8th edition**. WSSA. 810 East 10th Street, Lawrence, KS.

2. Several handouts and selected review or research papers will be placed in central locations for use by the students (e.g. Room 503, PPWS Seminar & Library Room).

3. Several slide sets, movies or videos will be also used during the lab sessions. These materials will be available to students for check-out and study on their own.

Evaluation Procedure:
GRADING: Grading scale will be A to F with pluses or minuses. Your final grade will be based on your performance in both the lecture and the laboratory part of the course. The Lecture part will correspond to65% of the final grade and will include a midterm exam (25%) and an oral presentation of a literature paper (15%). The Laboratory part will correspond to the remaining 35% of the final grade and will include a final exam (20%) and the identification of an unknown herbicide sample (15%).

PPWS 5754 HERBICIDE ACTION AND METABOLISM
LABORATORY SECTION - SPRING SEMESTER 2002

Lab Session	Date	Topic	Instructor
1	January 18	Introduction, Objectives, Evaluation Procedures. Review of Basic Chemical Concepts. Development of new Herbicides. Films.	Hatzios
2	January 25	Radioisotope techniques. Liquid Scintillation Counting, Theory and practice. Initiation of Uptake Experiment	Hatzios, Meredith, Deng
3	February 1	Methodology for studying absorption, translocation and metabolism of herbicides in plants. Autoradiography. Biological oxidation.	Hatzios, Meredith, Deng
4	February 8	Analysis of herbicide residues and metabolites. Extraction and partitioning.	Hatzios, Meredith, Deng
5	February 15	Herbicide analysis and chemical property determinations using spectrophotometric methods. GST-mediated conjugation of metolachlor with glutathione.	Deng
6	February 22	Herbicide analysis using chromatographic techniques. TLC, FPLC, HPLC.	Deng and Meredith
7	March 1	Other analytical techniques in herbicide research. Immunological methods, NMR and Mass Spectrometry. Visit Fralin Lab for demonstration of Departmental HPLC (Fabricio Bolivar). Hand out unknown analytical samples of herbicides to be characterized by students.	Hatzios, Deng, Bolivar
8	March 15	Demonstration of GC-Mass spectrometry instrumentation at the Pesticide Lab, 352 Litton Reaves (Joy Burroughs). Students can work on their unknown herbicides.	Burroughs, Meredith, Hatzios
9	March 22	Molecular Techniques in Weed Science #1	Westwood, Meredith
10	March 29	Molecular Techniques in Weed Science #2	Westwood, Meredith
11	April 5	Molecular Techniques in Weed Science #3	Westwood, Meredith
12	April 12	1st part: Laboratory Examination 2nd part: Herbicide injury, diagnosis, causes, prevention and remedial action. Video on symptoms of herbicide injury.	Meredith, Hatzios
13	April 19	Open Lab session for student work on characterizing unknown sample	Meredith, Deng, Hatzios
14	April 26	Lab reports on characterizing unknown sample are due. Presentation of research papers chosen by students in lecture part of the course	Hatzios

PPWS 6004

ADVANCED TOPICS IN PLANT PATHOLOGY, PHYSIOLOGY AND WEED SCIENCE

EPIDEMIOLOGY OF PLANT DISEASES

Equivalent to the Epidemiology section of:
GENETIC AND EPIDEMIOLOGICAL ASPECTS OF PLANT PATHOLOGY
PPWS 5404

The study of plant disease in populations, of environmental factors that influence the amount and distribution of disease in populations, and of rates of change in the amount of disease in time, in space, or both.

Course is primarily designed for plant pathology majors and those interested in in-depth study of epidemiology of plant diseases. It combines theory and practical aspects.

Course offered: Alternate years: Spring 2002, 2004, etc. when demand justifies

Instructor: Dr. **Anton Baudoin**, 417-A Price Hall, Tel: 231-5757, email: abaudoin@vt.edu

Course topics

1. Introduction; definition and scope of epidemiology, historical development; terminology
2. Quantitative plant pathology: measurement of host, pathogen, environment, and disease
    - Pathogen monitoring
        - quantifying populations of propagules
        - sampling of soil, leaves, etc.; assay
        - air sampling for spores
    - Host monitoring
        - biomass and leaf area
        - developmental stages
    - Disease measurement
3. Models in epidemiology, types and use
4. Growth curves, "Vanderplankian" and related models:
5. Derivation of simple exponential and logistic models
    - Refinements by adding latent and infectious period
    - Monocyclic disease -- monomolecular model
    - Other growth curves; Gompertz, Richards, etc.
    - Implications of models for designing disease control strategies
6. Multiple regression models; Integration of factors affecting disease severity
7. Simulation models and systems analysis; implication for design of disease control strategies

8. All the little pieces: epidemiological processes; effects of the abiotic environment on epidemics and their components; microclimate.
9. Effects of temperature, radiation, moisture, and wind. Environmental monitoring -- temperature, humidity, rain, leaf wetness, radiation, etc.
10. Forecasting of disease
11. Dispersal: take-off, transport, deposition. Air sampling, spore traps
12. Disease gradients, their study and interpretation
13. Inoculum potential/disease incidence relationships
14. Effect of host spacing and host mixtures; disease development in natural communities
15. Use of epidemiology in the analysis of host resistance to disease
16. Crop loss assessment; yield loss models; techniques in crop loss assessment research

Text: none required. The following two books will be used extensively.

- Campbell, C. L. and L. V. Madden 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York, NY. 532 pp.
- Zadoks, J. C. & R. D. Schein 1979. Epidemiology and Plant Disease Management. Oxford University Press. 427 pp.

STUDENT ANNUAL PROGRESS REPORT

Academic Year: _____ **Current Date:** _____

Each student is required to have a formal committee meeting prior to Thanksgiving break for each year of residence. A second meeting each year is encouraged. This will help to ensure that progress is being made, in a timely manner, toward fulfilling degree requirements, and that all parties understand the requirements and progress being made. This form must be signed by each committee member, the advisor, and the student indicating that a meeting was held, and that all approve of the information presented on the form.

Name: (Last) _____ (First) _____ (M.I.) _

Local Address and Phone Number:

Street: _____ City: _____

State: _____ Telephone: _____
Major: _____ Degree: _____ Advisor:

Entrance date: _____ Diagnostic Exam (date completed) :

Program of Study (date completed): _____ (on file)

Research proposal (date approved): _____ (on file)
Preliminary Exam (Ph. D only, date completed):
Teaching requirement (date completed): _____

Teaching evaluations (overall student rating): _____
(Note: Attach copy of supervisor's evaluation of teaching performance.)

Overall QCA as of September 1: _____

Journal articles and abstracts, etc. (complete citations):

Seminars (title, date, location):

Meetings attended (professional, workshops, short courses, field days; name of meeting, date, location):

Scholarships/Honors/Awards:

Membership in professional and honor societies:

Committee service (Dept., College, Univ.):

Grant proposals written and/or funded:

Advisor's comments concerning student's progress:

(**Attach a separate letter to the department head** with copies to the student and committee members, summarizing specific accomplishments of the student and comments made by the committee regarding the student's progress and future direction).

Date committee members met with the student:

Committee member's signatures: Progress is:

	Adequate	**Inadequate**
_____ Chairperson	_____	_____
_____ Member	_____	_____
_____ Member	_____	_____
_____ Member	_____	_____

Student Certification: I have read the evaluation(s) of my progress for the past year and I agree

disagree _____ that this it is a fair statement.

Student's Signature: _____ Date: _____

7/98

ANALYSIS OF CUMULATIVE ANNUAL PROGRESS OF PPWS GRADUATE STUDENTS

NAME: _____ **SOCIAL SECURITY:** _____
SEMESTER ENTERED: _____ **DEGREE:** _____
DISCIPLINE: _____ **MAJOR ADVISOR:** _____

ADVISORY COMMITTEE*:

Chairperson: _____

Member: _____

Member: _____

Member: _____

Member: _____

PLAN OF STUDY*: Submitted: Yes _____ **No** _____ **Approved (date):** _____

RESEARCH PROPOSAL: Submitted (date):** _____ **Approved (date):** _____

SEMINAR REQUIREMENTS:

1ST Seminar - Semester given: _____
2nd Seminar - Semester given: _____
Defense Seminar Scheduled (date): _____

TEACHING REQUIREMENTS:

1ST Assignment Yes _____ **Course: PPWS** _____ **Semester:** _____
2nd Assignment Yes _____ **Course: PPWS** _____ **Semester:** _____

PRELIMINARY EXAM (PHD) * Scheduled:** _____ **Passed:** _____

CURRENT QCA: _____

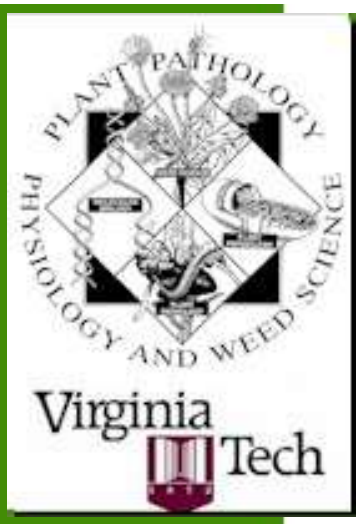
ANNUAL PROGRESS REPORT: (due by December 1 of each year)

Year 1 Submitted (date): ____
Year 2 Submitted (date): ___
Year 3 Submitted (date): ___

EXPECTED DATE OF COMPLETION: _____

ADDITIONAL COMMENTS: _____

***Must be formed and/or completed by the end of first semester of residence at Virginia Tech**
**** Must be completed by the end of second semester of residence at Virginia Tech**
***** Exam must be taken at least nine months prior to final examination**



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Seminars

Plant Pathology, Physiology, and Weed Science
Seminar Program - Fall Semester
Fralin Hall Auditorium

4:00 PM on Wednesday

2003 Schedule

click here for a PDF version of the 2002 schedule

click here for a PDF version of the 2000 schedule

Last Updated July 30, 2003
http://www.ppws.vt.edu/

Plant Pathology, Physiology, and Weed Science
Seminar Program - Fall 2000
Fralin Hall Auditorium

4:00 PM on Wednesday

Aug. 30	**Dr. Fred Shokes** - "From the mule to precision farming"
Sept. 6	**Ms Elizabeth Bush** - "Characterization of *Phytophthora* species present in recycled irrigation water at a container nursery in Virginia"
Sept. 13	**Dr. Cynthia Denbow** - "Subcellular localization of tomato 3-hydroxy-3-methylglutaryl coenzyme A reductase"
Sept. 20	**Ms Amanda Griffitts** - "Characterization of host plant defense responses to parasitization by Orobanche"
Sept. 27	**Mr. Greg Armel** - "Corn weed management programs with ZA-1296"
Oct. 4	**Mr. Rob Richardson** - "CGA-362622, a new sulfonyl urea herbicide for broadleaf weed control in cotton"
Oct. 11	**Ms Laura Good** - "Isolation and characterization of a myo-inositol phosphate synthase (mIPS) gene family in soybean"
Oct. 18	**Mr. Steve Abler** - "Leptosphaerulina leaf blight of turfgrasses"
Oct. 25	**Mr. Arthur Graves** - "Replacing copper and chlorothalonil in staked tomatoes on Virginia's Eastern Shore"
Nov. 1	**Mr. Bryan Johnson** - "Impact of Herbicides on Soybean Leaf Area"
Nov. 08	**Mr. Andy Bailey** - "Growth and reproductive characteristics of ALS-resistant smooth pigweed populations"
Nov. 15	**Mr. Selester Bennet - "**Modification of protein glycosylation in transgenic tobacco"
	Thanksgiving Recess, Nov. 21-29
Nov. 29	**Mr. Cory Whaley** - "Fall herbicide applications for perennial broadleaf weed control"
Dec. 6	**Ms Myoung Hui Yun** - "Partitioning of electrons to carbon reduction in tobacco cultivars with contrasting sensitivity to ozone"

*Jon Eisenback, Seminar Chairman Tel. 540.231.4650 .E-mail: jon@vt.edu

Extension Publications

These publications are in a PDF format therefore you must have an Adobe Acrobat Reader in order to view them. If you do not have an Acrobat Reader on your computer, you can download this for free by clicking on the Get Acrobat Reader icon below. Once you have installed the Acrobat Reader, just click on one of the publications below for viewing and/or downloading.

Get Acrobat Reader

Identification and Control of Honeyvine Milkweed (*Ampelamus albidus*) in Virginia.

Identification and Control of Horsenettle (*Solanum carolinense*) in Virginia.

Identification and Control of Trumpetcreeper (*Campsis radicans*) in Virginia.

Identification and Control of Hemp Dogbane (*Apocynum cannabinum*) in Virginia.

Identification and Control of Mugwort (*Artemisia vulgaris*) in Virginia.

Identification and Control of Annual Ryegrass (*Lolium multiflorum*) in No-till Corn in Virginia.

Control of Common Pasture and Hayfield Weeds in Virginia and West Virginia.

Control of Undesirable Woody Species in Pastures and Hayfields

Home

Identification and Control of Honeyvine Milkweed (*Ampelamus albidus*) in Virginia

Kevin W. Bradley, Paul Davis, and Edward S. Hagood, Jr.
Postdoc. Research Assoc., Extension Agent, and Extension Weed Scientist, VPI and SU

IDENTIFICATION

A perennial with slender, twining stems that may reach 10 feet in length. Leaves are 3-7 inches long, 1.5-5 inches wide, opposite, entire, and heart-shaped (4). Leaves do not have hairs and occur on petioles that are 1-4 inches long. Leaf surfaces have conspicuous white veins that arise from a common point (palmate venation) (1). Flowers are small (2-3 mm broad), white, numerous, and occur on flower stalks that arise between stems and leaves (axillary). The fruit is a smooth, angled follicle that is 3.5-5 inches long, 1-2.5 inches wide (4). Roots from a clustered fibrous underground rootstock capable of vegetatively reproducing additional plants (4,2). Although the name implies a secretion of milky sap as in other milkweed species (*Asclepias* spp.), this does not occur in the leaves or stems of honeyvine milkweed. This weed is often incorrectly identified as field bindweed (*Convolvulus arvensis*).

CONTROL IN CORN

Experiments conducted in no-till corn fields throughout Virginia reveal that similar levels of season-long honeyvine milkweed suppression may be achieved with applications of Permit®, Exceed®, or Callisto® when these herbicides are applied with either Banvel® or Distinct (Table 2). Additional research conducted in Virginia has revealed that a mid-May application of Roundup Ultra® to Roundup Ready® corn hybrids affords only initial suppression of honeyvine milkweed and regrowth is likely to occur. This suggests that the timing of herbicide application is an important component of a successful control program. This was confirmed in herbicide application timing studies, where significantly higher levels of honeyvine milkweed control were achieved when herbicides were applied in the pre-bloom (late-June) and early-bloom (mid-July) stages of growth (Figure 1). Based on these experiments, adequate control of seedlings or sprouts arising from underground rootstocks should not be expected until these plants reach at least 1-2 feet in height, and highest control should be attained when plants are treated in the early bloom stage of growth (2). Unfortunately, treatment at this time is often impossible due to the typical size of corn in early- to mid-July when honeyvine milkweed plants have reached this stage of growth. Therefore, where severe infestations exist, growers may be required to consider applications in fallow or the use of a genetically altered crop. For example, honeyvine milkweed can be controlled effectively in corn using Lightning®. This combination of two imidazolinone herbicides does, however, require the use of an IR® or IT® corn hybrid, and its use may restrict rotation to subsequent crops.

Table 1 . Effect of sequential annual herbicide applications on honeyvine milkweed control in Kansas (5).

		Control[a] 1YAT[b]		
Herbicide(s)	Rate/A	1 trtmt.	2 trtmts	3 trtmts
		----------(%)----------		
2,4-D	2 qts	59	36	73
Banvel	1 qt	59	50	88
Roundup + 2,4-D	1.5 qt + 1 qt	79	69	89
Roundup + Banvel	1.5 qt + 1 pt	90	81	88
2,4-D + Banvel	1 qt + 1 pt	58	51	77

[a]Control calculated from stem density counts following treatment as the % of the pretreatment density

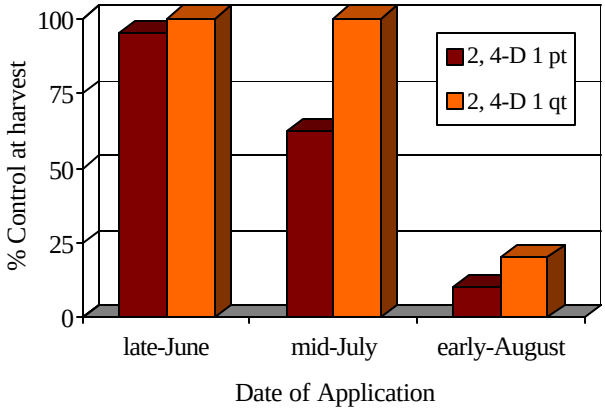
[b]YAT = year after treatment

Table 2. Honeyvine milkweed control in no-till corn with POST herbicides in Middlesex County, Virginia (3).

Herbicide[a]	Rate/A	End of Season H. Milkweed Control
2,4-D	1/2 pt	54
2, 4-D	1 pt	51
Banvel	1/4 pt	51
Banvel	1/2 pt	45
Distinct	6 ozs	53
Exceed	1 oz	46
Exceed + Banvel	1 oz+1/4 pt	74
Exceed + Distinct	1 oz + 6 ozs	75
Exceed + 2, 4-D	1 oz + 1/2 pt	58
Permit	1 1/3 ozs	48
Permit + Banvel	1 1/3 ozs+1/4 pt	79
Permit + Distinct	1 1/3 ozs + 6 ozs	83
Permit + 2, 4-D	1 1/3 ozs + 1/2 pt	83
Beacon	3/4 oz	48
Beacon + Banvel	3/4 oz+1/4 pt	59
Beacon + Distinct	3/4 oz + 6 ozs	74
Beacon + 2, 4-D	3/4 oz + 1/2 pt	76
Callisto	0.094 lbs ai	48
Callisto + Banvel	0.094 lbs ai + 1/4 pt	78
Callisto + Distinct	0.094 lbs ai + 6 ozs	89
Callisto + 2, 4-D	0.094 lbs ai + 1/2 pt	63
LSD (0.05):		10

[a]All Exceed, Permit, Beacon, and Callisto treatments applied with 1/4 % (v/v) non-ionic surfactant.

Figure 1. Effect of timing of 2,4-D applications on honeyvine milkweed control in corn (2).



CONTROL IN SOYBEANS

Relatively few options are available for the selective control of honeyvine milkweed in soybeans. Where appropriate, tillage to disrupt the underground rootstock will greatly enhance the effectiveness of herbicide treatments. Diphenyl ether herbicides such as Blazer®, Reflex®, and Cobra® will provide some suppression of honeyvine milkweed via desiccation of foliage, but regrowth from underground rootstocks will occur. A more effective alternative for the control of honeyvine milkweed in soybeans is the application of Roundup Ultra® to a genetically engineered Roundup Ready® soybean variety. The suppression afforded by the highest labeled rates of Roundup Ultra® coupled with the competitive effects of good soybean canopy closure, should provide control or good suppression of this weed.

CONTROL IN FORAGES

Honeyvine milkweed is rarely encountered in Virginia pastures or hayfields. However, small infestations should be treated with a 2% v/v Roundup Ultra® solution before this hard-to-control perennial weed spreads further.

REFERENCES

1. Britton, N. L., and H.A. Brown. 1970. An Illustrated Flora of the Northern United States and Canada.
2. Coble, H.D. and F.W. Slife. 1970 Development and control of honeyvine milkweed. Weed Sci. 18:352-356.
3. Hagood, E. S., and K. W. Bradley. 2000. Summary of 2000 weed control trials for agronomic crops. 312 p.
4. Elmore, C.D. Weed Identification Guide. Southern Weed Science Society. Champaign, IL.
5. Moshier, L.J., O.G. Russ, J.P. O'Connor, and M.M. Claassen. 1986. Honeyvine milkweed (*Ampelamus albidus*) response to foliar herbicides. Weed Sci. 34:730-734.

Identification and Control of Horsenettle (*Solanum carolinense*) in Virginia

Kevin W. Bradley, Graduate Research Assistant, VPI and SU
Edward S. Hagood, Jr., Extension Weed Scientist, VPI and SU

IDENTIFICATION

A perennial from rhizomes with conspicuous spines on leaves and stems reaching 3 feet in height. Leaves are elliptic-oblong to oval, alternate, petioled, 2.5-4.5 inches long and covered on both surfaces with hairs. Leaves also emit a potato odor when crushed, and contain prominent prickles on the midvein and petiole (2). Stems are angled at the nodes, become woody with age, and also have prickles and hairs. Flowers occur in clusters and are star-shaped with 5 white to violet petals and a yellow center. The fruit is a berry, green when immature, turning yellow and wrinkled with maturity (2). All parts of the plants, except the mature fruit, are capable of poisoning livestock if eaten in sufficient quantity, however consumption rarely occurs due to the prickly stems and leaves (5).

Table 1 . Effect of postemergence corn herbicides on horsenettle control and subsequent populations (4).

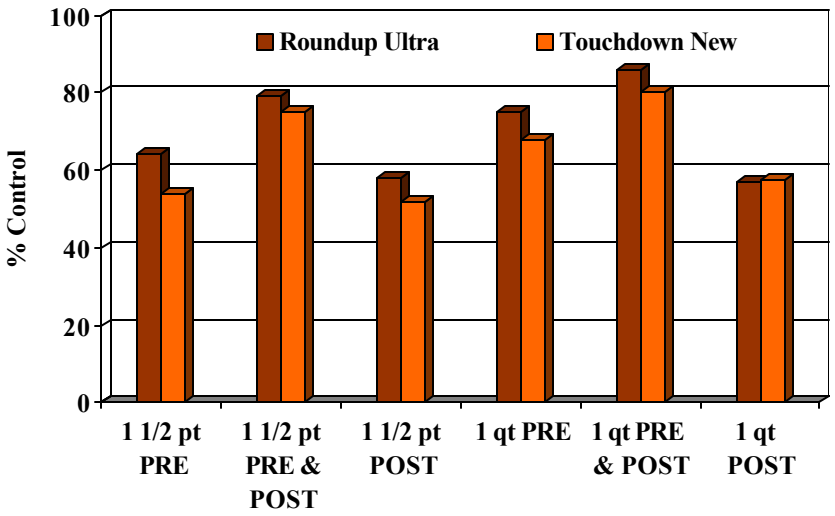
Herbicide[a]	Rate	Control[b]	Population 1 YAT[c]
		%	%
Accent	2/3 oz	40	135
Accent + Banvel	2/3 oz + 1/2 pt	64	107
Beacon	3/4 oz	68	105
Beacon + Banvel	3/4 oz + 1/2 pt	74	90
Banvel	1/2 pt	61	135
Stinger	1/3 pt	48	140

[a]Accent and Beacon treatments included a NIS at 1/4 % v/v.
[b]Control 11 weeks after treatment.
[c]Year after treatment; % of the preapplication population.

CONTROL IN CORN

As illustrated in Table 1, few postemergence corn herbicides provide acceptable short- or long-term control of horsenettle. Beacon in combination with Banvel provided the highest level of horsenettle suppression at 74%, however horsenettle populations were not reduced by any of the herbicides applied in this experiment when evaluated one year after treatment. These lower levels of horsenettle control commonly observed in corn fields are often due to a lack of translocation of these herbicides from the foliage to the root systems. Previous studies have illustrated that the maximum translocation of herbicides into the roots occurs when horsenettle plants are in the early- to mid-bloom stages of growth (5). Unfortunately, this is not a compatible time period for postemergence herbicide applications in Virginia corn production systems, as most postemergence corn applications are made from late-May to mid-June when horsenettle plants are at a much younger stage of growth. Therefore, rotation of fields to Roundup Ready® soybeans should be considered one of the most effective methods of control where severe infestations occur. In addition to the herbicides included in Table 1, similar levels of horsenettle suppression or partial control will be achieved with applications of Exceed® at 1 oz/A plus or Permit® at 2/3 oz/A plus Banvel® or Clarity® at 1/4 or 1/2 pt/A. Lastly, recent experiments conducted on severe horsenettle populations in Virginia have revealed that Callisto® will provide good to excellent control of horsenettle when applied either alone or with 1/4 pt Banvel® or Clarity®.

Figure 1 . **Influence of Roundup Ultra and Touchdown New on horsenettle control at 6 weeks after treatment (1).**



CONTROL IN SOYBEANS

The most effective option for horsenettle control in soybeans is the use of Roundup Ultra® or Touchdown New® in combination with a genetically engineered Roundup Ready® soybean variety. As illustrated in Figure 1, a sequential application of Roundup Ultra® or Touchdown New® at 1 1/2 pts or 1 qt/A provides effective control of horsenettle throughout the growing season. These levels of control are also enhanced by the competitive effects of the soybean canopy. It is critical, therefore, that soybeans be planted in narrow rows and managed intensively for maximum competitive effect.

CONTROL IN FORAGES

Research conducted at the Southwest Virginia Agricultural Research Station (Table 2) indicates that applications of Remedy® (triclopyr), Banvel® or Clarity®, and 2,4-D in combination with Banvel® or Clarity® will provide acceptable levels of season-long horsenettle control in a grass pasture. Additionally, high rates of Crossbow®, a pre-packaged mix of 2,4-D and triclopyr, affords similar levels of horsenettle control. Long-term control of horsenettle, however, is much more difficult to achieve. High rates of Remedy® or Crossbow® will provide acceptable levels of long-term horsenettle control (Table 2), however repeated applications of these herbicides over several years may be required for complete elimination of severe horsenettle infestations.

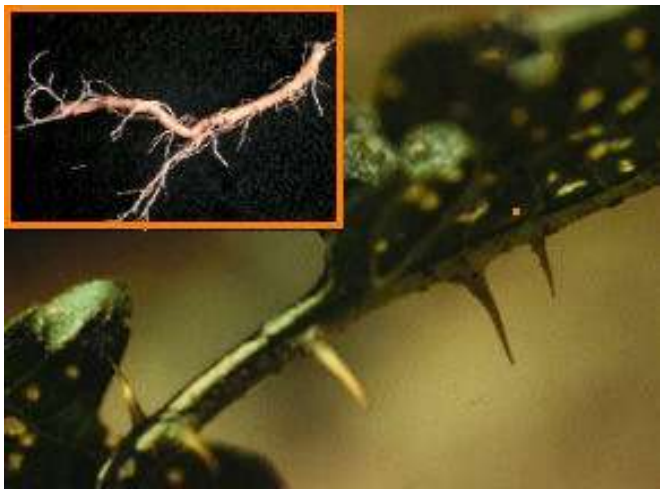


Table 2 . Horsenettle control in pastures at the Southwest Virginia Agricultural Research Station (3).

Herbicide	Rate/A	Control 3MAT[a]	Control 1YAT[b]
2,4-D	1 qt	75	64
Banvel	1/2 pt	75	56
Banvel	1 pt	95	73
Banvel + 2,4-D	1 pt + 1.5 qts	94	79
Remedy	1.5 qts	95	76
Remedy	3 qts	99	89

[a] MAT=months after treatment
[b] YAT=years after treatment

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Identification and Control of Trumpetcreeper (*Campsis radicans*) in Virginia

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IDENTIFICATION

Perennial woody vine that may reach 40 feet or more in length. Leaves are opposite and composed of several similar leaflets also arranged oppositely from one another (pinnately compound). A single leaf may contain 7-15 leaflets that are 1-3 inches long, 1/2 to 1 1/2 inches wide, and coarsely toothed (1). Stems become woody, and may be either trailing along the ground or climbing on other vegetation (5). Stems root where they touch the ground and also produce aerial roots that aid in climbing. Showy red-orange trumpet shaped flowers (2-3 inches long) produce a long, narrow capsule containing many winged seed (5). This weed is also commonly referred to as "cow-itch."

CONTROL IN CORN

Trumpetcreeper infestations may be reduced and perhaps even eliminated in conventionally grown corn where disruption of the root system occurs due to plowing or disking (4). This effect of reducing the size of rootstocks is illustrated in Figure 1, where significantly higher control of trumpetcreeper was recorded with both 2,4-D and Banvel® in plants growing from 4-inch root sections compared to 18-inch root sections. However, in no-till corn production, trumpetcreeper roots are often left undisturbed and the resulting infestation may cause reductions in yield and/or interfere with harvest (4). The results presented in Table 1 illustrate that similar levels of season-long trumpetcreeper suppression may be achieved with applications of Permit®, Exceed® , Beacon® , or Callisto® when these herbicides are applied with either Banvel® or Distinct®. However, as illustrated in Table 1, some of the greatest reductions in the trumpetcreeper populations were achieved with applications of Callisto® and Banvel® or Distinct®. Several researchers have also investigated the efficacy of Roundup Ultra® on trumpetcreeper populations in combination with a genetically engineered Roundup Ready® corn hybrid. One of these studies has illustrated that good to excellent trumpetcreeper control can be achieved with early- to late-September applications of Roundup Ultra® (3). However, treatment at this time is often impossible due to the typical size of corn at this time of year. Therefore, were severe infestations exist, growers may be required to consider applications in fallow or rotation to Roundup Ready® soybeans where this weed can be managed much more effectively.

Figure 1 . Control of trumpetcreeper grown from 4-inch and 18-inch root sections with 2,4-D and Banvel (4).

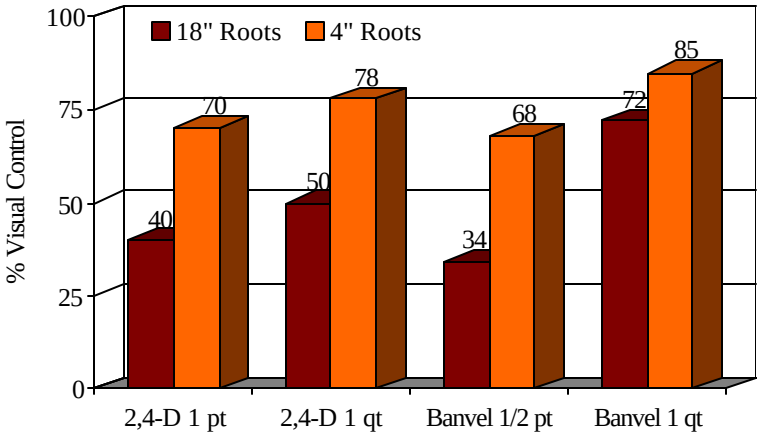

Table 2 . Trumpetcreeper control in corn with POST herbicides (2).

Herbicide[a]	Rate/A	Trumpetcreeper Control[b]
2,4-D	1/2 pt	55
Banvel	1/4 pt	61
Banvel	1/2 pt	65
Distinct	6 ozs	58
Exceed	1 oz	54
Exceed + Banvel	1 oz+1/4 pt	52
Exceed + Distinct	1 oz + 6 ozs	57
Exceed + 2, 4-D	1 oz + 1/2 pt	47
Permit	1 1/3 ozs	43
Permit + Banvel	1 1/3 ozs+1/4 pt	50
Permit + Distinct	1 1/3 ozs + 6 ozs	61
Permit + 2, 4-D	1 1/3 ozs + 1/2 pt	40
Beacon	3/4 oz	51
Beacon + Banvel	3/4 oz+1/4 pt	68
Beacon + Distinct	3/4 oz + 6 ozs	51
Beacon + 2, 4-D	3/4 oz + 1/2 pt	49
Callisto	0.094 lbs ai	70
Callisto + Banvel	0.094 lbs ai + 1/4 pt	66
Callisto + Distinct	0.094 lbs ai + 6 ozs	60
Callisto + 2, 4-D	0.094 lbs ai + 1/2 pt	56
LSD (0.05):		22

[a]Exceed, Permit, Beacon, and Callisto treatments applied with 1/4% NIS.
[b]Control expressed as the reduction in the trumpetcreeper population.

CONTROL IN SOYBEANS

The methods available for the control of trumpetcreeper in soybeans are similar to those described in no-till corn. For example, reductions in the size of trumpetcreeper rootstocks through plowing or discing in conventionally grown soybeans should contribute to a greater suppression of this weed following herbicide applications. Additionally, in research conducted on severe trumpetcreeper infestations in no-till Roundup Ready® soybeans in Virginia, sequential applications of Roundup Ultra® or Touchdown New® at 1 1/2 pts/A or at 1 qt/A provided greater than 90% trumpetcreeper control at 2 months after treatment (2). Other alternatives for the suppression of trumpetcreeper in soybeans include: Cobra® at 12.5 fl. ozs./A and Reflex® or Flexstar HL®, both at 1.5 pts/A. Applications of these dessicator-type herbicides will only provide topgrowth suppression of trumpetcreeper, however, and regrowth from underground rootstocks is likely to occur.

CONTROL IN FORAGES

Trumpetcreeper usually is not a problem weed in pastures and hay fields where its growth is restricted by mowing and grazing (4). However, where severe infestations occur, Banvel® or Clarity® at 2 qts/A, high rates of Crossbow®, or the combination of 2,4-D with a lower rate of Banvel® or Clarity® will provide from 60 to 100% control of this weed. Spot treatments of a 2% (v/v) Roundup Ultra® solution is also an effective means of controlling small infestations of trumpetcreeper.

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Identification and Control of Hemp Dogbane (*Apocynum cannabinum*) in Virginia

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IDENTIFICATION

A perennial weed that secretes a milky sap when broken, reaching 5-6 ft. in height. Leaves are entire, ovate or elliptic, 2-5 inches long, 1/2 to 1 1/2 inches wide, and arranged oppositely along the stem. Leaves have short petioles and are sparingly pubescent or lacking hairs beneath (1). Stems are without hairs, often have a reddish tint when mature, and are much-branched in the upper portions of the plant. Flowers are small, white to greenish-white, and produced in terminal clusters. The fruit are long (5 inches or more), narrow follicles that are produced in pairs (7). These plants tend to grow in colonies due to the long horizontal rootstock that develops after the original taproot, however reproduction by seed may also occur.

Table 1. Short- and long-term control of hemp dogbane in no-tillage corn with selected postemergence herbicides (3).

		Dogbane Control	
		1993	1994
Treatment	Rate	7-8WAT[a]	1YAT[b]
	Product/ A	----------%----------	
Accent	2/3 oz	69	28
Accent + 2,4-D	2/3 oz + 1/2 pt	88	40
Accent + Banvel[c]	2/3 oz + 1/4 pt	90	56
Accent + Atrazine	2/3 oz + 2 qts	48	27
Beacon	3/4 oz	42	27
Beacon + 2,4-D	3/4 oz +1/2 pt	83	39
Beacon + Banvel[c]	3/4 oz +1/4 pt	78	38
Beacon + Atrazine	3/4 oz + 2 qts	37	37
Banvel[c]	1 pt	77	23
Untreated		0	0
LSD (0.05)		11	21

[a]WAT, weeks after treatment.

[b]YAT, years after treatment.

[c]Represents one of several available herbicides containing dicamba as the single a.i.

CONTROL IN CORN

In no-till corn production, the horizontal rootstock of hemp dogbane is often left undisturbed, allowing new plants to develop from lateral root buds and produce significant infestations the following year (2). Previous research revealed that these infestations caused an average corn yield loss of 5 to 10% over a 3-year time period (6). Results from several experiments on the short- and long-term chemical control of hemp dogbane are summarized in Table 1 and Figure 1. As illustrated in Table 1, Accent® in combination with 2,4-D or Banvel® and Beacon® in combination with 2,4-D will afford similar levels of hemp dogbane suppression or partial control. However, relatively poor control was recorded one year after treatment (YAT) indicating that regrowth from underground rootstocks is likely to occur. Figure 1 also illustrates that the addition of 2,4-D to either Accent® or Beacon® will provide higher levels of hemp dogbane suppression when compared to the addition of Banvel® to either of these herbicides. Suppression of hemp dogbane may also be achieved through postemergence applications of Roundup Ultra® to genetically engineered Roundup Ready® corn hybrids. Similarly, suppression of hemp dogbane may be achieved with Marksman®, or through applications of sulfonylurea herbicides other than Accent® in combination with 2,4-D or Banvel®.

CONTROL IN FORAGES

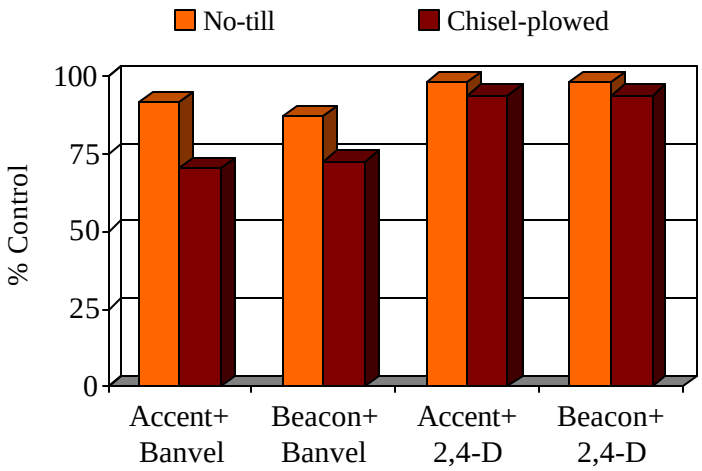
In pastures and hay fields, hemp dogbane represents a potential threat both as a weed capable of reducing yields and also as a poisonous plant to cattle, horses, and sheep. This weed may be poisonous whether green or dry, and only 15-30 grams of green leaves are required to kill one horse or cow (4). Crossbow® (a pre-package mix of 2,4-D and triclopyr) and Banvel® or Clarity® are two herbicides available for the suppression or partial control of hemp dogbane in grass pastures and hay fields. Each of these herbicides applied at the rate of 2 qts/acre should provide from 60 to 100% control of this weed. Additionally, 2,4-D in combination with lower rates of Banvel® or Clarity® will also provide suppression or partial control of this weed.

In established alfalfa stands, Gramoxone Extra (paraquat) at 3/4 pt/A applied post-cutting will provide suppression of this perennial weed. In forages with minor hemp dogbane infestations, spot treatments of a 2% Roundup Ultra solution (v/v) should be considered one of the most effective means of suppression or partial control, however all nearby treated foliage will also be killed.

CONTROL IN SOYBEANS

There are relatively few options available for the selective control of hemp dogbane in soybeans. Where appropriate, tillage to disrupt the perennial rootstock will greatly enhance the effectiveness of herbicide treatments. Diphenyl ether herbicides commonly used for the desiccation of perennial broadleaf weeds in soybeans such as Blazer®, Reflex®, and Cobra® are much less effective on hemp dogbane due to the extremely waxy leaf cuticle of this weed and associated inability of the herbicide to reach the leaf cell membrane. Therefore, partial control or suppression of hemp dogbane in soybeans is limited to the use of Roundup Ultra® in a Roundup Ready® soybean variety. Applications of Roundup Ultra® at the highest labeled rate to these genetically-engineered varieties coupled with the competitive effects of good soybean canopy closure should be considered one of the most effective means of hemp dogbane control.

Figure 1. Hemp dogbane control with POST corn herbicides at no-tillage and chisel-plowed sites (5).



Rates: 1/3 oz. Accent, 0.38 oz. Beacon, 1/2 pt. Banvel/Clarity, 1 pt. 2,4-D

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*The use of trade names in this publication does not imply endorsement of the product named or imply criticism of similar ones not mentioned.

Identification and Control of Mugwort (*Artemisia vulgaris*) in Virginia

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IDENTIFICATION

Perennial weed with persistent rhizomes that may be spread or transported by cultivation equipment or also in burlaped nursery stock infested with rhizomes. Leaves are 2 to 4 inches long, 1 to 3 inches wide, alternately arranged on the stem, deeply lobed, and have a distinctive aroma. Leaves on the upper portions of the plant are more deeply lobed and may lack petioles. Leaf undersides are covered with soft, white to gray hairs, while upper leaf surfaces may be smooth to slightly hairy. Stems may reach 5 feet in height and often become woody with age. Flowers are inconspicuous and occur in clusters at the top of the plant. The fruit is an achene that encloses the seed, however viable seed are rarely produced in North America (4).

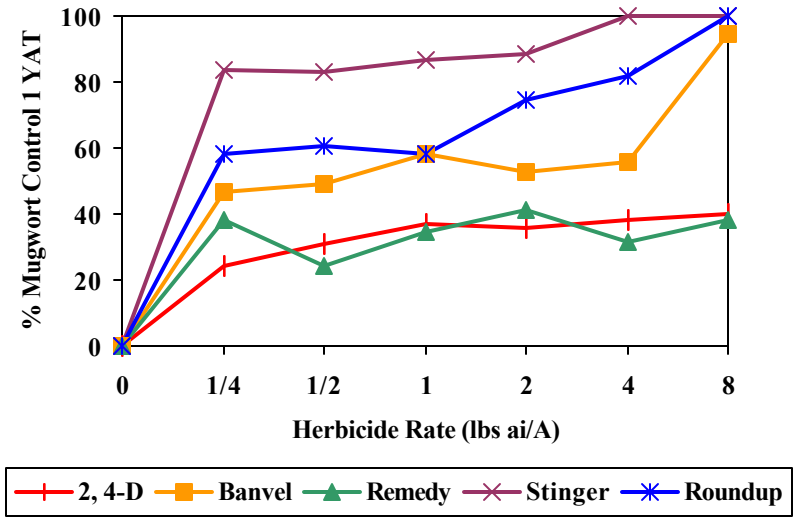
CONTROL IN CORN

Experiments conducted in no-till corn fields during 1995 and 1996 in Westmoreland County, Virginia revealed that relatively good mugwort suppression can be achieved with Stinger® and other pre-packaged herbicides that contain the active ingredient in Stinger® (2). As illustrated in Table 1, early postemergence applications of Stinger® provided greater than 70% mugwort control in 1995 and late postemergence applications of Stinger® provided greater than 70% mugwort control in 1996. In each of these years, the highest level of mugwort control was achieved when Stinger® was applied to mugwort that was approximately 8 to 10 inches in height. Additionally, the results from both years indicated that the addition of 2, 4-D to Stinger® treatments did not significantly improve mugwort control compared to Stinger® treatments alone. Similarly, the pre-packaged mix of Hornet® did not provide significantly higher levels of mugwort control than Stinger® alone.

Table 1 . Mugwort control in no-till corn with corn herbicides during 1995 and 1996 in Westmoreland County, Virginia (3).

		End of Season Mugwort Control (0-100%)					
		1995			1996		
Herbicide	Rate/A	PRE	E-Post	L-Post	PRE	E-Post	L-Post
2,4-D	1 pt	9	43	41	1	9	53
Stinger	1/3 pt	6	75	59	40	53	74
Stinger	2/3 pt	59	85	78	58	50	85
Hornet	4 ozs	10	66	64	4	43	78
Hornet + 2, 4-D	4 ozs + 1 pt	8	53	79	45	55	76
Stinger + 2, 4-D	1/3 pt + 1 pt	10	71	65	36	39	86
Stinger + 2, 4-D	2/3 pt + 1 pt	70	81	83	39	53	93
LSD (0.05): Herbicides:			12			8	
LSD (0.05) Timing:			9			7	

Figure 1 . **Mugwort Control at 1 Year After Treatment (1YAT) in Virginia Pastures During 1998 and 1999 (1).**



CONTROL IN SOYBEANS

Relatively few options are available for the selective control of mugwort in soybeans. Diphenyl ether herbicides such as Blazer®, Reflex®, and Cobra® should provide some suppression of mugwort via desiccation of foliage, but regrowth from underground rootstocks will occur. A more effective alternative for the control of mugwort in soybeans is the application of Roundup Ultra® to a genetically engineered Roundup Ready® soybean variety. The suppression afforded by the highest labeled rates of Roundup Ultra® coupled with the competitive effects of good soybean canopy closure should provide relatively good suppression of this weed.

CONTROL IN PASTURES AND HAYFIELDS

As illustrated in Figure 1, mugwort can be selectively removed from grass pastures and hayfields with either Stinger® or Banvel® (1). However, extremely high rates of Banvel® will be required to provide greater than 80% mugwort control at 1 year after treatment (YAT), whereas Stinger® will provide equivalent or higher levels of mugwort control at much lower application rates. These results also indicate that relatively high application rates of Roundup Ultra® will provide good mugwort control at 1 YAT in those situations where a nonselective herbicide may be applied. Additional experiments conducted in Virginia during 1998 and 1999 revealed that sequential treatments of certain herbicides made at 7 week intervals is also an effective mugwort control strategy (2). For example, three sequential treatments of 2, 4-D amine and 2, 4-D ester at 4 qts/A provided greater than 70% mugwort control at 1 year after treatment. Similar levels of mugwort control were also achieved with 2 sequential applications of Banvel® at 2 qts/A, and only 1 application of Stinger® at 2/3 pt/A was required to achieve even higher levels of control. Other experiments conducted in Virginia revealed that overall there was no significant difference in mugwort control when herbicides were applied to vegetative- vs. flowering-stage mugwort.

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Table 2 . Mugwort control at 1 year after treatment (YAT) following three sequential herbicide treatments during 1998 and 1999 (2).

		Treatment Regime [a]		
Treatment	Rate	1 Application	2 Applications	3 Applications
	product/A	% Control (0-100%) [b]		
2, 4-D Amine	4 qts	12	39	70
2, 4-D Ester	4 qts	17	46	73
Banvel/Clarity	2 qts	26	70	71
Remedy	2 qts	0	38	36
Stinger	2/3 pt	84	82	89
Ally	2/10 oz	33	48	49
Liberty	4 qts	22	49	58
Roundup Ultra	4 qts	63	54	76
Untreated	----	0	0	0
LSD (0.05): herbicide treatments (columns):				23
LSD(0.05): applications (rows):				12

[a] Indicates sequential herbicide applications made at 7-week intervals.
[b] Based on % reduction in shoot weight at 1YAT.

*The use of trade names in this publication does not imply endorsement of the product named or imply criticism of similar ones not mentioned.

Identification and Control of Annual Ryegrass (*Lolium multiflorum*) in No-Till Corn in Virginia

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Kevin W. Bradley, Post-Doctoral Research Associate, VPI and SU

Identification

Annual ryegrass is a winter annual grass found throughout the United States that may reach 3 ft in height. Stems are often tinged red at the base, and leaves are rolled in the bud with claw-like auricles in the collar region. Leaf blades are 2.5-8 in. long, 1/8-1/4 in. wide and have a membranous ligule. The seedhead is a 4-16 in. long spike with spikelets that have long awns arranged alternately up the stem. The plant has a fibrous root system.

Objectives

In Virginia, annual ryegrass has become one of the most troublesome and difficult to control weeds in small grains, as well as in corn and soybeans grown in rotation with small grains. Annual ryegrass control has declined due to the development of resistance to Hoelon, which has been the only treatment available for control in wheat and barley. Lack of control in small grains has allowed annual ryegrass to proliferate and become problematic in no-till corn establishment where high triazine herbicide rates or sequential applications of nonselective herbicides are frequently required for acceptable control. The use of Bladex has proven effective for annual ryegrass control in no-till corn establishment, and loss of registration of this compound severely limits control options in this crop. Experiments were initiated in 2000 to evaluate herbicide programs using transgenic corn hybrids for control of annual ryegrass in no-till establishment in comparison to traditional herbicide programs typically utilized in Virginia. Transgenic corn hybrids utilized included those with tolerance to Roundup, Liberty, Lightning, and Poast Plus.

Table 1. Effect of Sequential Herbicide Applications on Annual Ryegrass Control in No-till Corn in Virginia.

		Control of Annual Ryegrass[1]	
Herbicide	Rate/Acre	2 WAT[2]	8 WAT[3]
		---------- % ----------	
Roundup	1.5 pts	68	87
Roundup	3.0 pts	84	98
Roundup	1.5 pts + 1.5 pts	76	99
Liberty	20 ozs	8	8
Liberty	34 ozs	6	0
Liberty	20 ozs + 20 ozs	10	50
Poast Plus	1.5 pts	11	65
Poast Plus	2.25 pts	20	69
Poast Plus	1.5 pts + 1.5 pts	13	68
Lightning	1.28 ozs	4	49
Lightning	1.28 ozs + 1.28 ozs	4	35
Gramoxone	1.5 pts	83	47
Gramoxone	2.5 pts	88	55

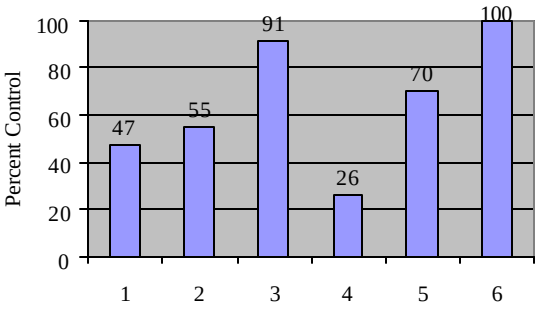
[1] Indicates visual ryegrass control (0-100%).
[2] WAT = weeks after treatment.
[3] Sequential treatment applied 6 weeks after initial treatment.

*The use of trade names in this publication does not imply endorsement of the product named or imply criticism of similar ones not mentioned.

Results

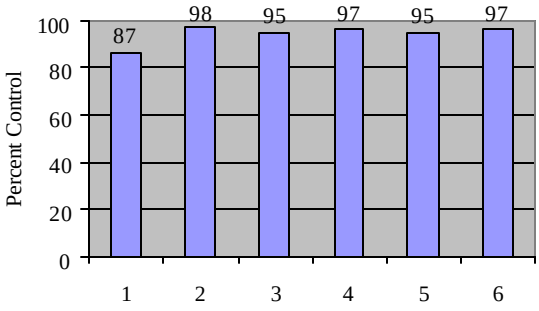
Evaluation of annual ryegrass control indicated that there was no advantage associated with the use of the Liberty, Lightning or Poast-Plus. Roundup applied alone at either 1.5 pints or 3.0 pints provided significantly higher levels of annual ryegrass control 8 weeks after treatment (WAT) than any of the other postemergence treatments applied alone, and provided excellent control with sequential early postemergence applications after corn emergence. The use of Gramoxone alone provided rapid desiccation of the above ground portion of the plant and adequate control levels 2 WAT. Due to lack of effects on roots, however, annual ryegrass regrowth occurred in subsequent weeks (Table 1). Gramoxone treatments applied in combination with atrazine with or without Bladex resulted in acceptable control 8 WAT (Figure 1). Gramoxone applied in combination with 1/2 oz Basis resulted in significantly decreased levels of control. Roundup applied alone at 3.0 pints or 1.5 pints in combination with atrazine with or without Bladex provided excellent ryegrass control. Roundup applied at 1.5 pints in combination with Basis also provided excellent ryegrass control (Figure 2). Results indicate that standard Roundup and Gramoxone treatments containing atrazine and Bladex continue to be very efficacious.

Figure 1. Annual Ryegrass Control 8 WAT with Gramoxone Treatments



1 = 1.5 pts Gramoxone
2 = 2.5 pts Gramoxone
3 = 1.5 pts Gramoxone + 3.0 pts Atrazine
4 = 1.5 pts Gramoxone + 1/2 oz Basis
5 = 1.5 pts Gramoxone + 3.0 pts Atrazine + 1/2 oz Basis
6 = 1.5 pts Gramoxone + 3.0 pts Atrazine + 2.0 pts Bladex

Figure 2. Annual Ryegrass Control 8 WAT with Roundup Treatments



1 = 1.5 pts Roundup
2 = 3.0 pts Roundup
3 = 1.5 pts Roundup + 3.0 pts Atrazine
4 = 1.5 pts Roundup + 1/2 oz Basis
5 = 1.5 pts Roundup + 3.0 pts Atrazine + 1/2 oz Basis
6 = 1.5 pts Roundup + 3.0 pts Atrazine + 2.0 pts Bladex

Conclusions

Results indicated that levels of annual ryegrass control similar to standard treatments containing Bladex can be realized through the use of Gramoxone + Atrazine or Roundup applied alone at 3.0 or 1.5 pints in combination with either atrazine or Basis. Gramoxone treatments in combination with Basis are not advisable. Initial annual ryegrass control (1 WAT, data not shown) was much lower in Roundup treatments compared to Gramoxone treatments, due to their respective modes of action. Therefore, chemical choice depends upon the growers anticipated time of planting. The use of Roundup-ready corn hybrids does appear to be advantageous due to the ability to apply postemergence treatments of Roundup after corn emergence for the control of annual ryegrass. The use of the other transgenic hybrids, however, does not seem to provide any potential benefit.

This research was conducted in cooperation with Randolph Aigner, Henrico Co. Va.; and Rueben L. Blaunton, Amelia Co. Va.

Control of Common Pasture and Hayfield Weeds in Virginia and West Virginia

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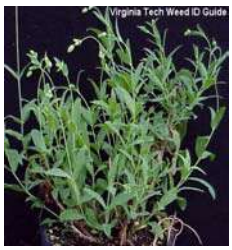
Horsenettle
Solanum carolinese

Spiny pigweed
Amaranthus spinosus

Canada thistle
Cirsium arvense



Bladder campion
Silene vulgaris

Stickweed
Verbesina occidentalis

Introduction

In Virginia and West Virginia, annual and perennial weed control in pastures and hayfields is an important aspect of successful forage management. This publication will discuss control measures for many of the common weeds found in Virginia and West Virginia permanent fescue and mixed fescue / bluegrass / orchardgrass pastures and hayfields. In mixed grass / legume pastures and hayfields, selective removal of many problematic weed species is often not possible as most legumes will be killed after applications of broadleaf herbicides. In mixed grass / legume pastures and hayfields, weed control can only be accomplished during establishment or renovation prior to seeding. Roundup or other glyphosate-containing products can provide control of most of the emerged grass and broadleaf weed species. Control of perennial weed regrowth or new weed flushes in newly established mixed grass / legume pastures and hayfields, however, is not possible. It is recommended that two years be allowed for the control of broadleaf weeds. Therefore, in fields where some of these weeds are expected to be problematic, reseed the grass but not the legume species for the first two years. After the weeds are under control, a legume species can then be planted.

Recently, the registration of two herbicides in Virginia and West Virginia has increased grower options for control of broadleaf weeds in pastures and hayfields. These two herbicides are Redeem R&P and Grazon P+D. Redeem R&P contains 2.25 and 0.75 lbs ai/gallon of triclopyr and clopyralid, respectively. Grazon P+D contains 0.24 and 2.0 lbs ai/gallon of picloram and 2,4-D, respectively. Grazon P+D is a restricted use herbicide and **is not labeled** for use in the West Virginia counties of Cabell, Jackson, Lincoln, Mason, Mineral, Putnam, Roane and Wirt. In Virginia, Grazon P+D **is labeled** in the counties shown in orange in Figure 1. These restrictions are due to the picloram content of Grazon P+D, which can cause injury to tobacco, tomatoes, grapes, and other sensitive broadleaf crops at very low concentrations. Because there are grazing and haying restrictions for both of these herbicides, be sure to follow label directions carefully.

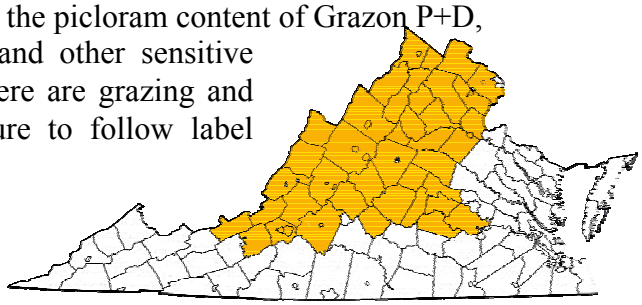


Figure 1.

Common Weeds and Their Control

Spiny pigweed: Spiny pigweed is a summer annual that is very similar in appearance to other pigweed species, but has spines along the stems. Spiny pigweed is primarily a weed of pastures and hayfields, and occurs less often in agronomic crops. Control of spiny pigweed is most effective when the plant is less than 2 inches tall. At this stage, spiny pigweed can be controlled with any of the herbicides listed in Table 1. However, control of spiny pigweed becomes more difficult as the size of the plant increases. The treatments described in Table 1 were applied to 6 to 8 inch spiny pigweed plants.

Table 1. **Spiny pigweed Control**

Herbicide	Rate	2 WAT	8 WAT
	product/acre	---------- % Visual Control ----------	
Redeem R&P + Ally	1.0 pt + 0.2 oz	53 b	69 b
Redeem R&P + Ally	1.5 pt + 0.2 oz	62 a	82 ab
Redeem R&P + Ally	1.5 pt + 0.1 oz	60 ab	78 ab
Redeem R&P + Ally	2.0 pt + 0.2 oz	62 a	80 ab
Redeem R&P	2.0 pt	18 c	18 cd
Ally	0.1 oz	52 b	57 b
Ally	0.2 oz	60 a	87 a
Ally	0.3 oz	67 a	90 a
2,4-D + Ally	2 pt + 0.2 oz	67 a	85 ab
Pastureguard + Ally	2 pt + 0.2 oz	65 a	85 ab
Grazon P + D + Ally	2 pt + 0.2 oz	60 ab	87 a
Weedmaster	2 pt + 0.2 oz	28 c	28 c
Untreated	----	0 d	0 d
LSD (0.05)		10	18

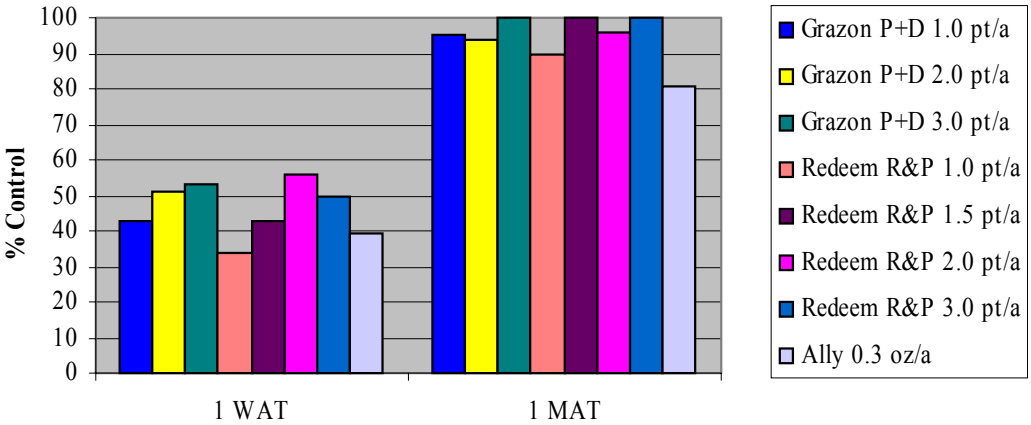
* Ally and Redeem applied with 0.5% v/v non-ionic surfactant

As illustrated in Table 1, at least 80% spiny pigweed control was achieved at 8 weeks after treatment (WAT) with 0.2 oz per acre of Ally in combination with 1.5 pints (pt) of Redeem R&P, 2 pt of 2,4-D, 2 pt of Grazon P+D, or 2 pt of Pastureguard. Ally, however, applied alone at 0.2 oz per acre controlled spiny pigweed 87% at 8 WAT. Redeem R&P applied alone at 2 pt per acre provided only 18% control at 8 WAT.

Canada thistle: Canada thistle is a perennial weed that spreads via rhizomes which grow 2 to 6 feet deep, and is a persistent weed of many pastures and hayfields. Both Grazon P+D and Redeem R&P controlled Canada thistle greater than 90% at 1 month after treatment (MAT) with rates of 1 pt per acre or greater (Figure 2). Ally, however, applied at 0.3 oz per acre controlled Canada thistle only 81% at 1 MAT. Grazon P+D and Redeem R&P are also effective for the control of other thistle species such as bull and musk thistle. For superior control of Canada thistle, herbicide treatments should be applied when plants are in the prebloom to early bloom stage of growth. For bull and musk thistle, treatments should be made when plants are in the rosette stage of growth.

Combinations of 2,4-D and Banvel provide approximately the same level of control of Canada thistle as Ally. Better long-term control of Canada thistle, however, is possible with Grazon P+D and Redeem R&P in comparison to other herbicides.

Figure 2. Canada Thistle Control

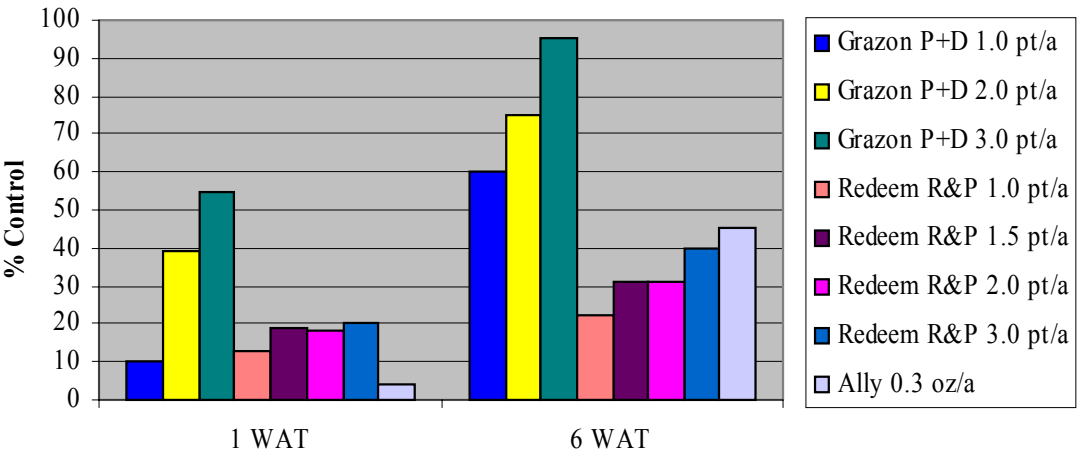


The combination of Redeem R&P and Ally would be very effective when pastures and hayfields contain infestations of both spiny pigweed and Canada thistle because of the control of Canada thistle provided by Redeem R&P (Figure 2), and the control of spiny pigweed afforded by Ally (Table 1).

Horsenettle: Horsenettle is an erect, perennial, broadleaf weed prevalent in pastures, meadows, and hayfields of Virginia and West Virginia. This weed is characterized by conspicuous spines that make it undesirable for consumption by cattle and other grazing animals. Horsenettle can reproduce from seeds that can persist in dry berries found in hay and from rhizomes or adventitious shoots that emerge from the creeping roots. A single plant can produce up to 5000 seeds. Therefore this persistent plant can take over entire fields if not managed.

In research conducted in Virginia, Grazon P+D at 3 pt per acre controlled horsenettle 95% at 6 WAT (Figure 3). Similar results have been observed in West Virginia where 2 to 3 pt of Grazon P+D applied to horsenettle at the prebloom to bloom stage provided control between 80 and 90%. Previously, horsenettle control at this level has not been economically feasible in Virginia and West Virginia because of the high rates necessary to achieve control with the other available herbicides.

Figure 3. Horsenettle Control in Virginia 2002



Redeem R&P and Ally applied at 3 pt and 0.3 oz per acre, respectively, provided less than 50% control of horsenettle at 6 WAT.

Stickweed: Stickweed, also known as yellow crownbeard, is a perennial weed that may reach as much as 13 feet in height. Mature plants have showy yellow flowers and 'wings' that run along the length of the stem. Stickweed is a weed of pastures, hayfields, fencerows, roadsides, and rights-of-way.

Stickweed was controlled 93% and 83% in 2001 and 2002, respectively, with 2 pt per acre of Grazon P+D (Table 2). However, at least 3 pt of Redeem R&P per acre were required to achieve this same level of stickweed control.

Table 2. **Stickweed Control**

Herbicide[a]	Rate/A	2001	2002
		-------- % Visual Control 5 MAT [b]---------	
2, 4-D Ester	1 qt	80	76
2, 4-D Ester + Banvel	1 qt + 1 pt	67	83
Banvel	1 pt	45	38
Grazon P+D	1 pt	60	64
Grazon P+D	2 pt	93	83
Grazon P+D	3 pt	97	93
Grazon P+D	4 pt	100	96
Redeem R&P [c]	1.5 pt	63	55
Redeem R&P [c]	2 pt	75	74
Redeem R&P [c]	3 pt	90	83
Redeem R&P [c]	4 pt	88	88
Ally [c]	0.3 oz	45	2
Crossbow	2 qts	67	76
Untreated	----	0	0
LSD (0.05)		16	13

[a] Applications made to stickweed ranging from 4 to 12 inches in height.
[b] 5 MAT = months after treatment
[c] Applied with non-ionic surfactant at 0.50% (v/v).

Stickweed control with 4 Pt Grazon P+D: 2 MAT

Stickweed Continued: Crossbow, 2,4-D alone, or 2,4-D in combination with Banvel generally controlled stickweed between 67 and 83%. Banvel alone or Ally, however, resulted in less than 50% stickweed control.

Wild carrot, Broadleaf and Buckhorn plantain, Poison-ivy and Bladder campion: These biennial and perennial weeds are often common, difficult to control weeds in pastures and hayfields in Virginia and West Virginia. One quart of 2,4-D alone or in combination with Banvel controlled both plantain species greater than 90% (Table 3). The other weed species in Table 3, however, were not adequately controlled with 2,4-D alone or in combination with Banvel. Effective control of wild carrot and the two plantain species was accomplished with Grazon P+D and Redeem R&P at rates of 2 to 4 pints per acre and 3 to 4 pt per acre, respectively. Poison-ivy control of 70% or greater was provided by: 2,4-D in combination with Banvel, 3 to 4 pt per acre of Grazon P+D, and 4 pt per acre of Redeem R&P.

Bladder campion, which is becoming more prevalent in Virginia, is a very difficult to control weed in pastures and hayfields. The highest level of control of bladder campion was observed with 0.3 oz of Ally per acre. Bladder campion control with Ally, however, was only 66%. The use of the other herbicides typically resulted in 59% or less control.

Table 3. **Biennial and Perennial Weed Control**

Treatment	Rate product/A	Weed Species: Wild carrot	Broadleaf plantain	Buckhorn plantain	Poison-ivy	Bladder campion
		% Control (End of Season)				
2, 4-D Amine	1 qt	59 c	94 ab	95 a	16 e	8 hi
Banvel	1 pt	30 d	36 c	38 c	20 e	9 ghi
2, 4-D + Banvel	1 qt + 1 pt	61 c	96 ab	96 a	71 ab	19 efg
Grazon P+D	1 pt	73 bc	93 ab	93 a	15 e	14 fgh
Grazon P+D	2 pt	100 a	100 a	100 a	41 d	34 cd
Grazon P+D	3 pt	100 a	98 a	100 a	75 ab	35 bcd
Grazon P+D	4 pt	99 a	99 a	99 a	83 a	59 a
Redeem R & P[a]	1.5 pt	70 bc	46 c	48 b	28 e	24 def
Redeem R & P[a]	2 pt	80 b	85 b	91 a	25 e	33 cd
Redeem R & P[a]	3 pt	100 a	91 ab	95 a	53 cd	35 bcd
Redeem R & P[a]	4 pt	100 a	96 ab	98 a	71 ab	41 bc
Crossbow	2 qt	70 bc	94 ab	93 a	61 bc	43 bc
Ally[a]	0.3 oz	70 bc	90 ab	90 a	18 e	66 a
Untreated	----	0 g	0 d	0 d	0 f	0 I
LSD (0.05):	----	13	11	9	13	10

[a]Applied with non-ionic surfactant at 0.5% v/v.

Conclusions: Most of the weeds discussed in this publication are difficult to control in pasture and hayfield situations. Superior control of certain weeds often requires a specific herbicide choice. Care must be taken to match the weed species and weed size with the herbicide and rate needed for effective control. Repeat applications are often necessary to provide long-term control of some of these weed species. Weed control with herbicides alone often results in reinfestation of the pasture or hayfield. Long-term weed control must utilize herbicides in combination with a healthy, dense forage that can successfully compete with the weeds of pastures and hayfields. Please utilize your state's Extension Service if you have any concerns, and feel free to consult Virginia Tech's on-line weed ID site to help in the correct identification of a particular weed species.

The Virginia Tech Weed ID website is located at: http://www.ppws.vt.edu/weedindex.htm

Control of Undesirable Woody Species in Pastures and Hayfields

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Buckbrush

Southern Dewberry

Eastern Red Cedar

Yucca

Black Hawthorn

Multiflora Rose

Autumn Olive

Introduction: The registration of Grazon P+D in selected regions of the Mid-Atlantic United States and national registration of Remedy has allowed growers to effectively and economically control most annual, biennial, and herbaceous perennial broadleaf weeds in pastures and hayfields. Growers, however, continue to request information regarding control of various undesirable woody species in pastures and hayfields. Control recommendations for woody species that are most commonly requested include: buckbrush (*Symphoricarpus orbiculatus*), black hawthorn (*Crataegus douglasii*), autumn olive (*Elaeagnus umbellata*), multiflora rose (*Rosa multiflora*), eastern red cedar (*Juniperus virginiana*), southern dewberry (*Rubus trivialis*), and yucca (*Yucca filamentosa*). Presently, there is little information regarding the control of these woody species with Grazon P+D and Remedy.

Dow Agrosciences LLC has recently began evaluating two additional experimental herbicide combinations for the control of broadleaf weeds in pastures and hayfields. These two herbicides combinations are Surmount, which contains 0.67 plus 0.67 lbs ae/gallon[1] of picloram and fluroxypyr, respectively, and Pasturegard, which contains 1.5 plus 0.5 lb ae/gallon of triclopyr and fluroxypyr, respectively. Grazon P+D contains 0.54 and 2.0 lbs ai/gallon of picloram and 2,4-D, respectively. In Virginia, Grazon P+D **is labeled** in the counties shown in orange in Figure 1. These restrictions are due to the picloram content of Grazon P+D, which can cause injury to tobacco, tomatoes, grapes, and other sensitive broadleaf crops at very low concentrations. Remedy contains 4.0 lbs ai/gallon of triclopyr.

The objective of these experiments was to evaluate control measures for many of the common woody weed species found in Virginia's permanent fescue and mixed fescue / bluegrass /orchardgrass pastures and hayfields

Materials and Methods: All experiments were conducted in randomized complete block designs at multiple sites throughout Virginia. Most experiments contained treatments of various rates of registered and experimental Dow Agrosciences products compared to other registered pasture and hayfield herbicides. Yucca experiments evaluated non-selective herbicides for pasture and hayfield renovation. Treatments and rates varied between experiments.

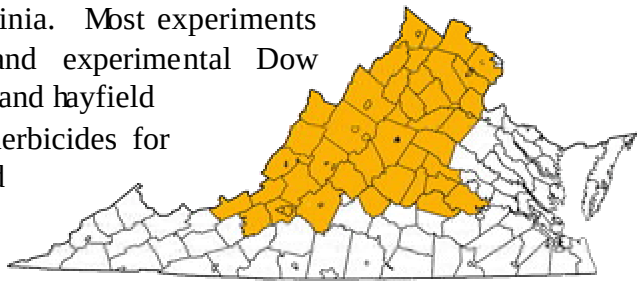


Figure 1.

[1] Abbreviation: ae/gallon, acid equivalent per gallon

Common Woody Weeds and Their Control

Buckbrush: Buckbrush, also referred to as coralberry or devil's shoestring, is a low-growing (1.5-6.0 ft tall) perennial shrub with rhizomes and distinctive red berries that persist well into the winter. Young plants are relatively tender, but become woody with age. Buckbrush is a very common and difficult-to-control weed of pastures, hayfields, and roadsides that is found primarily in the mountainous regions of Virginia. Control of buckbrush is most effective when the plant is young and has not yet become woody. The treatments described in Table 1 were applied to 8 to 16 inch buckbrush plants.

Table 1. **Buckbrush Control**

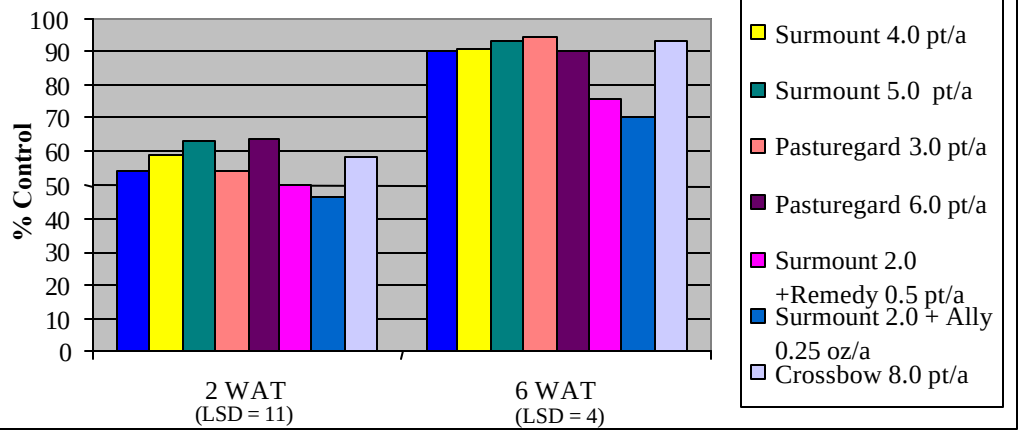
Herbicide	Rate	1 MAT	3.5 MAT
	product / acre	-------- % Visual Control ---------	
Grazon P + D	2.0 pt	55	75
Grazon P + D	3.0 pt	75	88
Remedy	1.0 pt	70	65
Grazon P + D + Remedy	2.0 pt + 1.0 pt	62	93
Grazon P + D + Remedy	3.0 pt + 1.0 pt	82	97
2,4-D amine	2.0 pt	48	73
2,4-D amine	4.0 pt	88	97
Cimmaron	0.3 oz	35	75
Cimmaron + Weedmaster	0.3 oz + 2.0 pt	70	92
LSD (0.05)		15	10

* Treated May 28th 2003; all treatments except 2,4-D applied with Activator 90 at 0.25 % (v / v)
Abbreviation: MAT, months after treatment

As illustrated in Table 1, buckbrush was controlled 75, 70, 82 and 88% with 3.0 pts of Grazon P+D, 1.0 pt of Remedy, 3.0 pts. of Grazon P+D plus 1.0 pt of Remedy, and with 4.0 pts of 2,4-D, respectively, at 1 month after treatment (MAT). Buckbrush control of 97% at 3.5 MAT was attained with 3.0 pts of Grazon P+D plus 1.0 pt of Remedy, and was equivalent to control with 4.0 pts of 2,4-D alone.

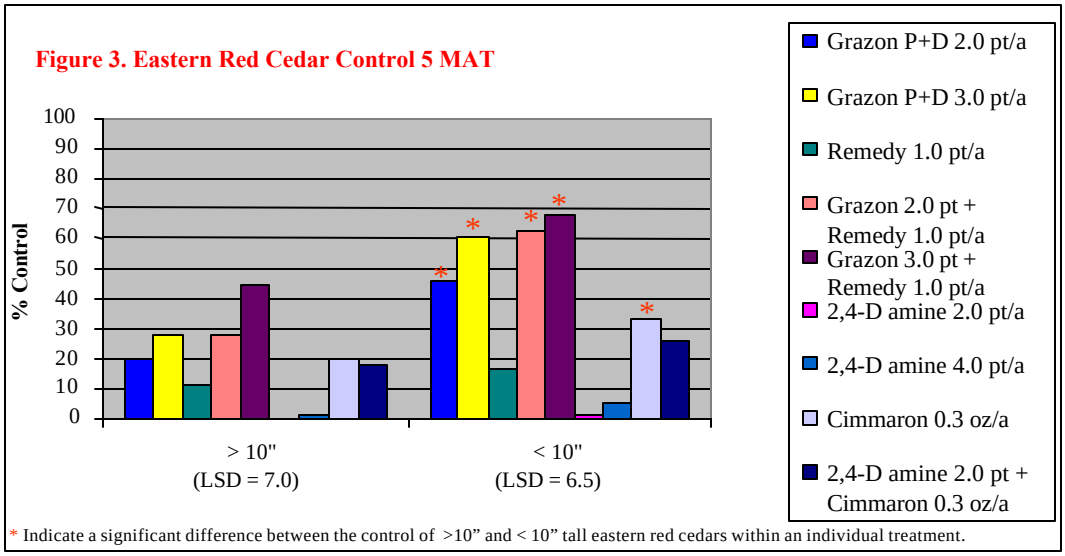
Southern Dewberry: Southern dewberry, which is a Rubus species, is a rhizomatous erect perennial with prickly trailing stems that produces one inch long black berries. Other similar Rubus species include raspberries and blackberries. Generally, Rubus species are referred to with the generic term "brambles" because of the similarity between species, and all species are relatively difficult to control. At 2 weeks after treatment (WAT), all treatments controlled southern dewberry greater than 50% except the Surmount treatments applied in combination with either Remedy or Ally, which only controlled southern dewberry 50 and 46%, respectively (Figure 2). At 6 WAT, southern dewberry was controlled 90% or greater with 3, 4, and 5 pints of Surmount, however, 6 pints of Pasturegard or 8 pints of Crossbow were required for equivalent control. The treatments of 2 pints of Surmount in combination with Remedy or Ally did not provide acceptable southern dewberry control. Similar levels of control of other rubus species are expected with these treatments, however, confirmation with additional experiments is needed. For superior control of rubus species, herbicide treatments should be applied when plants are in the prebloom to early bloom stage of growth.

Figure 2. Dewberry Control



Eastern Red Cedar: Eastern red cedar is a tree that can reach up to 100 feet in height and have a trunk diameter of 5 feet. Small (< 15 feet tall) eastern red cedars are a prevalent weed in pastures in Virginia. This tree is fast growing, rapidly spread, and very difficult to control. Effective control can only be achieved with spot treatment of growth regulator herbicides or through mechanical removal of all green tissue above the soil surface. These processes, however, are expensive and very labor intensive. Therefore experiments were conducted to evaluate broadcast treatments for the control of eastern red cedar. Results, however, indicated the eastern red cedar control was generally ineffective with all treatments evaluated (Figure 3). Small red cedars (<10") were controlled less than 70% at 5 MAT with 3 pints of Grazon P+D plus 1 pint of Remedy, which was the treatment that provided the highest level of control. Significantly higher levels of eastern red cedar control occurred with 5 of the 9 treatments applied to <10" tall eastern red cedars compared with >10" tall eastern red cedars. However, all of these eastern red cedars are expected to recover, and larger cedars (>10") were controlled less than 50% with all treatments. These herbicides were applied as broadcast treatments at 22.5 gallons per acre (GPA). It may be possible to increase control by increasing the GPA of the sprayer output, which would provide better coverage of the eastern red cedar trees. This theory will be investigated in subsequent experiments.

Figure 3. Eastern Red Cedar Control 5 MAT



* Indicate a significant difference between the control of >10" and < 10" tall eastern red cedars within an individual treatment.

Yucca: Yucca, also known as bear-grass, is a perennial weed that may reach 5 feet in height with thick underground rootstocks. Yucca is becoming more common in many of Virginia's pastures. Previous experiments by the authors evaluated various treatments for the control of yucca in hayfields. Subsequent experiments were then designed using herbicides that afforded the best control. These herbicides were applied broadcast as renovation treatments.

Table 2. **Yucca Control**

Herbicide	Rate / A	8 WAT	15 WAT
		---------- % Visual Control ----------	
Roundup	6 qt	48	54
Reward	1 qt	0	0
Roundup + Ally	6 qt + 0.75 oz	69	65
Reward + Ally	1 qt + 0.75 oz	63	63
LSD (0.05)		16	13

* All treatments applied with Cide-kick at 1.0% (v / v).

Check Roundup Reward Roundup + Ally Reward + Ally

Yucca continued: The treatments evaluated consisted of Roundup Ultra alone and Reward alone, and Roundup Ultra and Reward in combination with Ally. At 8 WAT, 48% yucca control occurred with 6 quarts of Roundup Ultra compared to zero percent control with Reward (Table 2). No difference in control occurred between Roundup Ultra or Reward when either was combined with 0.75 oz of Ally per acre. Control of yucca, however, was still less than 70% with these treatments at both rating timings. No significant difference in the level of control between evaluation timings occurred within an individual herbicide treatment. These results indicate that broadcast applications of these herbicides are not effective in the control of yucca. Previous research has indicated that effective control can be achieved with a 2% solution of Remedy in diesel fuel applied as a spot treatment.

Black Hawthorn, Multiflora Rose, and Autumn Olive: These perennial weeds are common, difficult to control weeds in pastures and hayfields in Virginia. Excellent (95-100%) control of black hawthorn and multiflora rose was observed with all treatments at 4 MAT (Table 3). These treatments included Surmount or Pasturegard applied at 1.0 and 2.0% volume to volume (v/v), Crossbow at 1.5% v/v, Grazon P+D at 1.0% v/v plus Remedy at 0.5% v/v, and 1 ounce of Ally applied per 100 gallons of water. Similar levels of control with most of these treatments occurred when applied to autumn olive, however, Ally applied at 1 ounce per 100 gallons of water controlled autumn olive only 30%.

Table 3. **Black Hawthorn, Multiflora Rose, and Autumn Olive Control**

		Weed Species				
		Black Hawthorn		Multiflora Rose		Autumn Olive
Treatment	Rate % Solution (v/v)	1 MAT	4 MAT	1 MAT	4 MAT	7 WAT
		% Control				
Surmount	1.0%	75	100	100	100	100
Surmount	2.0%	93	100	100	100	99
Pasturegard	1.0%	70	100	100	100	99
Pasturegard	2.0%	89	100	100	100	100
Crossbow	1.5%	53	100	100	100	99
Grazon P+D + Remedy	1.0% 0.5%	41	100	100	100	100
Ally	1 oz / 100 gal	95	100	95	100	30
LSD (0.05):	----	14	0	3	0	4

* All treatments applied with Activator 90 at 0.25% v/v.

Conclusion: Most of the weeds discussed in this publication are difficult to control in pasture and hayfield situations. Superior control of certain weeds often requires a specific herbicide choice. Care must be taken to match the weed species and weed size with the herbicide and rate needed for effective control. Repeat applications are often necessary to provide long-term control of some of these weed species. Weed control with herbicides alone often results in reinfestation of the pasture or hayfield. Long-term weed control must utilize herbicides in combination with a healthy, dense forage that can successfully compete with the weeds of pastures and hayfields. Please utilize your state's Extension Service if you have any concerns, and feel free to consult Virginia Tech's on-line weed ID site to help in the correct identification of a particular weed species.

The Virginia Tech Weed ID website is located at: http://www.ppws.vt.edu/weedindex.htm

Virginia Tech Weed Identification Guide

Select a Resource...

Aquatic Weeds:

Common Name	Scientific Name
Alligatorweed	*Alternanthera philoxeroides*
American Elder	*Sambucus canadensis*
American Speedwell	*Veronica americana*
American Water Plantain	*Alisma subcordatum*
American Water Willow	*Justicia americana*
Arrowhead, Long-beaked	*Sagittaria australis*
Arrow-leaved Tearthumb	*Polygonum sagittatum*
Asian Dayflower	*Murdannia keisak*
Asian Spiderwort	*Murdannia keisak*
Bladderworts	*Utricularia* spp.
Brazilian Elodea	*Egeria densa*
Brittleleaf Naiad	*Najas minor*
Cattails	*Typha spp.*
Chara	*Chara* spp.
Common Reed	*Phragmites australis*
Coontail	*Ceratophyllum demersum*
Creeping Primrose	*Ludwigia palustris*
Creeping Rush	*Juncus repens*
Curlyleaf Pondweed	*Potamogeton crispus*
Dayflower, Asian	*Murdannia keisak*

Dayflower, Marsh	*Murdannia keisak*
Duckweeds	*Lemna* spp.
Egeria	*Egeria densa*
Elderberry	*Sambucus canadensis*
Eurasian Watermilfoil	*Myriophyllum spicatum*
Hornwort	*Ceratophyllum demersum*
Lizard's Tail	*Saururus cernuus*
Musk-grass	*Chara* spp.
Naiad, Brittleleaf	*Najas minor*
Pennywort, Marsh	*Hydrocotyle umbellata*
Pickerelweed	*Pontederia cordata*
Pondweed, Curlyleaf	*Potamogeton crispus*
Pondweed, Slender	*Potamogeton pusillus*
Pondweed, Variable-leaf	*Potamogeton diversifolius*
Slender Naiad	*Najas minor*
Slender Pondweed	*Potamogeton pusillus*
Spiderwort, Asian	*Murdannia keisak*
Stonewort	*Chara* spp.
Tearthumb, Arrow-leaved	*Polygonum sagittatum*
Tearthumb	*Polygonum arifolium*
Variable-leaf Pondweed	*Potamogeton diversifolius*
Water Hyacinth	*Eichhornia crassipes*
Waterthread Pondweed	*Potamogeton diversifolius*
Waterlilies	*Nymphaea* spp.
Watermeal	*Wolffia* spp.
Watershield	*Brasenia schreberi*
Waterpurslane	*Ludwigia palustris*

Water-starwort *Callitriche heterophylla*

Water Willow *Justicia americana*

Virginia Cooperative Extension

Knowledge for the CommonWealth

Weed I.D. References

Title	Authors	©, Publisher
Weeds of The Northeast	Richard H. Uva Joseph C. Neal Joseph M. DiTomaso	Copyright © 1997 by Cornell University.
SWSS Weed Identification Guide	Various authors	Published by the Southern Weed Science Society.
Manual of the Vascular Flora of the Carolinas	Albert E. Radford Harry E. Ahles C. Ritchie Bell	Copyright © 1964, 1968 by The University of North Carolina Press, Chapel Hill.
An Illustrated Flora of the Northern United States and Canada	Nathaniel L. Brittain Hon. Addison Brown	2nd Edition Published in 1970 by Dover Publications, Inc., NY.
Weeds of the West	Tom D. Whitson Larry C. Burrill Steven A. Dewey David W. Cudney B.E. Nelson Richard D. Lee Robert Parker	5th Edition Published in 1996 by the Western Society of Weed Science in cooperation with the Western United States Land Grant Universities Cooperative Extension Services.
Identifying Seedling and Mature Weeds Common in the Southeastern United States	Jon M. Stucky Thomas J. Monaco A.D. Worsham	Copyright © 1994 by The North Carolina Agricultrual Research Service and the North Carolina Cooperative Extension Service.

Home

Virginia Tech Weed Identification Guide

Select a Resource...

Scientific Name Index:

A

Abutilon theophrasti	Velvetleaf, Buttonweed
Acalypha ostryifolia	Hophornbeam Copperleaf
Acalypha virginica	VA Copperleaf, Three-seeded Mercury
Achillea millefolium	Common Yarrow, Yarrow
Ailanthus altissima	Tree-of-Heaven, Paradise Tree
Albizia julibrissin	Mimosa, Silktree
Alisma subcordatum	American Water Plantain
Allaria petiolata	Garlic Mustard
Allium vineale	Wild Garlic
Alternanthera philoxeroides	Alligatorweed
Amaranthus blitoides	Prostrate Pigweed, Prostrate Amaranth
Amaranthus hybridus	Smooth Pigweed
Amaranthus palmeri	Palmer Amaranth
Amaranthus retroflexus	Redroot Pigweed
Amaranthus spinosus	Spiny Amaranth, Spiny Pigweed
Ambrosia artemisiifolia	Common Ragweed, Ragweed

Ambrosia trifida	Giant Ragweed
Ampelamus albidus	Honeyvine or Climbing Milkweed
Anagallis arvensis	Scarlet Pimpernel
Andropogon virginicus	Broomsedge
Anoda cristata	Spurred Anoda
Anthemis cotula	Mayweed Chamomile
Anthoxanthum odoratum	Sweet Vernalgrass
Apocynum cannabinum	Hemp Dogbane
Arabidopsis thaliana	Mouse-ear Cress
Arctium minus	Common Burdock
Arrhenatherum elatius var. bulbosa	Bulbous Oatgrass
Artemisia vulgaris	Mugwort, Wild Chrysanthemum
Arthraxon hispidus	Jointhead Arthraxon
Asclepias incarnata	Swamp Milkweed
Asclepias syriaca	Common Milkweed, Milkweed
Asclepias tuberosa	Butterfly Milkweed, Butterfly Weed
Aster pilosus	White Heath Aster

B

Barbarea vulgaris	Yellow Rocket
Bidens bipinnata	Spanishneedles
Bidens frondosa	Devils Beggarticks, Stick-Tights
Bidens polylepis	Coreopsis Beggarticks, Beggarticks

Bignonia capreolata	Crossvine
Brachiaria platyphylla	Broadleaf Signalgrass
Brachiaria ramosa	Browntop Millet
Brasenia schreberi	Watershield
Brassica kaber	Wild Mustard
Bromus tectorum	Downy Brome
Brunnichia ovata	Redvine

C

Calamintha nepeta	Calamint
Calepina irregularis	Calepina
Callitriche heterophylla	Water-starwort
Calystegia sepium	Hedge Bindweed
Campsis radicans	Trumpetcreeper, Cow-Itch
Cannabis sativa	Marijuana
Capsella bursa-pastoris	Shepherd's-purse
Cardamine hirsuta	Hairy Bittercress
Cardiospermum halicacabum	Balloonvine
Carduus acanthoides	Plumeless Thistle
Carduus nutans	Musk Thistle, Nodding Thistle
Cassia fasciculata	Partridgepea
Cassia obtusifolius	Sicklepod
Cassia occidentalis	Coffee Senna
Cenchrus longispinus	Longspine Sandbur

Centaurea cyanus	Cornflower, Bachelor's Buttons
Centaurea maculosa	Spotted Knapweed, Star Thistle
Cerastium vulgatum	Mouseear Chickweed
Ceratophyllum demersum	Coontain, Hornwort
Chara spp.	Chara, Musk-grass, Stonewort
Chenopodium album	Common Lambsquarters
Chrysanthemum leucanthemum	Oxeye Daisy
Cichorium intybus	Chicory
Cirsium altissimum	Tall Thistle
Cirsium arvense	Canada Thistle
Cirsium vulgare	Bull Thistle
Commelina communis	Asiatic or Common Dayflower
Conium maculatum	Poison Hemlock
Conopholis americana	Squaw-root, Cancer-root
Convolvulus arvensis	Field Bindweed
Conyza canadensis	Horseweed, Marestail
Coronilla varia	Crownvetch, Trailing Crownvetch
Crepis capillaris	Smooth Hawksbeard
Crotalaria spectabilis	Showy Crotalaria
Croton glandulosus	Tropic Croton
Cuscuta spp.	Dodder
Cynodon dactylon	Bermudagrass, Wire Grass
Cyperus esculentus	Yellow Nutsedge or Nut-grass, Chufa
Cyperus iria	Rice Flatsedge

Cyperus rotundus	Purple Nutsedge or Nut-grass, Chufa

D

Dactyloctenium aegyptium	Crowfootgrass
Datura stramonium	Jimsonweed
Daucus carota	Wild Carrot, Queen Anne's Lace
Delphinium tricorne	Dwarf Larkspur
Desmodium tortuosum	Florida Beggarweed
Desmodium viridiflorum	Tick Trefoil
Dianthus armeria	Deptford Pink
Dicentra cucullaria	Dutchman's Breeches
Dichanthelium clandestinum	Deer-tongue Grass
Dichondra repens	Dichondra
Digitaria ischaemum	Smooth Crabgrass
Digitaria sanguinalis	Large Crabgrass, Hairy Crabgrass
Diodia teres	Poorjoe, Common Buttonweed
Diodia virginiana	Virginia Buttonweed
Dioscorea batatas	Cinnamon Vine, Chinese Yam
Dipsacus fullonum	Common Teasel
Duchesnea indica	Indian Mock-Strawberry

E

Echinochloa crus-galli	Barnyardgrass

Echium vulgare	Viper's Blugoss, Blueweed
Eclipta prostrata	Eclipta, Yerba-de-Tago
Egeria densa	Brazilian Elodea
Eichhornia crassipes	Water Hyacinth
Elaeagnus umbellata	Autumn Olive
Eleusine indica	Goosegrass
Elytrigia repens	Quackgrass
Eragrostis cilianensis	Stinkgrass
Eragrostis spectabilis	Purple Lovegrass
Erechtites hieracifolia	Fireweed, American Burnweed
Eremochloa ophiuroides	Centipedegrass
Erigeron annuus	Annual Fleabane, Daisy Fleabane
Erodium cicutarium	Redstem Filaree, Filaree
Eupatorium capillifolium	Dogfennel
Euphorbia cyparissias	Cypress Spurge
Euphorbia dentata	Toothed Spurge, Wild Poinsetta
Euphorbia helioscopia	Sun Spurge
Euphorbia lathyris	Caper Spurge, Mole Plant
Euphorbia maculata	Spotted Spurge

G

Galinsoga ciliata	Hairy Galinsoga
Galium mollugo	Smooth Bedstraw
Geranium carolinianum	Carolina Geranium, Crane's-bill

Geranium dissectum	Cutleaf Geranium
Geum canadense	White Avens
Glechoma hederacea	Ground Ivy, Creeping Charlie
Gnaphalium purpureum	Purple Cudweed

H

Helianthus tuberosus	Jerusalem Artichoke
Hesperis matronalis	Dame's Rocket
Hibiscus trionum	Venice Mallow
Hieracium pilosella	Mouseear Hawkweed
Hordeum pusillum	Little Barley
Humulus japonicus	Japanese Hops
Hydrocotyle umbellata	Marsh Pennywort
Hypericum perforatum	Common St. Johnswort
Hypochoeris radicata	Common Catsear

I

Impatiens capensis	Touch-me-not, Jewelweed
Ipomoea coccinea	Red Morningglory
Ipomoea cordatotriloba var. *torreyana*	Cotton Morningglory
Ipomoea hederacea	Ivyleaf Morningglroy
Ipomoea hederacea var. *integriuscula*	Entireleaf Morningglory

Ipomoea lacunosa	Pitted Morningglory
Ipomoea pandurata	Bigroot Morningglory
Ipomoea purpurea	Tall Morningglory
Ipomoea quamoclit	Cypressvine Morningglory
Ipomoea wrightii	Palmleaf Morningglory

J

Jacquemontia tamnifolia	Smallflower Morningglory
Juncus repens	Creeping Rush
Justicia americana	American Water Willow, Water Willow

K

Kochia scoparia	Kochia
Krigia caespitosa	Dwarf Dandelion
Krigia oppositifolia	Dwarf Dandelion
Kyllinga brevifolia	Green Kyllinga

L

Lactuca serriola	Prickly Lettuce
Lamium amplexicaule	Henbit
Lamium purpureum	Purple Deadnettle
Lathyrus latifolius	Sweat Pea, Everlasting Pea

Lemna spp.	Duckweed
Lepidium campestre	Field Pepperweed
Lepidium virginicum	Virginia Pepperweed
Lespedeza cuneata	Sericea Lespedeza
Lespedeza striata	Common Lespedeza, Japanese Clover
Linaria canadensis	Common Toadflax
Lolium multiflorum	Italian Ryegrass
Lonicera japonica	Japanese Honeysuckle
Lonicera morrowii	Morrow's Bush-Honeysuckle
Lotus corniculatus	Birdsfoot Trefoil
Ludwigia palustris	Waterpurslane, Creeping Primrose
Lupinus perennis	Perennial Lupine
Luzula bulbosa	Woodrush
Lythrum salicaria	Purple Loosestrife

M

Malva neglecta	Common Mallow, Button Weed
Marrubium vulgare	Horehound, White Horehound
Matricaria matricarioides	Pineapple-weed
Mazus japonicus	White Flowered Mazus
Medicago lupulina	Black Medic
Melilotus alba	White Sweetclover
Mertensia virginica	Virginia Bluebells, Virginia Cowslip

Microstegium vimineum var. *imberbe*	Japanese Stiltgrass, Annual Jewgrass
Mirablis nyctaginea	Wild Four-o' Clock
Mollugo verticillata	Carpetweed
Monarda fistulosa	Bee-balm, Wild Bergamot
Muhlenbergia schreberi	Nimblewill
Murdannia keisak	Marsh Dayflower, Asian Spiderwort
Murdannia nudiflora	Doveweed
Muscari racemosum	Starch Grapehyacinth, Blue-Bottles
Myriophyllum spicatum	Eurasian Watermilfoil

N

Najas minor	Brittleleaf or Slender Naiad
Nepeta cataria	Catnip
Nicandra physalodes	Apple-of-Peru
Nymphaea spp.	Waterlily

O

Oenothera biennis	Common Eveningprimrose
Oenothera laciniata	Cutleaf Eveningprimrose
Opuntia humifusa	Pricklypear
Ornithogalum umbellatum	Star-of-Bethlehem
Oryza sativa	Red Rice

Oxalis corniculata	Creeping Woodsorrel
Oxalis stricta	Yellow Woodsorrel

P

Panicum capillare	Witchgrass
Panicum clandestinum	Deer-tongue Grass
Panicum dichotomiflorum	Fall Panicum
Panicum miliaceum	Wild-Proso Millet
Panicum texanum	Texas Panicum
Papaver dubium	Field Poppy
Parthenocissus quinquefolia	Virginia-Creeper
Paspalum dilatatum	Dallisgrass
Passiflora incarnata	Maypop Passionflower
Pastinaca sativa	Wild Parsnip
Perilla frutescens	Perilla Mint
Phacelia dubia	Small-flowered Phacelia, Phacelia
Phlox divaricata	Blue Phlox
Phlox subulata	Creeping Phlox, Moss Pink
Phragmites australis	Common Reed
Phyllanthus tenellus	Long-stalked Phyllanthus
Physalis heterophylla	Clammy Groundcherry
Phytolacca americana	Pokeweed, Pokeberry
Plantago lanceolata	Buckhorn Plantain
Plantago major	Broadleaf Plantain

Plantago rugelii	Blackseed Plantain
Plantago virginica	Paleseed or Hoary Plantain
Poa annua	Annual Bluegrass
Poa trivialis	Roughstalk or Rough Bluegrass
Podophyllum peltatum	Mayapple, Mandrake
Polygonum arifolium	Tearthumb
Polygonum aviculare	Prostrate Knotweed
Polygonum caespitosum var. *longisetum*	Tufted Knotweed
Polygonum coccineum	Swamp Smartweed
Polygonum convolvulus	Wild Buckwheat
Polygonum cuspidatum	Japanese Knotweed, Japanese Bamboo
Polygonum pensylvanicum	Pennsylvania Smartweed
Polygonum persicaria	Ladysthumb
Polygonum sagittatum	Arrow-leaved Tearthumb
Polygonum virginianum	Virginia Knotweed
Pontederia cordata	Pickerelweed
Portulaca oleracea	Common Purslane
Potamogeton crispus	Curlyleaf Pondweed
Potamogeton diversifolius	Variable-leaf Pondweed
Potamogeton pusillus	Slender Pondweed, Small Pondweed
Potentilla recta	Sulfur Cinquefoil
Prunella vulgaris	Healall
Pueraria lobata	Kudzu

R

Ranunculus abortivus	Smallflower Buttercup or Crowfoot
Ranunculus arvensis	Corn Buttercup
Ranunculus bulbosus	Bulbous Buttercup
Raphanus raphanistrum	Wild Radish
Robinia pseudoacacia	Black Locust
Rosa multiflora	Multiflora Rose
Rubus spp.	Brambles (Raspberries, Blackberries, etc.)
Rumex acetosella	Red Sorrel, Sheep Sorrel
Rumex crispus	Curly Dock
Rumex obtusifolius	Broadleaf Dock

S

Sagittaria australis	Long-beaked Arrowhead
Sambucus canadensis	Elderberry, American Elder
Sanguinaria canadensis	Bloodroot
Saponaria officinalis	Bouncingbet, Soapwort
Satureja vulgaris	Wild Basil
Saururus cernuus	Lizard's Tail
Scleranthus annuus	Knawel, German Moss
Senecio tomentosus	Wooly Ragwort

Senecio vulgaris	Common Groundsel
Sesbania exaltata	Hemp Sesbania
Setaria faberi	Giant Foxtail
Setaria glauca	Yellow Foxtail
Setaria viridis	Green Foxtail
Sherardia arvensis	Field Madder
Sicyos angulatus	Burcucumber
Sida rhombifolia	Arrowleaf Sida
Sida spinosa	Prickly Sida
Silene alba	White Campion
Silene virginica	Fire Pink
Silene vulgaris	Bladder Campion
Sisymbrium officinale	Hedge Mustard
Smallanthus uvedalia	Yellow-flowered Leaf Cup, Bearsfoot
Solanum carolinense	Horsenettle, Sand Briar
Solanum dulcamara	Bittersweet Nightshade
Solanum eleagnifolium	Silverleaf Nightshade
Solanum nigrum	Black Nightshade
Solanum ptycanthum	Eastern Black Nightshade
Solanum rostratum	Buffalobur
Solidago canadensis	Common Goldenrod, Canada Goldenrod
Soliva pterosperma	Lawn Burweed
Sonchus asper	Spiny Sowthistle

Sonchus oleraceus	Annual Sowthistle
Sorghum halepense	Johnsongrass
Spergula arvensis	Corn Spurry
Stachys floridana	Florida Betony, Rattlesnake Weed
Stellaria media	Common Chickweed, Chickweed
Symphoricarpos orbiculatus	Coral-berry, Devil's Shoestring

T

Taraxacum officinale	Dandelion
Thlaspi arvense	Field Pennycress
Thlaspi perfoliatum	Thoroughwort or Perfoliate Pennycress
Toxicodendron radicans	Poison-Ivy
Tragopogon dubius	Goat's-beard, Western Salsify
Tribulus terrestris	Puncturevine
Tridens flavus	Purpletop
Trifolium arvense	Rabbitfoot Clover
Trifolium pratense	Red Clover
Trifolium repens	White Clover
Triodanis perfoliata	Common Venus' Looking-Glass
Tripsacum dactyloides	Gama-grass
Typha spp.	Cattail

U

Urtica dioica	Stinging Nettle
Utricularia spp.	Bladderwort

V

Valerianella radiata	Corn Salad
Verbascum blattaria	Moth Mullein
Verbascum thapsus	Common Mullein
Verbesina alternifolia	Wingstem
Verbesina occidentalis	Stickweed
Vernonia noveboracensis	New York Ironweed
Veronica americana	American Speedwell
Veronica persica	Persian Speedwell
Vicia sativa	Common Vetch
Vicia dasycarpa	Smooth Vetch
Viola arvensis	Field Violet, Wild Pansy
Viola papilionacea	Common Blue Violet
Viola pedata	Bird's Foot Violet, Crowfoot Violet
Vitis spp.	Wild Grape

W

Wolffia spp.	Watermeal

X

Xanthium strumarium **Common Cocklebur**

Xanthium spinosum **Spiny Cocklebur**

Y

Yucca filamentosa **Yucca, Bear-grass**

Virginia Cooperative Extension

Knowledge for the CommonWealth

Dwarf Larkspur: *Delphinium tricorne*

Weed Description: **A perennial from tuberous roots with lobed leaves and attractive blue flowers. Dwarf larkspur is primarily found in or along the edges of woods, and is extremely poisonous to cattle. Dwarf larkspur primarily occurs in the mountains and lower piedmont of Virginia, North Carolina, Georgia, Alabama, Mississippi, Tennessee, Kentucky, and West Virginia.**

Leaves: **Leaves are lobed such that each lobe arises from a common point (palmately lobed). Leaves are approximately 3/4 to 6 inches wide, and are usually without hairs but are sometimes sparsely hairy.**

Stems: **Stems are hairy and may reach 16 inches in height.**

Flowers: **Each flower occurs on a flowering stalk that may be from 10 to 30 mm in length. Individual flowers are star-shaped and blue in color.**

Identifying Characteristics: **Palmately divided leaves with blue, star-shaped flowers.**

Virginia Tech Weed Identification Guide

Select a Resource...

Dutchman's Breeches: *Dicentra cucullaria*

Weed Description: **Perennial from a bulbous-like rootstock that is primarily found in or along the edges of woods, or along river banks. Primarily occurs in the mountains and piedmont of Virginia, North and South Carolina, Georgia, Tennessee, Kentucky, and West Virginia.**

Leaves: **Leaves are ovate in outline, approximately 2 to 3 1/2 inches long or wide, with petioles that are from 3 to 8 inches long. Leaves are compound and divided into leaflets that occur oppositely from one another alon the central axis.**

Roots: **A bulbous-like rootstock.**

Flowers: **Several white flowers occur on a long, drooping flower stalk. Individual flowers resemble kernels of corn, thus the name.**

Fruit: **A capsule.**

Identifying Characteristics:
Plants with divided leaves and conspicuous "corn-like" flowers. This plant may be confused with Wild Carrot (*Daucus carota*) or Poison Hemlock (*Conium maculatum*) at the early stages, but squirrel corn blooms in March or April, which is much earlier than the other two species. Additionally, squirrel corn is usually confined to woods or river banks.

Virginia Tech Weed Identification Guide

Select a Resource...

Virginia Bluebells or Virginia Cowslip: *Mertensia virginica*


Virginia Tech Weed ID Guide

Virginia Tech Weed Identification Guide

Select a Resource...

Small-flowered Phacelia: *Phacelia dubia*

Weed Description: **An annual with attractive blue flowers that occurs most often in woodlands or along the edges of woods, along roadsides, and in abandoned fields. This plant is more likely to be viewed as an attractive wildflower than a common 'weed'.**

Leaves: **Basal and stem leaves are divided into leaflets, the lateral segments being elliptic to oval-shaped in outline. All leaves contain sharp, stiff hairs. Basal leaves occur on petioles while stem leaves are usually without petioles (sessile).**

Stems: **Erect or spreading, reaching 15 inches in height. The stems contain many stiff hairs.**

Flowers: **Occur in clusters at the ends of stems. Individual flowers occur on flower stalks (pedicels) that may reach 26 mm in length. Flowers are blue to white in color.**

Fruit: **A capsule.**

Identifying Characteristics: **The leaves of small-flowered phacelia are similar in appearance to some buttercups, such as Bulbous Buttercup (*Ranunculus bulbosa*). However, the buttercups do not have sharp, stiff hairs on the leaves, petioles, and stems to the extent that small-flowered phacelia does. Additionally, these plants generally grow in different habitats and have yellow flowers unlike small-flowered phacelia.**

Virginia Tech Weed Identification Guide

Select a Resource...

Fire Pink: *Silene virginica*


Virginia Tech Weed ID Guide