

AT MICROFICHE
REFERENCE
LIBRARY

A project of Volunteers in Asia

Fields and Pastures in Deserts: A Low Cost Method
for Agriculture in Semi-Arid Lands

Published by:

The Management of the Experimental Farm
"Wadi Mashash"
Wadi Mashash, Bodenacker 10
D-6114 Gross Umstadt
Wiebelsbach
Federal Republic of Germany

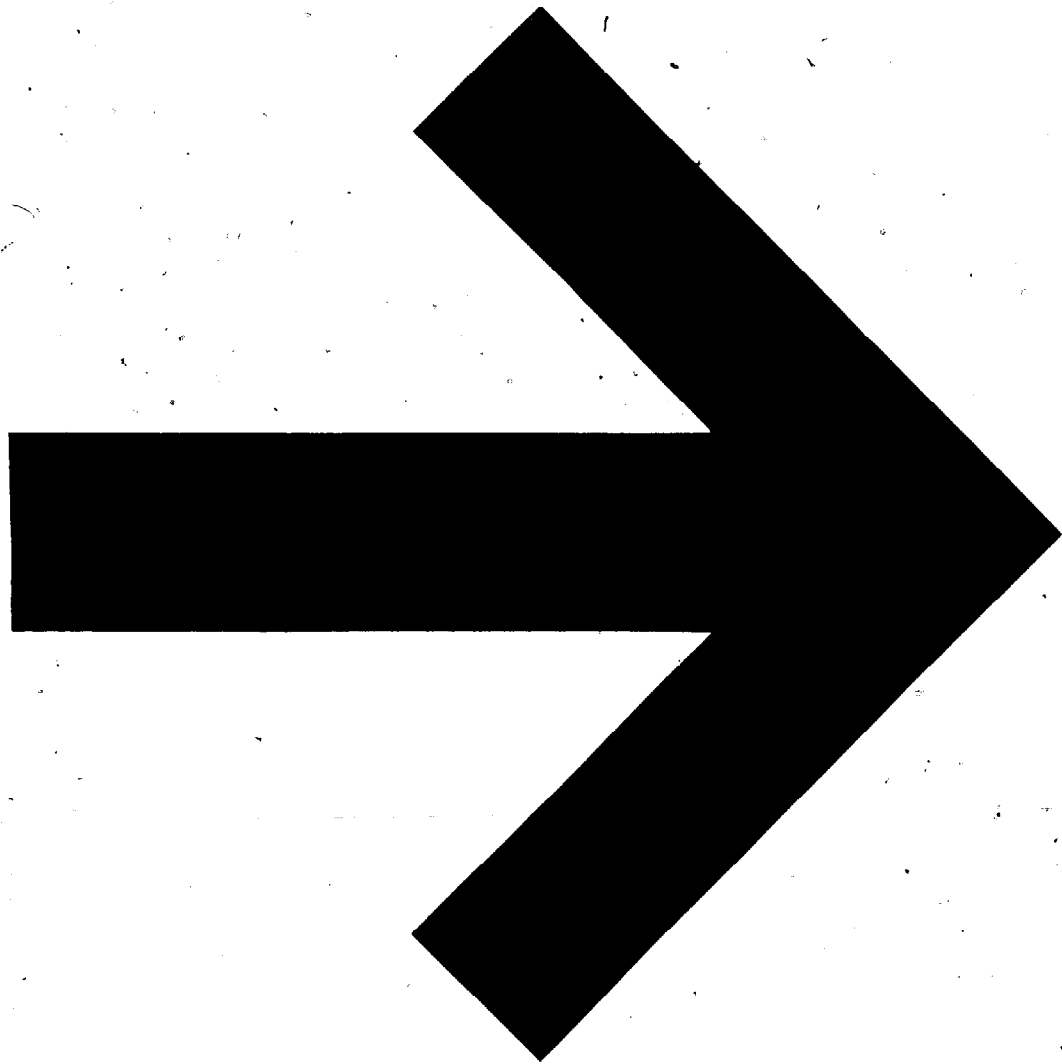
Paper copies are \$ 4.00.

Available from:

The Management of the Experimental Farm
"Wadi Mashash"
Wadi Mashash, Bodenacker 10
D-6114 Gross Umstadt
Wiebelsbach
Federal Republic of Germany

Reproduced by permission of Michael Evenari.

Reproduction of this microfiche document in any
form is subject to the same restrictions as those
of the original document..



Contents

Foreword	1
Description of the Experimental Farm of Wadi Mashash	2
Ancient Agriculture in the Negev Desert	8
The Reconstruction of Two Ancient Farms	11
Water Supply for Man and Beast in the Negev	15
Loess	17
Lessons Learned from the Establish- ment of the Wadi Mashash Farm	19
Co-operation with the Bedouin	24
Opinions About the Desert Agri- culture in the Negev	27
In the Footsteps of the Ancient Farmers	31
Report on a Journey to Tunisia and Niger	34
Bibliography	37

Editor:

The Management of the Experimental
Farm »Wadi Mashash«:
M. Evenari, U. Nessler, A. Rogel,
O. Schenk

Information and Consultation:
6111 Heubach, Erzbergerstraße 16,
Bundesrepublik Deutschland

Edition: Eduard Roether,
Buchdruckerei und Verlag, Darmstadt

FIELDS
and
PASTURES
in
DESERTS

A Low Cost Method
for Agriculture in
Semi-Arid Lands



Foreword

Whoever speaks of deserts and steppes, certainly does not think of fertile fields and rich pasture grounds.

Is agriculture in arid zones possible at all, apart from oasis?

Hundreds of years ago people had already learned how to establish flourishing and productive agriculture by using the rain and the floods which filled the dry watercourses (wadis) for only a few hours per year.

In Northern Africa and in the Middle East the remains of ancient agriculture can easily be traced to this day.

A team of scientists of the Hebrew University of Jerusalem investigated and reconstructed the remains of two ancient farms in the Negev desert. How could agriculture be practiced in a region of scarcely 100 mm of yearly precipitation? Can similar yields be attained today as well, and can these yields sustain life, frugal and modest, but free of hunger and famine?

The results of the research on both of the reconstructed farms justified the erection of a new experimental farm. The main purpose of this farm was to use the scientific results for the development of practical methods which can be applied in other arid zones. Today, the experiences, the knowledge and the methods of desert agriculture can be demonstrated and taught on this farm of WADI MASHASH. The knowledge has been successfully applied in Afghanistan, Australia and Africa and it is hoped that its use will be spread to more and more arid regions.

Since this form of desert agriculture is not only scientifically interesting, but may also be of some help to check the hunger in arid zones, therefore churches in the Federal Republic of Germany — such as “Brot für die Welt” and “Evangelische Kirche in Hessen und Nassau” — and in Switzerland the “Hilfswerk Evangelischer Kirchen der Schweiz”, — took part in and financed the erection of the farm of WADI MASHASH. The organization “Weltfriedensdienst” in Berlin sent the German co-workers to the farm and took care of them. All these sponsors of the runoff-farming will try to help the transfer and the application of this method in the future as well.

FIELDS and PASTURES in DESERTS ought no longer be a Fata Morgana.

D. Helmut Hild
Church President of the
“Evangelische Kirche in Hessen
und Nassau”

Hans Schaffert
Secretary General of the
“Hilfswerk Evangelischer
Kirchen der Schweiz”

Description of the Experimental Farm of Wadi Mashash

Geographical situation

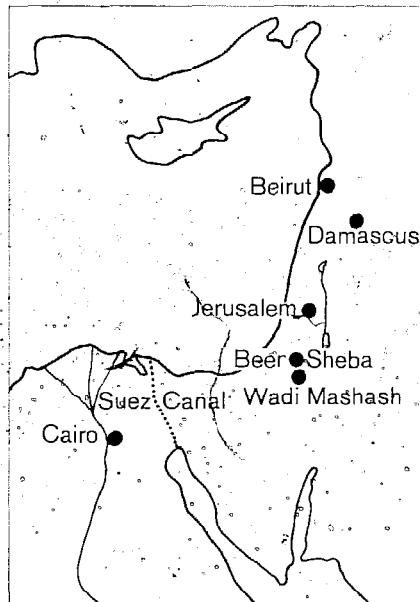
The desert region of the Negev — corresponding to the Biblical 'South Country' — covers an area of 12 500 km². The central and southern Negev belong to the vast Sahara-Arabian desertbelt, which extends from the Sahara over the great Arabian desert — including the Sinai and the Negev — to the desert of Sind in India. The northern Negev is a transition region between desert and steppe.

The lowland of the Negev is an area of rolling plains which are separated by numerous low hills, composed of limestone. This lowland has an altitude of 200–400 m above sea-level. Long and broad wadis — dry watercourses — run through the plains. These "rivers" have water only for some hours during the rainy season. Often these plains are covered with a 2–3 m deep layer of loess, which is not too saline and is nearly stoneless. The temperature of the lowland does not fall below 0° C, nor even during the cool rainy season.

The climate of the Negev is characterized by a hot, dry and rainless summer of 7–8 months and a cool rainy winter.

The rainfall during the rainy season is sporadic and irregular — a typical feature of desert areas —; therefore figures of annual average precipitation such as 100–120 mm in Wadi Mashash can only be used with care. During the 1971/1972 rainy season for instance 207 mm of rain were recorded in Wadi Mashash (WM) whereas the next season yielded only 55 mm! Both, the amount of rain and its distribution in time are unpredictable. The farm of Wadi Mashash is situated 20 km south of Beer Sheba, about 60 km

east of both the Mediterranean and the Dead Sea, and about 250 km north of the Red Sea.



General Map of the Farm

The experimental farm of WM is located in a valley which is 2 km broad and lies between two ridges of about 400 m of height. A wadi meanders through the valley. Only in winter for a few hours torrential floods stream through this wadi from east (rain-gauge No. 8) to west (road to Beer Sheba).

Natural perennial and dense vegetation exists mainly in the bed of the wadi, in small depressions and in remains of dams, dating back to an earlier, primitive

agriculture. The foothills, slopes and ridges carry only a scarce vegetation. The farm was erected in three stages:

1. Investigation of the territory, setting up of the rain gauges (1–15). Installation of runoff plots (beside the rain gauges No. 2, 3, 4, 6).

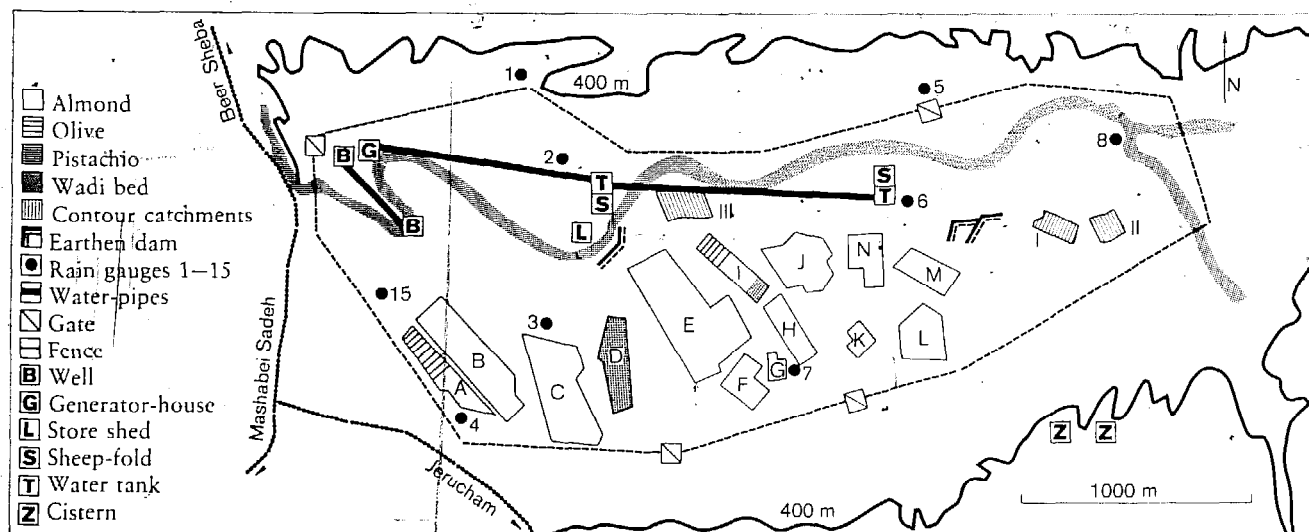
Analysis of soil samples from 40 different, 2.50 m deep holes. Survey of the territory and drawing of maps:

Aerial photograph of the territory; one map 1 : 10 000, partial maps of 1 : 1000. 400 ha of the rented land, which covers 2000 ha as a whole; gets fenced-in with Australian fence (12 km).

Since no farm house has been planned on the farm, a store depot and a room for the workers had to be built (L).

2. Plantation of the trees. The areas for the plots — microcatchments — ("A" "to N") were measured. The basins for the trees were dug by means of an excavator; the border check between all the plots were raised by a tractor with a discus. Altogether 3000 trees (almonds, pistachio nuts, olives) were planted into the plots. Each tree stands alone on an area of 250 m².

3. Sheep and pasture program. First, contour-catchments were built, in which pasture plants were planted and sown (I–III). We planted then 30,000 range plants, which we had raised in plastic-bags, behind two old earth dams. These pasture plants are supposed to provide additional food for the flock in



those months of the year in which the sheep do not find enough to eat on the natural pasture.

Two wrecked ancient wells (B) were dug out and reconstructed. By means of a generator (G) the water for the flock is being pumped from the wells to the sheepfold (S) and to the watering-places in the wadi (T) through a 2.4 km long water pipe. The flock numbers 300 Awassi-sheep (a fat tail race which stores up to 10 kg of fat in its tail).

A Construction for the Collecting and Measurement of Runoff-water and a Design of the Microcatchments for the Trees

Before runoff farming can be started the following facts have to be known:

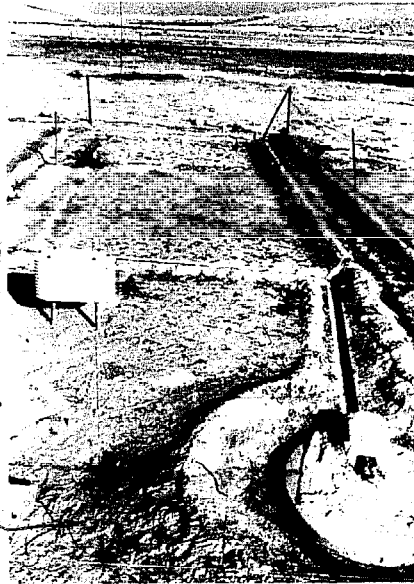
- Average annual rainfall,
- Amount of runoff as percentage of rain,
- Chemical and mechanical composition of soil.

21 rain gauges were set up all over the area. 6 devices for the collecting of runoff-water were built.

Such a device consists of two plots of 20 m² each. When it rains, the loessial soil forms its typical crust, and the water flows in the direction of the natural slope. At the end of the plot a small conduit collects the water and leads it into a tank of a capacity of 500 l. After every rain the amount of precipitation collected in the rain gauges is being measured, the water is bailed out of the runoff tank and measured, and thus the percentage of runoff-water can be determined.

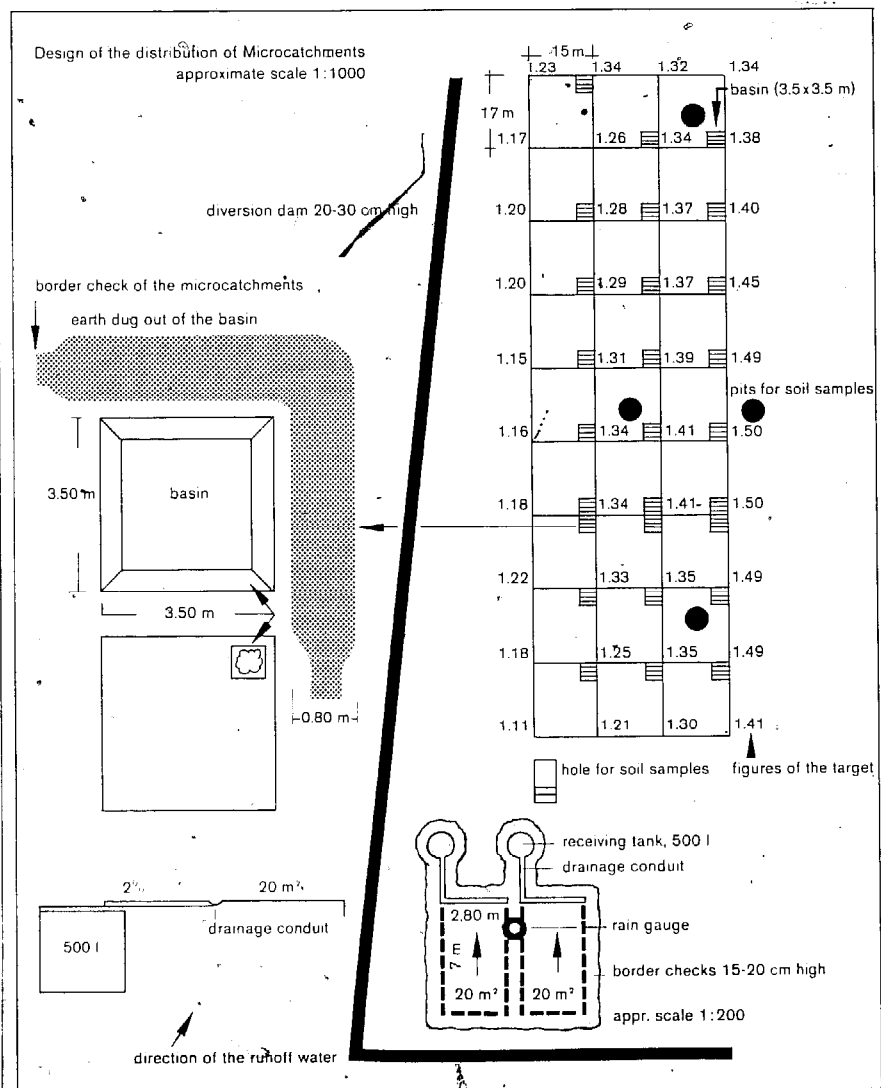
Example: On the 24th April 1971, 10 mm of rain were measured at the runoff-plot No. 4. 6.8 mm ran off, that is 68%. Had there been a tree instead of the tank, it would have received 136 l of water with a precipitation of 10 mm. (68% of 10 mm = 6.8 mm x 20 m² = 136 l.) (See also the table of No. 4, page 4).

Based on our runoff measurements we calculated that a tree will receive about 8 to 10 m³ of water from a watershed of 250 m² in one rainy season (about 120 mm). This amount of water guarantees the existence of a tree.



The tree is being planted at the deepest point of the plot in a square basin of 3.50 x 3.50 m and 20 cm of depth.

According to the topographical conditions we laid out field blocks containing 10–500 microcatchments (see the design).



Plot No. 4; Construction for the collecting of runoff-water.

Precipitation of the rainy season 1970/1971

Month:	December 1970					
Day:	1.	8.	10.	13.	20.	Total
Amount:	3.0	7.0	3.0	17.0	1.0	31.0 mm
Month:	January 1971					
Day:	10.	12.	16.	27.		Total
Amount:	18.5	15.5	1.0	2.0		37.0 mm
Month:	February 1971					
Day:	8.	14.	22.			Total
Amount:	1.0	4.5	0.5			6.0 mm
Month:	March 1971					
Day:	13.	24.				Total
Amount:	6.0	1.0				7.0 mm
Month:	April 1971					
Day:	3.	13.	14.	15.	24.	Total
Amount:	11.0	23.0	13.0	4.0	10.0	61 mm
						together 142.0 mm

The amount of runoff-water collected during the rainy season of 1970/1971 at one of the plots for the collecting of runoff on the farm of Wadi Mashash.

Day	Rainfall	Runoff	Percentage
8. 12.	7.0 mm	0.4 mm	5%
10. 12.	3.0 mm	1.3 mm	43%
13. 12.	17.0 mm	7.2 mm	42%
10. 1.	18.5 mm	9.1 mm	49%
12. 1.	15.5 mm	8.8 mm	56%
16. 1.	1.0 mm	0.3 mm	30%
14. 2.	4.5 mm	1.0 mm	22%
13. 3.	6.0 mm	1.5 mm	25%
3. 4.	11.0 mm	3.5 mm	32%
13. 4.	23.0 mm	10.3 mm	45%
14. 4.	13.0 mm	5.8 mm	45%
15. 4.	4.0 mm	3.8 mm	95%
24. 4.	10.0 mm	6.8 mm	68%

Annual average: 42%

On a microcatchment of 250 m², about 15 m³ would have been collected.

Rainfall at rain gauge No. 2

	1970/ 1971	1971/ 1972	1972/ 1973	1973/ 1974
November	—	2.0	16.0	7.5
December	31.0	98.0	4.5	3.0
January	37.0	3.0	31.5	88.5
February	6.0	31.0	2.0	53.5
March	7.0	64.0	1.0	8.0
April	61.0	9.0	—	20.0
Total mm	142.0	207.0	55.0	180.5

This rainfall table shows that the agriculture of the Bedouin which grow only field crops (barley, wheat) can in most years not be profitable because its water source is only rain and not rain and runoff.

Here follows a short description of each of the above mentioned rainy seasons:

1970/1971

Though the rainfall in December and January was favourable for dry farming the field crops in the Negev suffered severely in February and March.

The 61 mm of rain in April were unusual and too late to save the harvest.

1971/72

An ideal rainy season with unusually high amount and an almost regular distribution of rain.

1972/1973

A dry year as it had not occurred for more than ten years. The only flood in January 1973 produced only little runoff (5—21%) since part of the precipitation was snow and did not run off.

1973/1974

The beginning of the rainy season made us fear a second dry year, but then from the end of January to the beginning of February 1974 a period of unusually long and heavy rainfall occurred. Wheat and barley which were sown by the Bedouin after the first rain in January could not develop normally since the hot east wind in April stopped its development before it was ripe.

Microcatchments and Flooded Basins with Olive Trees

The microcatchments cover the area like a wire-netting. Though the general slope leads towards the ridge — as the picture shows clearly —, it is necessary to determine the deepest point for the tree in every single plot. The plot of 250 m² is the watershed for the tree and *must not* be cultivated. Any kind of vegetation on the plot uses water which the tree lacks, consequently.

After the first good rainy season in 1971/72 a rich vegetation had developed on the plots and deprived the trees of much water. But how to destroy the vegetation without making the young tree suffer, too? The next year, nature itself solved the problem: There was so little rain that no vegetation did develop. Thus the small amount of runoff-water could be used exclusively by the tree.

On the microcatchments no animals may graze. It would not only be difficult to control them, but the hoofs of the sheep





and goats would destroy the crust of the loess and thus lessen the runoff.

The basin becomes a small pool after a flood. The time it takes the water to infiltrate is 2–6 days. Thereafter the soil is thoroughly moistened and serves the tree as a water reservoir for the dry period.

From 16th January, 1973 until 17th January, 1974 the trees in Wadi Mashash did not get any flood. During this entire year the trees lived by their "water-bank" and flourished. When the water has infiltrated, the basin must be hoed or tilled after every flood.

After this treatment the upper 20 cm of the soil dry out. This promotes root respiration, furthermore it destroys the capillary system and thus checks evaporation from the soil to a great deal. The growing weeds can be largely reduced, too, if the basin is hoed. It is absolutely necessary to control all the fields after every flood to be able to repair immediately small damages of the plots. For even little breaches in a dam can derange the whole construction, because then the flood water rushes in, a chain reaction from plot to plot.

Wells and Cisterns

The trees and range plants do *not* need any additional water apart from rain and floods. But for the collaborating Bedouin and their flock as well as for the sheep of the farm itself one must provide secure water reservoirs all through the year. Within the territory of the farm there was no well and no cistern that could be used. By means of the geo-electric method we searched the wadi and the surrounding pasture-grounds for ground-water, but we failed! Then the Bedouin showed us an old well filled up. We dug this well out, but even with a hand pump and with a great amount of effort it gave so little water, that not even the Bedouin were interested in using it.

The Bedouin dug out a second well all by themselves — it also had been filled in by gravel and boulders of the wadi. This well is 4 meter deep with a diameter of 1.2 m, it is built of well preserved unhewn stones, and dates probably back to Turkish times. It is situated near the bed of the wadi, and it provides 2 to 3 m³ of good drinking water daily, even in periods of extreme drought. At a short distance of these

two wells a third well was known to exist. (May be this well is identical with the "Bor Mashash" which occurs on old maps of the Negev.) It, too, was almost completely filled in and was scarcely recognizable as a well. We had to dig out more than 100 m³ of mud, earth, stones and gravel in manual work.

After the excavation the well is 12 m deep with a diameter of 3.80 m, but it produces only 1000 l in the dry season.

The two latter wells guarantee the supply of drinking water for the farm of Wadi Mashash.

In plastic pipes of a length of 2400 m the water is being transported from the wells to the sheep-fold and to the watering points in the pasture-grounds.

After some months of experiments with different pumps and generators we bought a Lister-Generator (8 kilowatt).

Two suction pumps bring the water up from a depth of about 8 m and then pump it upward against a gradient of 20 m over the 2.5 km of the pipeline to the watering-points at the sheep-fold and in the pasture-grounds.

A water-tank of 2,000 l capacity has been set up both beside the sheep-fold and in the pasture-grounds.

As an additional source of water we restored two ancient cisterns hewn into the soft limestone rock which in the winter of 1973/74 for the first time filled up with runoff water. Each cistern can store 200 m³.



Cisterns as Reservoirs

The cisterns in the Negev are easily recognizable from far away by the presence of high mounds of loose white silt alongside them. These mounds are the result of cleaning operations when the accumulated silt in the cisterns is cleared out and piled nearby. Every cistern has one or more channels which lead the runoff-water from the neighbouring hill into the cistern. Gently sloping the channels lead down the hill, collect all the runoff-water which streams down the slope and lead it through a small opening into the roofed rock cistern.

This closed water reservoir is well protected against pollution and evaporation.

In front of the opening a small silting basin holds back part of the silt and dirt carried by the water.

As we have already mentioned above both cisterns in Wadi Mashash were filled with water in the first winter after their restoration. For five months, 300 sheep can be supplied with the water stored in these two cisterns.

Pasture and Sheep Program

The program of the experimental farm is composed of two different sections: *The tree plantations* — vegetables and crops can be raised with the same method — and *the sheep program*.

One aim was to improve the sheep-breeding of the Bedouin and to make it less susceptible to any crisis.

Among other things we tried to produce additional food for the flock by planting strips of range plants, as the picture (p.7) shows. When the rain causes a flood, the water banks up at the dam and the





whole area is covered with water. This damming up provides so much water for the plants that they can be mowed several times a year and may be stored as fodder for the dry months.

The sheep-fold we built is nothing more than a protective roof — to give the flock a shelter in the hot summer months and during the stormy, cold winter.

The roof of 270 m² gives shade and protects against rain. The sheep-fold lies in a fenced in area (1,200 m²). The fence protects the sheep against jackals, wild dogs and other menaces. The 1.60 m high wall at the weather side leaves space for the wind to blow into the sheep-fold in summer. But in winter this space between wall and roof is being covered by plastic sheets as a protection against the cold winds.

The fold can be partitioned into different stalls — such as stalls for lambs or for rams — by means of easily movable grates. A weighing apparatus and several watering-points complete the sheep-fold.

The Pasture

One of the most serious problems in deserts and steppes is the overgrazing of the poor pasture-grounds. Wadi Mashash was also totally overgrazed.

After the area had been fenced in, the pasture was allowed to regenerate for one season. Then we spread artificial manure and sowed vetch (*Vicia dasycarpa*) and medick (*Medicago hispida*) in the wadi. Salt bushes (*Atriplex halimus*) were planted because they contain protein and thus may serve as additional food. Furthermore we eradicated the numerous bushes of *Thymelaea hirsuta* which the sheep do not touch. These bushes are “water thieves”, for their deep and widespread roots enable them to deprive the pasture of a great amount of water.

About 50 hectares of pasture in the wadi bed are at our disposal. After this area was divided into four sections, the flock was grazed in each section only for some time in order to preserve the pasture. After the first heavy flood the flock was kept in the fold for at least six weeks to give the pasture time for regeneration. This rotation demands absolute discipline on the part of the shepherd.

Ancient Agriculture in the Negev Desert

The daily grazing rhythm is as follows: At dawn the flock leaves the sheep-fold. At midday it is led to a resting-place on the pasture. There is water and shade under a roof of jute. After some hours of rest — the length of which depends on the temperatures — the sheep graze until sunset. In the evening they return to the sheep-fold where water is available for every sheep at any time.

The Awassi Sheep (Fat-tail-sheep)

Since the aim of the Wadi Mashash project is to develop a simple method by simple means for simple people, we bought that local breed of sheep which is most popular throughout the Middle East deserts. Our experience has taught us that the local inhabitant of arid zones ought to preserve as much of his familiar surroundings and way of life. It is difficult for him to adapt even changes which in the eyes of the expert are very small.

The Bedouin have raised the Awassi sheep for many centuries. The flock of Wadi Mashash was bought from a Bedouin. The 300 ewes and the 10 rams are our experimental flock used for our grazing experiment on the area of the farm. No other flock may enter the fenced area. A Bedouin and his family work as our shepherds.

After the lambing the ewes and their lambs stay together in the sheep-fold for two weeks, then the ewes return to grazing without their lambs.

About six weeks after the lambing ewes and lambs are finally separated. Part of the lambs are being fattened and reach a live weight of about 40 kg within 4 months. Then they are sold at the meat-market. Part of the lambs are used to regenerate and to enlarge the flock and therefore graze together with the flock. To prevent too long a lambing period the rams are separated from the flock and join it only in specific times for the insemination.

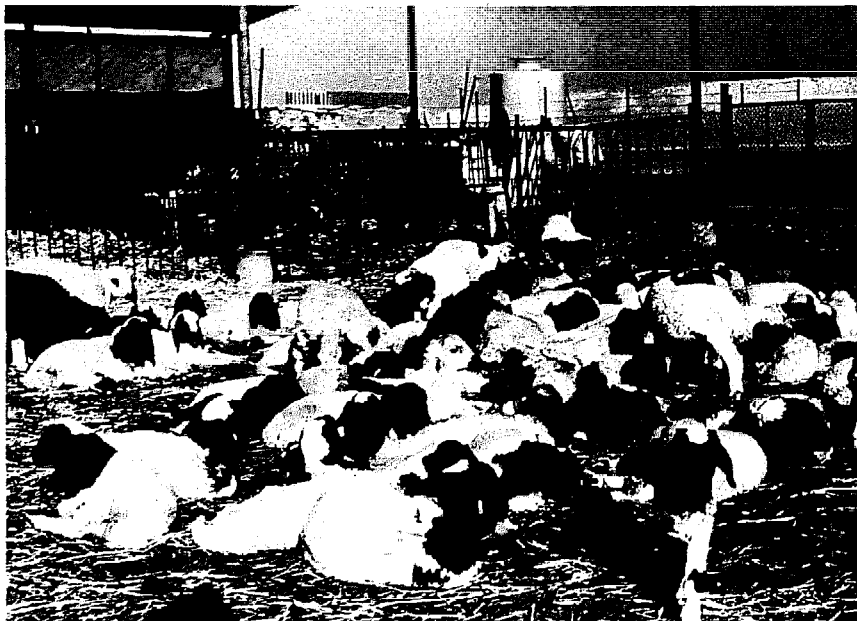
The Englishman Palmer was one of the first Europeans, who visited the Negev in 1870 and traced the ruins of ancient cities. In his report of the journey Palmer repeatedly emphasizes the astonishing fact that distinct traces of ancient agriculture can be found in a region, where desert stretches today. Palmer names already the problems which are to occupy scientists in the 20th century:

1. How can one explain the fact that in a desert area, where the Bedouin of today scarcely manage to raise any crop, extensive agriculture flourished?
2. Who were the farmers, and what was their method like?
3. Is it possible to carry on agriculture today with the same method? There is no doubt that the Negev was densely populated in the Middle Bronze Period (2000 B. C.). Many traces of this period are still to be found, such as the numerous burial mounds (tumuli).

No remains of human settlements or agriculture have been found from the period of 2000 B. C. to about 1000 B. C. In the time of the Judean Kings (1000—700 B. C.) the Negev saw a second prosperity. A net of roads, fortresses and villages stretched across the plains and hills. The Israelite settlement in the Negev came to an end in the 6th century B. C., and until the 3rd century B. C. the whole area seems to have been deserted.

Then the Nabateans coming from South Arabia settled in the Negev. They were merchants who carried precious Chinese and Indian goods on the backs of their camels from the ports of South Arabia to Damascus and the ports on the Mediterranean coast. This trade made them rich and powerful. They started to build fortresses and towns along their caravan-routes. In that manner they founded *Avdat* and *Shivta* and all the other towns in the Negev. In the neighbourhood of these towns they carried on runoff agriculture, often reusing the remains of the Israelite farms.

¹⁾ The chapters about the farms of *Avdat* and *Shivta* are based on the publications of M. Evenari, N. Tadmor and L. Shanan, listed in the bibliography at the end of the book.





Remains of terraces and stone walls are evidence of the ancient runoff agriculture. The various terraces are still clearly visible

In the year 106 A. D. the Roman Emperor Trajan subjugated the Nabatean empire, without destroying the towns, however. Thus the cultural and agricultural development of the Negev remained unbroken and reached its most flourishing time during the Byzantine Period (about 330–630 A. D.). The Byzantine farmers, who were probably baptized Nabateans, raised the runoff-farming to a very high level. The most elaborate and effective farms and runoff-systems date back to this period.

After the Arabs had conquered the Negev in the 7th century A. D. the towns were gradually abandoned and fell into ruin. The precious stones were used as building material by the inhabitants of Beer Sheba and Gaza. The farms decayed as well, and the Bedouin occupied the entire region with their flocks.

Landscape and Climate of the Negev

The lowlands in which the farm of Wadi Mashash is located is an undulating plain (200–400 m high) separated by low hills. The numerous dry water-courses have their origin in the central highlands and run into the direction of the Mediterranean-Sea. The central highlands are made up of parallel running ridges composed of limestone, which rise as high as 1000 m above sea level. The main wadis drain to the Mediterranean and to the Dead Sea. The watersheds are often expansive plains covered with loess.

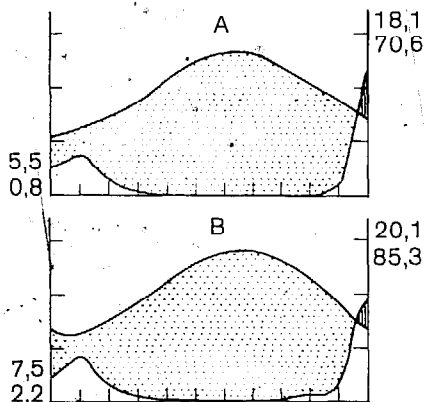
Loess has also been deposited in the wadi beds. The climate of the lowlands is warmer than that of the highlands.

The minimum temperatures are higher and the evaporation rate bigger. In the central highlands the minimum temperatures fall below 0° C in about 50 nights in winter. Like in the lowlands rain occurs only from November to March, and even then rainfall is rather irregular and unpredictable. A rainy year with 285 mm of rainfall may be followed by a drought year of only 25 mm.

The average annual precipitation is 80–100 mm. A heavy rain occurs very rarely. But if one happens to witness one in the desert, it is not only an interesting spectacle, but it illustrates the basic principle of runoff-farming:

The first drops that fall on the dry loess soil create a diffusion zone around the spot which they hit. If the intensity of the rain is high enough, the many zones of diffusion come into contact very quickly. Within seconds the surface changes its appearance from dull to shiny. In that moment the water starts to run down the hills, it builds small streamlets and drains towards the wadis: the runoff-flood has begun.

This specific characteristic of the loess has been thoroughly investigated. The aggregate structure of the loess surface is being destroyed as soon as it gets wet. The wetted layer slakes and the fine particles clog the surface layer to form a crust which is nearly impermeable to water. That is the moment when the surface becomes shiny and when the water begins to run down the slopes (beginning of runoff).



Climate diagram of Avdat (A) and Shivta (B). On the abscissa are given the months of the year, the lower curve indicates the mean monthly rainfall (one scale unit = 20 mm), the upper curve shows the mean monthly temperatures (one scale unit = 10°C). The upper figure on the right represents the mean annual temperature, the lower one the mean annual rainfall; the upper figure on the left is the mean daily minimum of the coldest month, the lower figure the absolute minimum. The dotted area represents the dry period. (From: "Die Landschaft der Negev-Wüste in Vergangenheit und Gegenwart".)

As long as the crust has not been formed, most of the rain infiltrates through the soil surface. Once the crust is there, the infiltration rate drops strongly and most of the rain runs off over the crust.

If the rain is of low intensity, the diffusion zones do not come into contact fast enough: for the evaporation — promoted by the strong winds which usually accompany the rainfalls — starts immediately and prevents the formation of the crust. In that case the runoff rate remains rather low and no flood occurs.

In fact, rain intensity and infiltration rate are more important for the creation of runoff floods than the amount of rain.

If the crust is being formed quickly, about 30–50% of the rainfall run off in a flood. This runoff water contains no harmful salts, and it is in every respect first rate water.

Ancient Methods of Desert Irrigation

The remains of ancient agriculture in the Negev can best be recognized from the air. It can be easily seen that the agriculture was strictly limited to the wadis and flood plains; that means to those areas where loess of 2–3 m of depth prevails. The reason for this is the fact that for the storing up of water for the dry season a layer of loess of a certain depth is needed. Investigations over some years have proved that the ancient desert agriculture was based exclusively on the utilization of runoff water. The water which came running down the slopes was collected in channels and led to the fields in the valleys. The local farmers, furthermore, invented an ingenious method how to increase the runoff rate considerably. The surface of the hills is usually covered with rocks and gravel, the well-known "desert-pavement". When it rains and the water starts running down the slope, the stones prevent the building of a complete crust. What is more, every stone holds back some water which infiltrates through the soil surface. Thus, if one removes the stones from the surface, the water harvest will become much greater. That is the reason why we find, in the catchment areas of the ancient farms, thousands of hectares covered with gravel strips and stone mounds. These strips and mounds resulted from the removal of the stones from the soil surface. The strips have the additional function to lead the flood runoff water in a certain direction. The Bedouin call these mounds "Tuleiat el Anab".

Solid stone walls served as borders of the fields. The ancient farmers cultivated even wide plains and made them fertile.



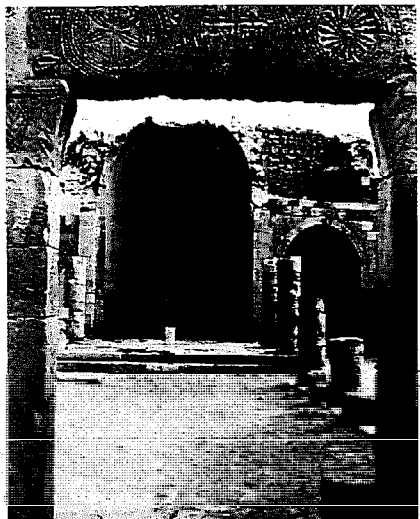
The Utilization: Runoff Farms

Hundreds of such runoff farms are to be found in the Negev. Every one of them consists of a farm-house or a watch tower, a few terraced fields, which are surrounded by a stone wall, and the catchment area, that is the adjacent hills and slopes. The farm gets its water by means of channels collecting the runoff water of the slopes. If the farm is located near a small wadi, the flood water of this watercourse is led to the fields as well. The terrace walls are built of two to three rows of stones and they are about 30–50 cm high. The distance from one wall to the next is the same with almost all farms; that is about 15 m.

After a runoff flood the terrace is like a pool. It takes the water 2–3 days to infiltrate completely into the soil. The height of the terrace walls determines the amount of water that can be retained. According to experiments, 1 mm of water suffices to moisten 8–10 mm of soil up to its full water holding capacity. The amount of water retained by a terrace wall of 30 cm height is therefore sufficient to wet completely a loess soil 2–3 m deep. The farmers of ancient times must have known this relation, for the ratio of the terrace walls to the depth of the soil is 1 : 8 or 1 : 10.

Should the flood produce more water than 30 cm for each terrace, the surplus is being led out over a spillway. These spillways are openings in the terrace walls which lead over a kind of stone

The Reconstruction of Two Ancient Farms

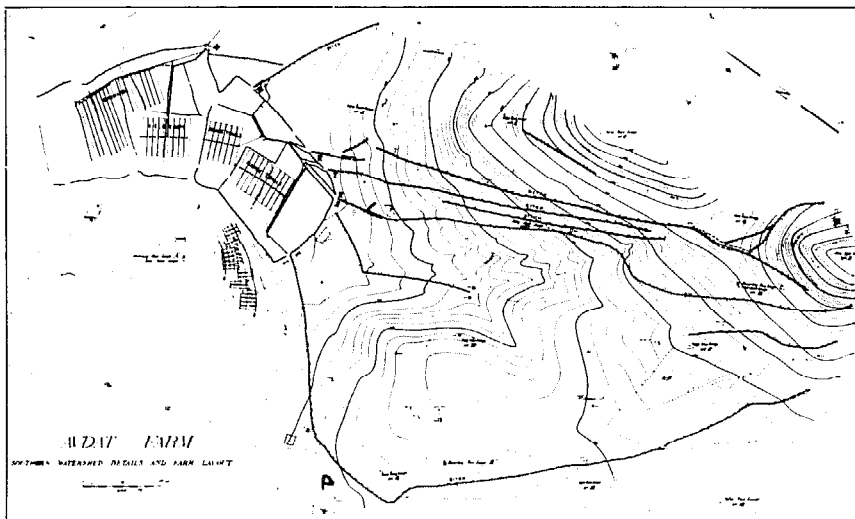


Majestic remains of churches in the ruined desert towns remind the visitor of their magnificence reached during the reign of the Roman and Byzantine Empire until the Arab conquest. The desert farmers traded with the caravans arriving from many parts of the world.

staircase to the deeper lying terrace. The water has to run over the "stairs", and so the destruction of the walls and erosion are prevented.

If the loess is once wetted to a depth of 2-3 m, all cultivated plants have enough water for a whole season.

An exact survey of hundreds of farms showed that the ratio of the cultivated area to the catchment area is 1 : 20 to 1 : 30. A simple calculation reveals the meaning of this fact. Let us suppose that the rainfall of one season amounts to 100 mm, that the catchment area is 20 times as large as the cultivated area and that 25% of the rain run off. That means that the farm receives $20 \times 25 = 500$ mm of runoff water in addition to the 100 mm of rain.



From: "Progress Report on the Avdat and Shivta Farm Projects 1958-62".

Two ancient farms were reconstructed. One, near the ruins of Shivta, covers an area of 1.5 hectare; the second near Avdat consists of 5 hectares. The scientific program on both farms contained the following items:

1. Meteorology:

- a) Measuring of rainfall and dew (daily and annual amounts, rainfall rates and intensity).
- b) Daily measurements of air and soil temperature, air humidity.
- c) Recording of the rainfall distribution in the catchment areas.

2. Hydrology:

- a) Recording of quantity, quality and rates of runoff from the catchment areas.
- b) Measuring of infiltration and runoff rates in the catchment areas.
- c) Analysing the relation between rainfall and runoff.

3. Range Plants:

- a) Selecting range plants which are drought resistant and yield well.
- b) Measuring water consumption and water use efficiency of representative species under natural flood conditions.

4. Orchard:

Recording the development of fruit trees, their water consumption and their yields under natural flood conditions.

5. Crops:

Measuring the yields of different species under natural flood conditions.

6. Vegetables:

Testing the possibility of growing vegetables under natural flood conditions.

The reconstruction of the Shivta farm was started in 1958, that of Avdat was begun one year later. In 1960 both farm units were functioning. On both farms the ancient terraces, stone walls, channels, and water gates were reconstructed exactly as they had been once.

On each farm a meteorological station was installed, and many rain gauges were set up in the farm and all over the catchment area.

At every water gate the water, brought down from the hillsides in channels, is being measured at a weir by an automatic flood gauge. In this way the amount of water, its flow intensity and the duration of every flood can be recorded accurately. By comparing these data with those of the rain gauges rain-flood relationship can be analysed.

Since in Avdat — in contrast to Shivta — not only trees, but also vegetables, field crops, and pasture plants are being grown, and since furthermore the water consumption of the different plants is being measured, it was necessary to guarantee an equal distribution of the flood water over all the experimental fields. For this purpose the flood water streaming into the farm is not directly distributed into the fields. Its flow is first measured by the automatic flood gauges at each point where a channel enters the farm. The water coming from various flood gates is then lead into concrete channels from where it passes through a distribution box provided with a water meter into pipes. These pipes lead the water to vertical risers which have two outlets each and thus

equally distribute the runoff water to two plots each. The plots are surrounded by an earth dam, 30 cm high. If the plots have received as much water as they can hold a shutter closes the distribution box and the water is lead into a second pipe. Thus full control over the quantity and over the distribution of the flood water is guaranteed. To test how deep the water infiltrates the soil, how much the plants consume in how long a time, and how much water evaporates at the surface, the soil moisture in some representative plots is measured regularly. All agricultural plants on both farms are being regularly controlled and their growth recorded. After the first flood in 1959 the first trees were planted in Shivta. Here as well as in Avdat the trees got some water when they were planted and during the first summer (about 30 l) to facilitate their

taking root. Later on they were completely dependent on the floods.

In Shivta only such trees were planted that are known to have been grown on the ancient farms. In old documents from the 6th and 7th century A. D. detailed reports about the trees grown at that time can be found. In Shivta were planted: olives, pomegranates, almonds, figs, vines, carobs, pistachio nuts, apricots, peaches, and plums, altogether 283 trees and bushes.

Almonds, olives, pomegranate, apricots and carobs have developed best. That is especially remarkable since the first years of the farm were drought years.

The working plan of Avdat differs from that of Shivta in some respect. The 404 trees were selected only with regard to their supposed resistance to drought.

(Apart from the varieties planted in Shivta, cherries, apples and loganberries were chosen.) Almonds, apricots, peaches, pistachio nuts and vines thrived best. They have survived the years of drought very well, and with regard to their development and growth they prove quite yielding.

Furthermore experiments with the following *pasture plants* and *field crops* were carried out in Avdat:

Pasture Plants

One of the possibilities of making agricultural use of the desert is to regenerate the once expansive pasture-grounds. For this purpose annual and perennial range plants were planted in a number of plots. The perennials were planted as seedlings, while the annuals were sown at the same time. Out of the 44 tested varieties and ecotypes of the annuals only 7 proved useful (6 varieties of *Medicago hispida* and *Trigonella arabica*.)

They survived the droughts occurring during 9 years of the experimental period quite well and they succeed to self seed from year to year; this latter fact is very important, if one wants to use annuals for the improvement of the pasture. These varieties produce also good yields of 20–25 tons/hectare fresh weight – equaling 4–6 tons/hectare dry weight –.

A vetch (*Vicia dasycarpa*) gave the highest yields, but it was less drought persistent.

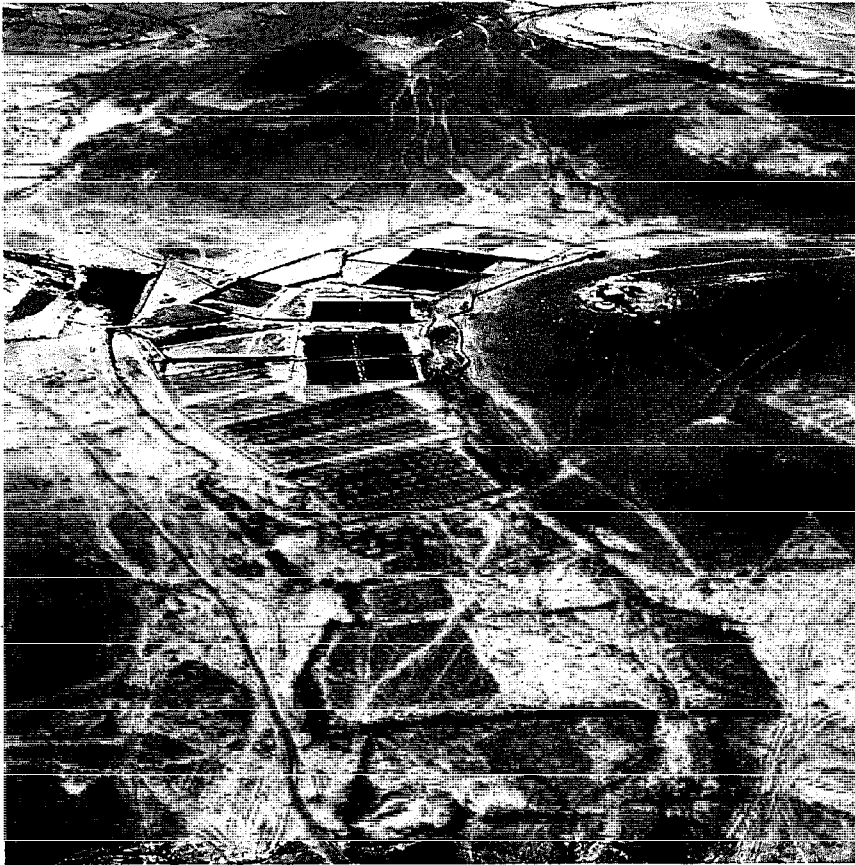
Among the 81 different species and ecotypes of perennial pasture plants

AVDAT Field Crops Yields

Crop	Use	Year	Yield (t/ha)	Notes
Wheat "Nanasit"	grain	1966	4.4	straw, dry weight 3.7 t/ha
Barley	grain	1966	4.8	
Peas "Perfection"	seed	1966	5.6	
Peas "Dun"	whole plant	1966	48.4	
Radishes	seed	1964	0.62	is fresh weight, its dry weight was 12.9 t/ha
Carrots	seed	1965	0.75	
Onions	seed	1974	1.16	
Onions	bulbs	1972	40.0	
Sunflower	grain	1974	2.8	
Safflower	grain	1972	3.3	
Chick peas	grain	1972	2.4	
Artichokes		1965	9.5	
Asparagus	shoots	1965	2.0	

AVDAT yields (Average yield per tree kg)

Species	Variety	Root-stock	Planting Year	Net weight dry shelled kgms (almond & pistachio)								
				1966	1967	1968	1969	1970	1971	1972	1973	1974
Almond	Poriya 10	Almond	1961	1.3	2.0	2.8	1.0	2.7	3.7	6.6	3.9	5.8
	Thabor	Almond	1962	1.7	1.7	1.0	2.0	2.0	1.8	5.0	2.9	6.2
	Ne Plus Ultra	Almond	1961/62	1.7	2.1	2.5	1.3	2.1	2.0	8.7	2.5	10.0
Pistachio	Kerman	Atlantica	1962	—	—	—	—	0.2	1.0	6.9	8.9	10.9
	Lassen	Vera	1964 grafted	—	—	—	—	0.1	3.1	3.2	4.7	9.8
Peach	Early Red	Almond	1961/62	20.1	27.7	20.2	4.5	5.2	12.0	27.2	11.4	112.7
	Free Robin	Almond	1962/63	10.9	22.8	37.7	16.3	8.2	26.8	40.4	7.8	60.7
Apricot	Colomer	Chlabi	1961/62	14.1	24.8	4.1	6.4	8.5	23.2	32.5	13.9	42.5
Grape Vine	Dabouki		1962	—	2.4	1.0	1.8	6.5	5.4	9.7	2.0	12.5



Aerial photograph of the Avdat farm and its watershed. In the foreground: unreconstructed ancient terraces. In the background: on the slopes one can easily identify the channels leading the runoff water to the farm.

A flooded orchard on the Avdat farm: loganberries and peach trees.



The flood water of the wadi flows over a weir at gate No. 8 into the farm and unto the fields.

Medicago sativa, Oryzopsis miliacea, and Phalaris tuberosa survived a drought of 34 months without any damage and yielded 25–30 t/ha fresh weight -- equaling 6–11 t/ha dry weight.

Field Crops

4 plots have been reserved for experiments with field crops. As one has to wait with the sowing for the first flood which sometimes occurs early, sometimes late, there exist two alternative possibilities. If the first flood occurs *before* the 15th December, winter crops, such as wheat and barley, legumes, onions and vegetables may be sown. If the first flood occurs *after* the 15th December, the following summer crops can be grown: sorghum, sesam, chick pea, safflower (Carthamus), and sunflower.

Wheat, barley, onions, and peas gave good yields, while chick peas, sesame and safflower did not yield much.

Among the vegetables asparagus and artichokes thrived especially well.

Another Method How to Use the Floods for Agriculture: the Microcatchments

Experiments with runoff plots of different size were carried out in Avdat.

These trials showed that the percentage of runoff becomes higher the smaller the size of the plot is. This is a scientifically interesting fact which has practical significance, too. That is to say that a tree, having a catchment area of its own, ought to get relatively more runoff water than a comparable tree on the terrace of a farm.

Consequently experiments were started with microcatchments. Each microcatchment is simultaneously catchment and cultivated area. A softly sloping flood plain, 1.8 hectares large, near the Avdat farm was chosen for the experiment. The loess soil was quite saline containing 1–2.5% of soluble salts, 0.3–1.3% of this amount being chlorine.

Gypsum was present in all layers, and the lime content was as high as 27–55%.

This soil composition is typical for the loessial plains of the Negev Highlands.

The area was subdivided into microcatchments of different size, a border check about 15 cm high was raised around each plot, and in the 30–40 cm deep basin of each plot one tree or one bush was planted. Since one could find out only by trial the optimal size of the catchment for each species, one specimen of each species was planted into plots of $\frac{1}{10}$, $\frac{1}{20}$, $\frac{1}{40}$, $\frac{1}{60}$, $\frac{1}{160}$, $\frac{1}{320}$, and $\frac{1}{640}$ hectare. We selected those plants that are most resistant to salt: pomegranates, vines, apricots, olives, pistachio, carobs and salt bushes (*Atriplex halimus*).

Before the trees were planted we fertilized the soil with 30 kg of manure. At planting time the trees received 30 l of water each and were covered with straw.

To insure their establishment, each tree received additionally 150 l of water in 5 installments during the summer. Later the trees did no longer get any artificial



irrigation. The salt bush did not even receive supplementary irrigation at planting time.

The trees and salt bushes rooted well (2 pomegranates and 2 salt bushes failed to take root), and the apricots sprouted quickly and satisfactory. Pomegranates and vines were delayed in growth, but later on developed as good as the other trees.

Some salt bushes were planted also without catchment ("Zero catchment") on the open loessial plain: None of the zero-catchment plants survived, because they did not receive any flood water.

The only tree that did not grow well is the carob.

The optimal size of the catchment was found to be about 250 m² for trees, 100–125 m² for vines, and 16–32 m² for salt bushes. A second important result was the fact, that the floods had leached the soil in the basins almost completely within two years.

On the whole the microcatchment experiments developed so satisfactory that on the large new farm of *Wadi Mashash* with its 3000 trees (almond, pistachio, olive) we made use mainly of this microcatchment method. The plot size in *Wadi Mashash* is $\frac{1}{40}$ hectare (250 m²). The trees did not even receive supplementary irrigation at planting

time, they were planted immediately after a flood.

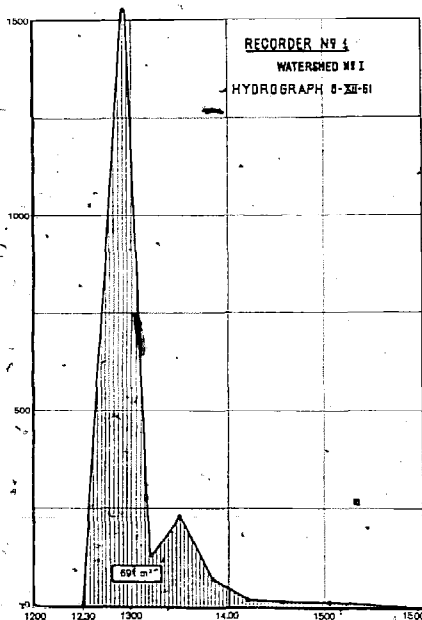
The advantages of the microcatchments are:

1. They are cheaper than the farms since no terraces, channels nor stone fences are required.
2. With this method larger areas of the Negev can be cultivated than with the farm method which is topographically confined to certain localities.
3. The relative water harvest of the microcatchments is higher than that of the large catchment areas of the farms.
4. Rainfalls of low intensity and short duration, which are ineffective on farms since they cause no flood, are effective, however, on the microcatchments and produce runoff. To give one example: in a certain rainy season in Avdat 6 floods were recorded on the microcatchments, while only 1 flood occurred on the farm.
5. Even saline soils can be used, since the floods are great enough to leach the soil within 1–2 years time.

Hydrological Data

We will give the example of one flood recorded in Avdad, to point out some of the typical observations. During this flood 4457 m³ of runoff water streamed through the 8 weirs altogether. The curve of the automatic rain gauge shows that the amount of 12.5 mm of rain sufficed to cause this enormous quantity of runoff water. Most of the rain fell within one and a half hour (11 mm), and within this time two periods of extremely high rain intensity can be distinguished. (12.30 h–12.48 h, and 13.12 h–13.30 h).

The highest intensity rate was 17.1 mm/h at one rain gauge, at another it reached even 48 mm/h. This high intensity lasted only a few minutes, however.



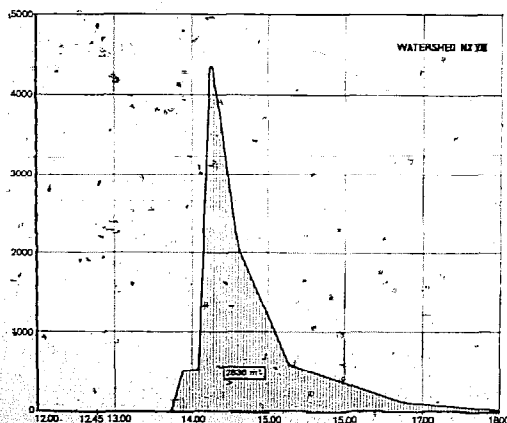
Comparing the rain intensity with the recording of the automatic flood gauge one can clearly see that the two periods of high intensity re-occur in the two peaks of the flood curve. It is rather surprising how little time it takes the rain to cause the flood and the flood to reach its peak intensity of 1530 m³/h.

Only at the weir "8" a different curve was registered. The flood water of quite a long wadi, is being led through this weir into the farm, that means that the watershed area of this weir is much larger than that of the other weirs.

Consequently, the flood reached weir No. 8 with a delay of 75 minutes. The flood curve, therefore, shows only one peak, as the two successive peaks of rain intensity became one, due to the longer distance. The maximal flood intensity amounted to 4340 m³/h at weir No. 8 and the flood lasted longer than at the other weirs.

Altogether this rain of 12.5 mm brought enough water to insure the growth of all the plants on the farm for one season. These observations, clearly indicate, what has been emphasized before, that not so much the absolute amount of rain, but mainly its intensity is the important factor that causes a flash flood. It happened that 5 mm of intensive rain caused a flood, while at a 10–15 mm rainfall of low intensity no flood occurred.

From: "Progress Report on the Avdad and Shivta Farm Projects 1958–62".



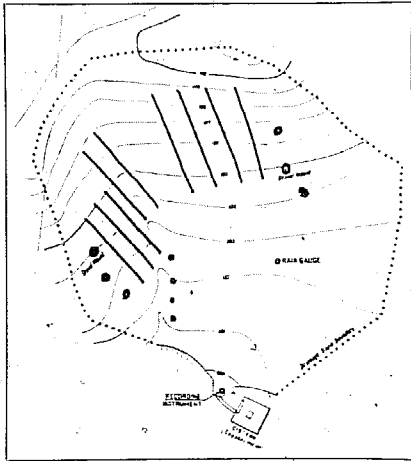
"It is hard to realize what a revolutionary change was effected in the history of civilization when cisterns were invented — that is, when men learned to dig holes in any kind of ground and plaster them so that they could serve as storage places for water. Without cisterns, few of the Judean fortresses and villages in the Negev could have been constructed. And without the still larger number of cisterns, dams and terraces in the Nabataean and Byzantine periods, the Negev could never have been made to sustain the tens of thousands of inhabitants who lived there then.

The great Nabataean to Byzantine cities in the Negev, some of which were built on hilltops, could never have come into existence without reservoirs and without at least one cistern in every house." (Nelson Glueck, *Rivers in the Desert*, Norton Library, New York, 1968; p. 94–95).

Modern man can only admire the accomplishments of the ancient farmers and inhabitants of the desert. The fact that many of the ancient cisterns are still functioning, though they have not been cared for during many centuries, proves the care with which they have been built.

An ancient cistern of 440 m³ of capacity was reconstructed near the road to the ruins of Shivta. The farm of Shivta lies at a distance of 600 m from it. The original channel, collecting the runoff from a watershed area of 1.2 hectare and leading it into the cistern, was reconstructed and a flood gauge set up near the inlet of the cistern. Since most cisterns have only small inlets and small holes for the drawing of water, they are screened from direct sunlight, and the evaporation rate is small.

Apart from the collection of runoff the ancient settlers made extensive use of wells which gave water through the whole year. Nelson Glueck comments: "From Ain Quadeis and Ain el-Qudeirat (Kadesh-barnea) in Sinai, there is an irregular line of watering places which have been used from earliest antiquity on and are of much importance in modern times too . . . The Way of Wells, as it might be called, was the shortest, easiest, and most direct one between Sinai and Canaan." (Nelson Glueck, *Rivers in the Desert*, p. 88). One of the wells of this ancient caravan-route is Bor Mashash, again used today on the



From: "Progress Report on the Avdat and Shivta Farm Projects 1958-62".



After heavy rain storms enormous torrential floods stream through the wadis. The photograph shows a flood in Wadi Mashash.

farm of Mashash. On ancient maps of the Negev this well is always clearly marked.

These ancient wells help the archeologist in his search for early human history, but for the explorer of the desert they signify something else: If these wells have given water to an endless chain of generations — and the deep grooves cut into the stones at the rim of the wells testify hundreds of years of drawing water — then the climate has not changed.

When reconstructing the ancient farms of Avdat and Shivta the scientists mainly aimed at re-discovering the ancient knowledge and skill. The farm of WADI MASHASH, however, uses this experience and skill already in a practical way.

In the dry season the two dug-out wells provide for 4 m³ of water per day.

5-8 men and about 300-350 sheep live on this water. The water of the two cisterns (400 m³ altogether) guarantees the water supply for another 5 months.

There exists no other agricultural settlement in the Negev which makes use only of the floods and the natural water reservoirs such as wells and cisterns. Most of the modern settlements in the desert area of the Negev have been founded after World War II and are attached to the central water supply by means of a pipeline. Asphalt roads, electricity, gaz, in short all the luxury of the 20th century make people often

forget that they are living in an arid zone.

South of Beer Sheba are some urban settlements and only a few villages which live mainly on agriculture. Three "quibutzim" (collective villages) are situated not far from Avdat and Wadi Mashash and therefore can be easily compared with our farms. In all three of them agriculture is exclusively based on artificial irrigation. They do not breed cattle on the natural pasture-grounds. Why not? One settler explained the reasons:

By 1940 a small group of people started to survey the soil in the neighbourhood of the village of today. They wanted to know if the local conditions of loessial, sandy soil and brackish water would permit any agriculture. The annual rainfall amounts to about 100 mm, that means that agriculture is impossible without runoff water or artificial irrigation. The well of brackish water produces 12-15 m³ per hour, its salinity is 0.1%. No one knew whether brackish water could be used for agriculture. Therefore the settlers tried to grow customary vegetables, but without success. Today it is known, however, that cotton, wheat, and turnip give good yields with irrigation of brackish water.

In 1954 a large dam was constructed in Wadi Revivim. It was planned to lead the flood water of the wadi to great reservoirs (250 000 m³) near the settlement. The flood water was to be lead through a 1 km long earthen channel to

the fields. The expensive project was a total failure.

The construction was only used for 5 years. For the last 20 years it has been decaying but it still looks impressive. We are fortunate to have been told the reasons for the failure, for this failure can teach us a lesson:

1. The ownership of the land did not allow the construction of the dam at the best topographical point.

2. Lack of time for thorough flood observations over years made people underestimate the immense amount of alluvial deposits which the floods carry along.

Thus the dam construction, the channels and the reservoirs got quickly filled up with these deposits.

3. The high infiltration and evaporation rate of the reservoirs demanded immediate use of the water. But in winter, when the reservoirs got filled, not much water was required because of the rain, while in summer, when irrigation is indispensable, no more water was left in the reservoirs.

4. The irregularity of the floods and the uncertainty of the reservoirs being filled every year — 24 hours of flood are needed per season — are impossible conditions for modern agriculture.

Loess



Microcatchments in "Wadi Masbasb" after a flood. The almond trees in the basins are standing some centimeters deep in water.

5. The construction was not sufficiently looked after because of lack of workers.

6. The construction of the water pipes from the north of the country solved the water problem.

Loess is the most suitable soil for runoff-farming in arid zones. Therefore some basic informations about the loess is important.

In ancient China yellow, the colour of the loessial soil, was a sacred colour. In China as well as in Persia and Turkestan the loess was the basis for an independent civilization and culture.

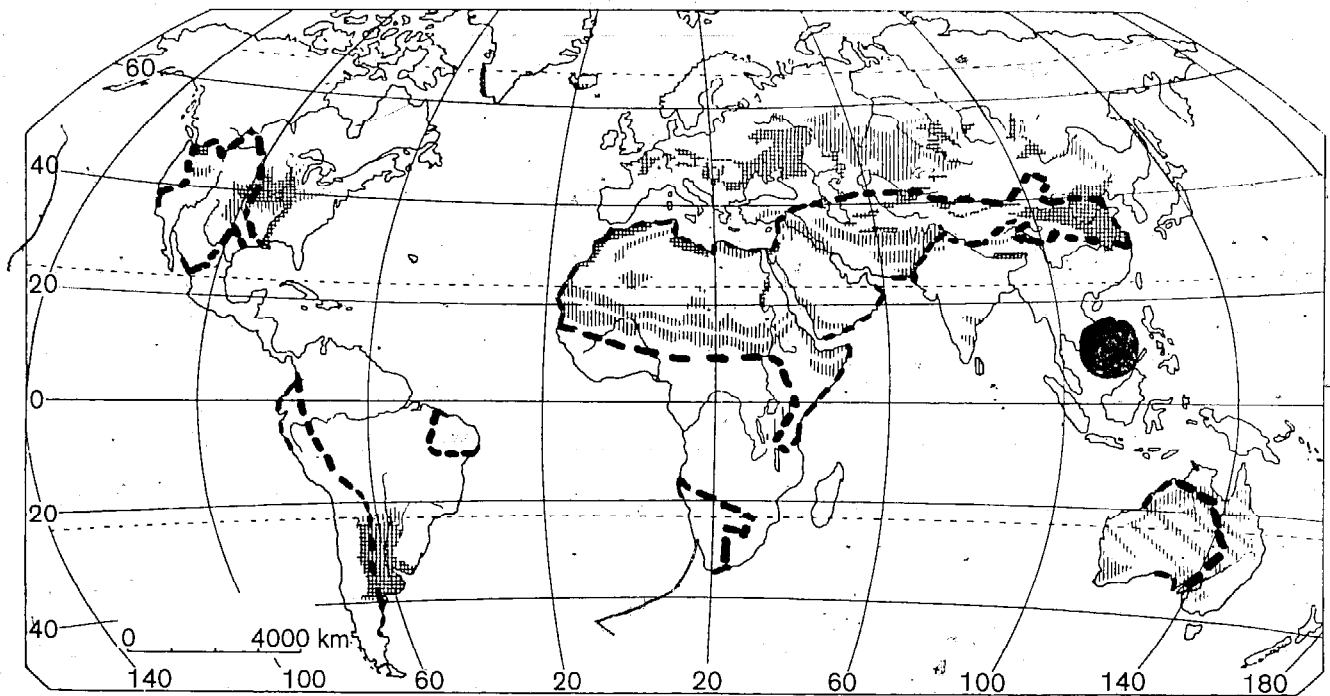
The colonization of Europe in the Early Stone Age began predominantly in loess areas where no woods covered the fertile soil. Fossil loess can be found at a certain distance of the immense glaciers of the ice age and it consists of the fine particles which the winds blowing over the vegetationless moraines at the edges of the glaciers removed (deflation) and deposited at some distance. The origin of the recent vast, and still growing loess areas of China prove to be the central Asiatic deserts, 1500–2000 km away from the area of accumulation.

The loess area in China covers more than 1 mill. km². In some regions the loess reaches a depth of more than 100 m. 4–9% of the earth's surface carries loess or loess-like soil.

The term "loess" is derived from the German word loesen (to detach), for the main characteristic is its breaking off in vertical cliffs. Though very friable the loess proves so firm that 20 m deep unplastered wells never crumble.

(In Persia and Afghanistan we have found such wells). The Chinese already recognized some centuries ago, that loess is ideally suited for the construction of roads and dams. They for example managed to control the devastating floods of the Huang Hqh by means of huge loess dams using the water for irrigation of the loessial plains.

Round the centre of a desert from which the fine sand and dust particles are being removed by winds one can find a zone of sandy soil, and at a greater distance, due to the sifting on the way, a zone of loess. To this very day loess is being deposited. Due to the transport by wind the sorting is very good. More than 60% of the loess is composed of particles with a diameter of 0.2–0.05 mm. Responsible for the fertility of the loess is its mineral composition and its mechanical structure: lime (10–13%), which may have been contained in the deposited particles, or may originate



||||| Loess probable

▣ Loess proved

▭ Arid zones of the world

in the weathering of the felspar), unweathered felspars, phosphates, other nutritive salts, small grain size.

The loess particles are not densely compacted and the loess is crumbly and porous. This accounts for its large pore volume and its high water holding capacity.

The mechanical analysis of the loess of the Negev is as follows:

30% fine sand particle diameter 0.1–0.05 mm
 40% silt 0.05–0.005 mm
 30% clay less than 0.005 mm

The 30% of fine sand and the 40% of silt form the skeleton of the soil; it checks erosion and prevents the clay particles from clogging. The protection against erosion is added to by lime, which cements the dust particles and gives cohesion to the loess. Thus the existence of cliffs, canyons, and caves of loess can be explained.

The sand contained in the loess favours the aeration and the mobility of the water in the soil. The loess soils in the

Negev have a water holding capacity of 24%. 7–8% of the soil water are not available to the plants. It is adhesive water retained by the soil with suction forces which are much higher than those which plant roots can develop.

The pH of a soil is determined by the concentration of hydrogen ions in a soil solution. The pH of the soil is very important for the growth of plants. For most plants a pH of 6–7 is optimal. The loess of the Negev has a pH of 7.5.

Arid zones usually suffer from saline soil. The salts derive partly from the weathering of saline rocks, and partly they have been deposited by salt-containing winds blowing in from the oceans. The loessial plains of the Negev show different salinity.

The salinity on the farms of Avdat and Shivta was very low from the beginning, on the microcatchments however it was high (1–2.5%). High soil salinity, especially a high percentage of common salt – sodium chloride – is harmful to plants.

If it is impossible to leach the salt to deeper layers or to neutralize it in other ways it can be removed biologically

by means of a halophilous plant as e. g. the saltbush (*Atriplex*) which grows well on extremely saline soils and its root take up much sodium chloride from the soil. Cutting the foliage when it is still green one can reduce the salinity of the soil, as it has been practised in the pasis of Gezira in Sudan.

Salinity can be determined by measuring electric conductivity expressed in millimhos (mmhos) compared with gravimetric measurement expressed in percentages of weight.

The first soil samples taken before the erection of the Wadi Mashash farm showed a salinity of 25 mmhos on an average for a profile depth of 0–2.5 m. After one rainy season only, the average salinity had been reduced to 2–6 mmhos. That means, that within one rainy season of 3–4 floods leaching had reduced salinity to $\frac{1}{4}$ and even to $\frac{1}{12}$ of the original amount. Cultivated plants tolerate soils of 4–8 mmhos without damage.

The resistance of plants to salinity increases with age.

The soils on the farm of Wadi Mashash were divided into two categories:

Lessons Learned from the Establishment of the Wadi Mashash Farm

Class I: No gravel layer appears in the first 2.50 m of depth.

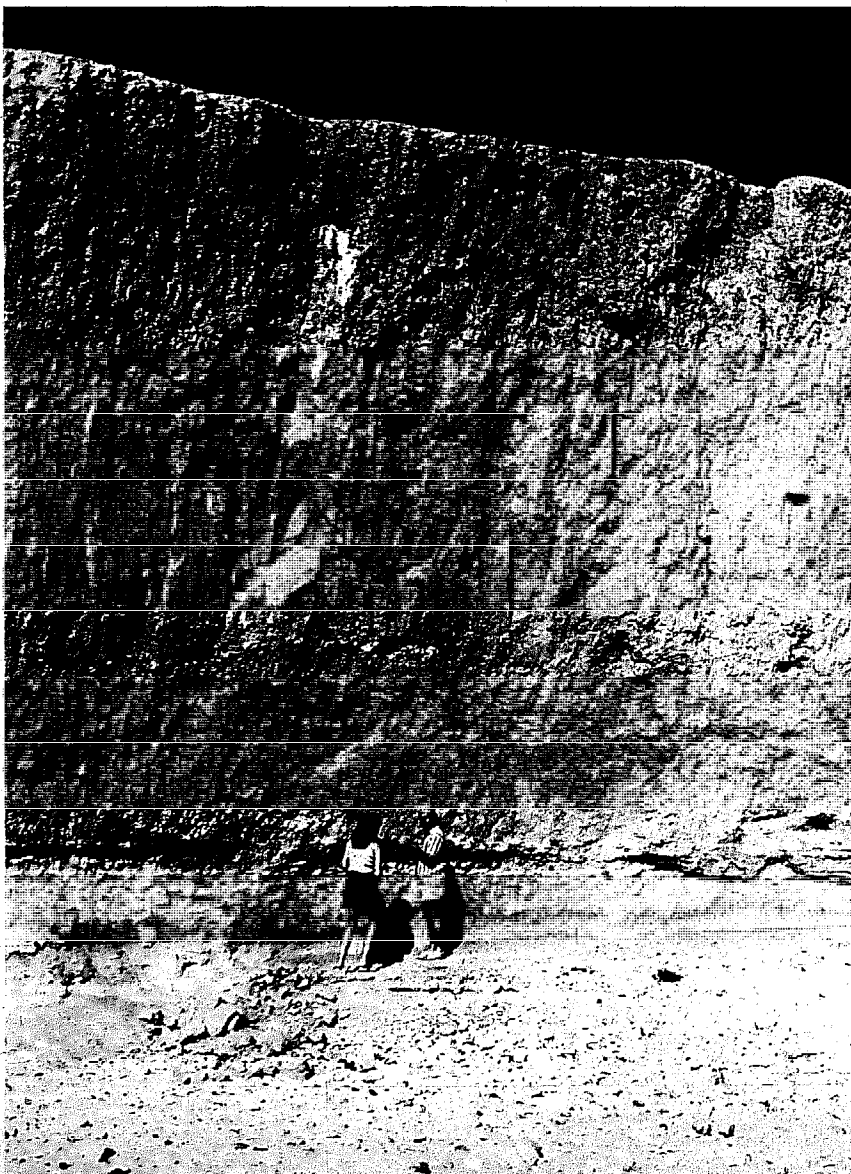
Class II: A gravel layer appears within the first 2.50 m of depth.

By gravel layer it is meant a layer in which stones larger than 2 cm take up more than 75% of the total volume of the soil. In Class I soils calcium carbonate concretions may appear in a depth of 80 to 150 cm. For the orchard only Class I land was chosen because of its good texture, aeration and the ease with which it can be cultivated.



The loessial crust promotes runoff and is therefore an essential condition of desert agriculture.

Loess deposits many meters high in the Negev.



The reconstruction of the ancient farm units of Avdat and Shivta was the basis for the experimental farm of Wadi Mashash. The following questions had to be answered:

1. Can the knowledge gained in Avdat and Shivta be used in a practical way for agriculture in arid regions?
2. Which scientific experiments and investigations have to be carried out when planning runoff-farming in any region? Which knowledge is scientifically interesting but without practical importance?
3. What is the best way to transfer knowledge gained scientifically to an economically relevant level?
Since we believe that one can learn a lesson from our positive and negative experiences made during the construction of the farm, we report here on the chronological development of the project.

Selection of the Area and Clarification of the Ownership

A team of experts from the Avdat farm together with some other specialists toured the Negev and finally decided on the Wadi Mashash area. This decision was influenced by a number of advantages: the wide wadi with its relatively rich pasture-grounds, the convenient topographical conditions for the construction of large field units for the orchard, and the neighborhood of a town (Beer Sheva). At that time a number of flocks of sheep and goats was still grazing on this area of about 2000 hectares.

The area was obviously "owned" by the Bedouin tribe El Asame, whose head is Sheik Ode Abu-Muamer. From time to time the area was also used by the army for training purposes. Legally, however, land is almost exclusively owned by the state and can only be taken on lease. After endless negotiations held on three levels at the same time — with the Bedouin, with the army, and with the state — we finally obtained the following agreement: The

army dispensed with the area in favour of the Hebrew University, and the state gave a 3 years lease to the Hebrew University of Jerusalem. It was promised that this lease will be prolonged without any difficulties: These negotiations were only held by local residents, since it is not advisable for foreigners to interfere with questions concerning the army or the lease of land. When these tedious and time-consuming negotiations came to an end, part of the farm was already ready for use. This risk could be taken as it had been obvious from the beginning, that this project was regarded favourably.

Local residents and foreigners together negotiated with the Bedouin tribe. These negotiations were mediated by the military commissioner for the Bedouin and by the lawyer of the Bedouin sheik in Beer Sheba. When we were ready to sign a contract with the Sheik, we were told that from a legal point of view the area of Wadi Mashash is not owned by the Bedouin. Their grazing right in this area is only based on custom and has to be renewed every year.

Their grazing right was therefore not renewed, and so the Bedouin would have been forced to leave the area without any compensation. We could not agree to such an arrangement, for it would have affected the aim of our project. Our work is meant to help the nomadic population and to check hunger in desert areas. Therefore it was impossible to start with an eviction of the Bedouin, which wanted to benefit of the runoff-farming.

Thus we fulfilled the contract with the Bedouin sheik, though it never was officially signed. In a ceremony of shaking hands we sealed our mutual friendship, and indeed, the result was a very good, though not always frictionless, but rather original and friendly cooperation. We paid our instalments in time, and the sheik sent us workers of his tribe who were paid by us. Of course, there were small misunderstandings and sometimes problems with Bedouin flocks grazing within our area. But if there had been hostility or lack of interest on the part of the Bedouin, our farm would probably not have succeeded.

After some months we found out that the Bedouin families in Wadi Mashash did not receive their share of the compensation we had paid the sheik. What

were we supposed to do? Should we pay individual supplementary compensation to each of the families? But nobody knew exactly which family had lived here at what time. Should we call the sheik to account, or should we encourage some families to complain to the sheik? We had passionate discussions within our group. Finally we decided to accept fully the authority of the sheik, not to interfere with the internal affairs of the tribe, and not to try to make the Bedouin adjust their concepts of right and justice to our Western ones. We continued to employ only Bedouin which the sheik recommended, and we asked for his permission.

To help the concerned families we changed our policy. We reserved the cultivable area (about 500 hectare) exclusively for ourselves. Later we also fenced it in. In the remaining area we "allowed" grazing of flocks, sporadic growing of crop and let some Bedouin families put up their tents in this area (we "allowed" means, we simply shut our eyes). In 1972 we even placed the pasture within the fence at the disposal of the Bedouin, but in this case we left it to the sheik to select the families since we intended to avoid any interference with the affairs of the tribe. In fact, we let the El Asasme Bedouin graze on the watershed area of the farm (1500 ha) though this area is an indispensable part of the farm unit as the ancient runoff-farming has proved.

But as long as they do not disturb the work on the farm, and they have not done so up to now, this form of peaceful coexistence may continue.

Rain Data, Runoff-plots, and Soil Samples

Though the Negev is thinly populated with only a few roads, and although it has only recently become an object of scientific interest, some meteorological observations have been made there for about 25 years before 1948. But extensive records exist only from 1948 onwards. They give a general idea of rainfall and its distribution. Nevertheless, we had to set up more than 20 rain gauges all over the farm area, which we control after every rain fall. These records are indispensable because rainfall in deserts varies tremendously within short distances.

Runoff measurements in the especially constructed runoff-plots are of utmost importance since the size of the micro-catchments depends decisively on the ratio of rainfall to runoff. The small runoff-plots should be fenced-in so that they can not be damaged.

In Wadi Mashash we measured runoff for one year only before deciding on the size of the microcatchments. But in a new area these runoff observations should be carried out at least for two years, before runoff-farming is started.

The soil samples taken from the fourty pits, each 2.50 m deep, provided important information about the soil profile. A number of soil qualities could be determined by experts on the spot, in addition to this a representative selection of samples was sent to be analysed.

The Necessity of Maps

We used an aerial photograph of the area. Then we drew a map on a scale of 1 : 10 000. Another map on a scale of 1 : 1000 was drawn of those areas where trees and pasture plants were to be grown. For the needs of the experimental farm of Wadi Masash these accurate and rather expensive maps were justified. On a "normal" farm one can certainly dispense with such detailed maps, since anyway, even with the maps, a number of surveys have to be conducted in the area. Therefore in "normal" cases exact sketch maps are sufficient.



Young olive trees behind an earthen dam in Wadi Mashash after a flood.

After every flood the basin must be hoed. Here it is done by a rotary hoe.



Construction of the Orchard

For the survey of the area and the soil analysis we could rely on teams of specialists. But when we started the 3000 microcatchments, each one with an area of 250 m², we were faced with a problem since nobody had any experience regarding such a large project.

The small experimental area of Avdat, consisting of only 117 plots of different size, had not been constructed in one year, consequently its lay-out was not to be compared with the immense technical problems of the new construction in Wadi Mashash. After the soil analyses had been evaluated and the area had been surveyed, the area set apart for the orchard had to be divided into micro-catchments. Unfortunately the planning did not work well, so that we lost a good deal of precious time. What is more, not all 3000 plots for the trees could be finished at one time, so that later on the survey team and the excavator had to come for a second time. When the plots were surveyed one by one it became obvious that it is not easy at all to determine the deepest point of an area. As the time pressed and the water engineer was overloaded with work, we often had to take ad hoc decisions which of course lead to otherwise avoidable mistakes. In fact, the planning phase should be completed before the beginning of the rainy season, and the responsible expert should be present when the constructing phase begins. About 40 hectares of the orchard area had to be leveled by a motor grader, because the previous Bedouin cultivation had left deep furrows. The driver of the motor grader managed to level about 15 ha in a ten-hours working day.

The motor grader was followed by the excavators. They had to dig the basins (3.5 m x 3.5 m, 20 cm deep). The 50 cm deep planting hole was also dug by the excavators. Since the excavators were supposed to make as few ruts as possible in order not to destroy the soil crust, one of our group who spoke Hebrew had to accompany each driver. With the observer attentive and the driver talented, most of the basins got square in the end. A JCB-No.3-excavator dug about 35 basins in a ten-hours working day. 15 minutes of manual refining work were needed for each basin.

A tractor with two discs raised the low border checks (20 cm high) between the

plots. Border checks of about 25 catchments can be made in one hour. It might be possible to raise the border checks before the basins are dug, which would be easier for the driver of the tractor.

In front of each field unit — consisting of 10–500 microcatchments dependent on the topography — we had to dig a water diversion channel. The motor grader did this work in two working days of 10 hours each.

If a microcatchment is constructed by manual work, it takes 4 good workers about 60 minutes to dig the basin (3.5 m x 3.5 m, and 20 cm deep) and to raise the border checks of about 20 cm of height around the 250 m² — sized area. When we erected the Wadi Mashash farm the labour cost equaled the cost for the machines. But if there is enough time, and if the labour cost is lower and there is no lack of workers, one should prefer manual work.

In spite of the above mentioned difficulties and technical problems and despite the fact that the first rainfall interfered with the progress of the work, we managed to complete 2000 microcatchments and to plant them with trees from 1st November, 1971 to 15th January, 1972.

Planting of 2000 Almond Trees

The almond trees were grown and grafted in a nursery about 60 km north of the farm. The following varieties were planted:

1000 Poriya 10
200 Greek
200 Thabor
300 Ne plus ultra
150 Um el Fahem
150 59/4

The trees were pruned to about 30 cm above the grafting knot, the roots were disinfected against nematodes, and then the trees were planted as quickly as possible. Wet jute sacks were tied round the roots to prevent their drying up.

When we planted the first 1000 trees the basins were still wet from the last flood so that we did not have to give any water. We took care not to break the roots and to trample the earth around the seedling. When we planted the second thousand we had to give 50 l

of water to each of a few hundred trees. That was tiresome work which we did but once. The water had to be brought from a distance of 10 km in a jeep trailer of 1 m³ capacity. It took 6 workers about 40 minutes to supply 20 trees with 50 l of water each.

A team of 6 workers planted about 250 trees in one working day. The cut surface of the seedlings was sealed with a paste, and the trunks were whitened with lime.

One year later the majority of the trees had taken root. Some varieties showed high failure rates — such as Ne plus ultra and Thabor with a failure rate of up to 30% — while the average failure rate amounted only to 10–15% despite the difficult conditions. The reasons for the failure were: weak seedlings; unsuitable gravel soil; "water holes" i. e. basins in which because of the soil structure the water remains standing for more than ten days suffocating the roots for lack of oxygen; damage by game (gazelles, hares etc.); salinity of the soil; and wrong position of the basin resulting in lack of water.

We planted again in the second year and the trees took root at a very good rate, though it was an extreme drought year. In addition to the almonds we planted 200 pistachio trees and 100 olive trees in spring 1972.

It is relatively easy to take care of the farm covering an area of about 70 ha of cultivated land which is divided into 13 separate field units. The cultivated area is about 3 km long because it includes small wadis and hillocks which cannot be cultivated.

After every flood all the plots must be examined for damages. Even the smallest break in a border check must be repaired immediately. After every flood the soil in the basin must be hoed, in order to

- promote root respiration;
- reduce the evaporation of water from the soil;
- facilitate the infiltration of the next flood;
- destroy the weeds.

For this purpose we bought two small HAKO — milling-machines. One machine can mill 250 basins in a 8-hours working day. One must be prepared for 2–3 milling operations in one rainy

season. Sometimes the floods follow so quickly upon each other that one can not mill before the next flood comes. Sometimes — like in 1973 — there occurs only one single flood during the whole rainy season.

In the dry period the trees only need observation. The fresh green foliage of the trees attracts vermin and game, therefore pest control may be necessary.

For this purpose we bought two portable motor-sprayers. The trees have not suffered much from pest up to now. We had to spray against the caterpillar *Anarsia lineatella* and against the plant-louse *Agrotis ypsilon* and, with olives, against the caterpillar *Chaerocampa celerio*. Pests did not cause much damage and the damage was locally confined, due to the distance that separates the trees (15 m). Thus quick propagation of the pests is checked.

Because of the shortness of the desert spring all the pests appear at the same time and can be destroyed simultaneously.

The damage done by hares and porcupines made it necessary to cover the trunk of the one and two years old trees with a protective paste.

An important operation is the pruning of the trees. We strongly pruned the young shoots every year to give the trees more strength and to increase their power of resistance to the strong wind. After the sprouting — in March as a rule — one should again prune part of the weaker shoots.

The trees should be fertilized after the first flood of the year. Most effectively this may be done together with the milling.

We fertilized as follows:

1st year: 5 kg of cow-dung per tree
2nd year: 1 kg of urea
3rd year and 4th year: 1 kg of ammonium sulphate and super phosphate each.
In the future the sheep-dung of our own flock will be used exclusively.

One worker is needed per year for all the work with the 3000 trees.

We expect the first harvest of almonds after the 5th year, that of olives and pistachio nuts after the 8th year.

**Supplementary Food Program:
Growing of Pasture Plants in Contour
Catchments and Behind Dams**

The following perennial range plants were grown in 30 000 small plastic bags filled with a mixture of sand, loess and compost: lucerne (*Medicago sativa*), *Phalaris bulbosa*, *Agropyrum elongatum*, *Oryzopsis miliacea*, and *Oryzopsis holciformis*. All these species had been successful in Avdat and were to be planted in Wadi Mashash after some months in a nursery in a quibbutz. This operation carried out by members of the management of the farm, by German volunteers and by Bedouin together was very tedious and wearisome. (It took us about 200 working-days to construct the lay-out and to care for the plants till the day of their transfer to Wadi Mashash.) The development of the plants was good.

Contourcatchments for pasture plants (see back of the title-page) were constructed in Wadi Mashash on an area of 0.5 ha, not including the catchment area. Following the contour lines, the motor grader drew a 3.50 m wide strip which was bordered by a low earthen retaining wall. Within this strip

we planted two rows of pasture plants. The distance between two walls is about 5–10 m. The space between the mounds is the catchment area for the range plants.

Though the driver of the grader did not always manage to draw the strips exactly according to the contours, and although therefore not all plants got the same amount of runoff water, the range plants developed satisfactory.

The contourcatchments are easy to mow, and the cut herbage serves the flock as dry fodder. Comparing the catchments with the natural vegetation of the vicinity one can clearly see an enormous increase in production.

Behind two dams, on an area of about 1 ha, we planted the remaining 20 000 range plants. The dams receive their water according to the Avdat method: flood water of a wadi is being led into the whole field. This plantation has been a success. Most of the plants have even survived the drought-year of 1973, when they never got any flood water but only 50 mm of rain. These dams provide us also with dry fodder for the foodless months. A second contour catchment

could not yet be planted as the floods did not occur early enough. In still another large dam we sowed Sudan grass. The result was not too good as the dam had been-flooded too often, so that more than 50% of the seed rotted, or was washed off.

We had a similar unpleasant experience when we sowed grass-seed in contour catchments. The seed was blown or washed off or had difficulties to push through the hard loess crust. The planting of the seedlings had been a success, but their growing was far too expensive in the case of Wadi Mashash. Such an operation is only feasible when the labour costs are very low.

The improvement of the natural pasture-ground proved quite successful. First, we let the pasture rest. Then we fertilized it with artificial manure and sowed *Atriplex halimus*, *Medicago hispida*, and *Vicia dasycarpa*. We, furthermore, removed in a tiresome operation hundreds of mitnan bushes (*Thymelaea hirsuta*). All this increased the carrying capacity considerably. The pasture-ground of the wadi bed produces about 800 FU/ha (1 Food unit = FU equals 1 kg of wheat, or 2.5 kg of hay, or 4 kg of oat straw).

Almond trees in microcatchments in Wadi Mashash.



Fencing-in of the Entire Farm Area

The farm area had to be fenced in. For this purpose the Australian pasture fence proved excellent. It is quite expensive to erect a 12 km long fence with hundreds of stakes and with some gates. But in this case it was absolutely necessary. 4 workers managed to erect the fence within one month. We believe that such a fence is not necessary if the farmer is living himself on the farm. We have seen this in Afghanistan.

Water Supply for Man and Beast

Orchard and range plants do not need supplementary irrigation apart from the annual rainfall. For man and animals, however, wells and cisterns are indispensable.

Our two wells and two cisterns guarantee the water-supply. The Bedouin would do with these two sources of water where they are. They would drive their flocks to the wells and draw the water by means of a bucket attached to a rope.

A small pump (RODOS) and a 1-kilowatt-generator make the drawing much easier and enable a better water-supply of the flock. In fact, a sheep should get in summer as much as 10 l a day, while the Bedouin gives only 3-5 l.

We pump the water to the pasture, because we do not want the sheep to waste so much energy by walking once or twice daily a stretch of some kilometres to the wells.

The water-supply system in Wadi Mashash consisting of two pumps, a water-pipe, an 8-kilowatt-generator and two watering-places in the pasture-ground, no doubt requires a certain amount of technical knowledge. It is also expensive but we believe that in the case of Wadi Mashash this investment was worth while because of the high price of mutton. For development of pastures in other regions we recommend the following plan which should be carried out in stages:

Utilization of the natural water sources. Simple technical machinery.

A modest investment as a starting capital.

Sheep Raising Program

We bought our flock of sheep as late as summer 1973 and we observed only one lambing period (from November 1973 to April 1974, with a lambing rate of



A Bedouin carries out pest control.

90%). Our experience therefore is quite limited.

We only can say that the flock developed quite well and that the program mentioned earlier in the text was accurately carried out.

Other desert settlements in the vicinity of Wadi Mashash have in recent years given up their flocks of sheep, because their care demanded too many workers, and sheep keeping became therefore too expensive. We hope that we can manage with one Bedouin and one part-time worker.

Research and Practical Work

The scientific research on the farms of Avdat and Shivta was carried out by professors, engineers and technical assistants. For the practical daily work experienced laymen were responsible: In Wadi Mashash we tried to develop a farm geared to the needs of simple farmers and peasants. Our aim was to run the farm in such a way that the experiences could be easily transferred to the nomads of other arid zones who are not used to this or any other kind of farming. We have tried to serve peace by providing a weapon against hunger. A team of experts and a group of laymen confronted each other. For one group science was the essence of life, and for the other it was only the instrument to accomplish one aim: To find means against poverty and hunger.

There was no strict border-line between the two groups, but tensions between the two poles arose frequently and had to be settled.

It is quite rare that scientists themselves deal with the practical application of their research; in Wadi Mashash, however, this has happened!

Though the purpose of the experimental farm of Wadi Mashash was not to be an example to the Bedouin, they were highly welcome as daily co-workers and as potential "utilizers" of the knowledge of runoff-farming. Often we could judge from their reaction to certain proposals whether our ideas and plans were realistic. For the work done in Wadi Mashash is supposed to help people all over the world whose social and cultural background is similar to that of the Bedouin.

Who are these Bedouin?

One of the first modern reports on a journey through the Sinai peninsula and the Negev was written by the Englishman Palmer. In his book published in 1870 he has some harsh words concerning the Bedouin:

"Wherever he goes he brings with him ruin, violence and neglect. To call him a 'son of the desert' is a misnomer, half the desert owes its existence to him and many fertile plains from which he has driven its useful and industrious inhabitants, become in his hand, like the 'South Country' a parched and barren wilderness."

From the 7th century A. D. the Bedouin have been roaming the Sinai and the Negev desert unhindered to the middle of the 20th century. The ingenious irrigation systems of the Nabateans and the Byzantines decayed, cisterns silted up, wells dried out, and the life giving floods now became a destructive force and slowly eroded away the once fertile fields.

Even if Palmer's opinion about the Bedouin is right one must not forget another aspect of the Bedouin problem.

The ancient Nabateans and Byzantines had managed to adapt their runoff-farming so well to the desert conditions that it fitted, even on the high level of production it had achieved, very well into the natural eco-system of the desert.

The Bedouin with their grazing flocks though destroying the ancient systems reached again an equilibrium with their desert environment. But this new equilibrium was a much lower level of production than that of the ancient cultures.

With the foundation of independent states in the Middle East the borders became impenetrable even for the Bedouin,



Prof. Evenari talks with the Bedouin sheik Ode Abu Muamer.

and this factor decisively influenced the lives of these nomads.

In 1948 about 60 000 Bedouin were living in the Negev. (The figures are not exact since not much statistic material is available.) Two third of the Bedouin fled when the state of Israel was proclaimed. About 20 000 remained and their number had increased to 35 000 by 1973. They are divided into 18 tribes, and graze their flocks on an area of

about 100 000 ha which is given to them on annual lease. On an area of 40 000 ha they try to grow barley, and the remaining 60 000 ha serve as pasture-ground.

They own about 100 000 sheep. The 70 000 ewes produce yearly about 50 000 lambs. Thus about 1000 tons of meat are being produced per year.

(The Bedouin also raise goats which economically are not so important.)

The fat-tailed Awassi sheep has been kept by the Bedouin since Abraham's days.



Since 1960 the Bedouin are more and more attracted by the modern society of Israel. It is quite normal to see a Bedouin leave his tent somewhere in the desert, walk to the main road from where he takes a bus or hitch-hikes to Beer Sheba, where he goes to work as a construction worker or as a waiter in a restaurant.

He may have some business at the municipality, or visit some relatives in hospital. He might also be a member of a transport cooperative having his own lorry parked in the evening near his traditional tent and driving it every morning into Beer Sheba to work. There are also Bedouin owning centres for agricultural machinery lending these machines to collective villages and other farms.

The salary of the Bedouin is as high as that of any member of the trade unions.

His work efficiency equals that of other workers. They are used to work with machines and all kind of technical devices. (In Wadi Mashash Bedouin drove the tractors, they worked with the milling-machines and with the portable motor-sprayers.)

In many cases the Bedouin wears European clothes and can not be distinguished from other local inhabitants.

All that represents only one aspect of the life of the modern Bedouin. Otherwise he lives in his traditional way. He stays in a tent without electricity, water, gaz, roads, modern hygiene and civilization.

His food has remained to be extremely frugal: flat unleavened bread, strongly sweetened tea, now and then a boiled potato and some tomatoes, quite rarely vegetables, and most rarely meat which is eaten only on rare festival occasions.

Though the Bedouin buys a transistor radio, jewellery for his wives, and an expensive watch for himself, he remains otherwise a traditional nomad.

The wives and children who never have changed their customary way of life care for the cattle, do the house-work and look after the small fields.

Today, many of the Bedouin try already to earn their living as hired labourers with some agriculture on the side as it has been practiced in Europe for many decades. As they have only few needs-

and do not have to pay any taxes, some of them manage to accumulate a small fortune. (One day we visited a Bedouin family in their simple tent and were told very casually that the head of the family had bought a big lorry the same day and had paid in cash!)

The government is very interested in the welfare of the nomads. It wants them first of all to become sedentary. Much was done for this purpose. Near Beer Sheba a village of nice stone bungalows was built for the Bedouin. Each house was equipped with a kitchen, a toilette, shower, large rooms, a small inner court-yard to protect the women against strangers looking at them, and with a large area behind the house for animals and any kind of portable goods.

The project was a complete failure. The houses were too solid, too modern, and too strange. The Bedouin pitched their tents behind the houses, lived in the tents and used the bungalows as storage-rooms. The sudden transition from the tent to a solid house was too drastic a jump.

When we once came to a feast with our Bedouin sheik Ode Abu Muamer he did not receive us any more in his large, majestic tent, but in an uncomfortable wooden barrack. We sat on hand-woven carpets on the floor, drank the customary coffee, and we used our fingers to eat rice and mutton from one common dish.

Two of the sheik's wives live already in barracks, but two others still stay in tents with their children. A young Bedouin who had been working with us on the farm bought a wooden barrack for his marriage. It collapsed in the first storm; but, apparently this kind of provisional living accommodations not yet immovably anchored to the soil is the appropriate accepted transition from the tent to a solid house.

A rural centre is planned for the El Asame tribe. The centre shall consist of the sheik's house, a kindergarden and a school-building. Among a number of different house types every family selects the one that fits them best. They will pay themselves for the construction of the house.

To counteract the very real danger of creating a Bedouin proletariat the government has established an agricultural advisory board for Bedouin. To make



The Bedouin Salem worked on the Wadi Mashash farm and his work was very satisfactory. In the photograph he prunes an almond tree.

this board known, employees of the ministry of agriculture visited all the sheiks. Soon they recognized that not all the Bedouin were eager to be advised.

It was then decided to arrange an exhibition of agricultural machines, fertilizers, and charts of animal diseases and their control to introduce the Bedouin visually to modern agricultural methods. This exhibition took place in a sheik's camp and it was combined with receptions and folklore entertainments.

The Bedouin were told: you know what we offer you, and you know where we are to be found, you are welcome! If you want some advise we are pleased to give it, but we do not want to force it upon you.

The members of the advisory board laid out a model field on neutral ground. It is below the dignity of a Bedouin to learn some thing from another one.

Furthermore the Bedouin receive seed-corn subsidies, in drought years, providing their fields are within the 250 mm precipitation zone.

For the improvement of sheep-breeding and for the regeneration of the pasture

we selected the fat-tailed Awassi sheep, well-known to the Bedouin. It is popular throughout the Middle Eastern deserts, and it might be an offshoot of the steppe sheep (*Ovis vignei*). On an Assyrian monument from the 8th century B. C. it is already mentioned, and later on Herodot reported this sheep to exist in Arabia. The Awassi sheep, whose name is supposed to be derived from a Bedouin tribe, the Awass, living in the Euphrates region, may be found in the hottest and driest of regions. It has the capability of drinking but once a day and then covering a grazing area of up to 15–20 km from the watering place.

It always moves as it grazes. The lumpy tail makes this breed capable of balancing the seasonal differences by means of building up food reserves in winter and spring for the dry summer months.

The Awassi sheep can store 5–10 kg of fat in its tail and live on this reserves in the meagre months of the year.

The Awassi sheep is a good, resistant partner for the Bedouin and his hard life in the desert. Could the Bedouin not learn from the sheep and store, for example, hay and straw in winter and in spring when the pasture abounds in food? In this respect the example of Wadi Mashash was not without effect.

Another important improvement would be to limit the lambing time to the few months when much food is available.

To attain this, one would have to separate the rams from the ewes and bring them together only for the purpose of insemination.

As for the fattening, the Bedouin should keep part of the lambs next to his tent in a separate fold where the lambs should be fattened. Some tribes in the northern, more rainy parts of the Negev have achieved good results with the fattening of lambs.

The improvement of the pasture in the Negev will remain a difficult task as everywhere in the world. The Bedouin see that we do not graze our flock as soon as the pasture starts to be green, but that we wait until the vegetation is 15–20 cm high. They observe that we graze according to a rotation system.

They themselves do it according to our instruction. Together with us they fertilize, they sow clover and vetch-seed, they

Opinions about the Desert Agriculture in the Negev

plant salt bushes and range plants, but they still hesitate to make use of this knowledge with their own flocks and pastures.

Why? Because we are strangers who do not live with them, who have a different cultural background and represent some higher authority. They are conservative and suspicious of everything new. They live from day to day and are not concerned about problems of tomorrow. Why should they worry about the flock as long as there is food? If no more food exists in July, they will find some, somewhere.

They have good reasons for not trying too much to improve the pasture: they do not own the land, the grazing right belongs to the tribe as a whole, not to the individual families. They fear that they might have to pay higher taxes to the sheik, if they achieve better yields. Their flock is their living bank. If cash is needed, they take a sheep and sell it at the market. In our time of high inflation rates such a barter system seems quite reasonable. The Bedouin likes big

flocks to show off his prosperity. But the bigger the flocks, the worse the pastures. The Bedouin does not yet understand this interrelation. He owns expensive camels, they give him good milk, but actually, he does not need them any more. His life — like the lives of many nomads and small farmers all over the world — is subjected to revolutionary changes but he wants to take it easy. Shortly after the last war, at a time when the situation at the labour market was bad, our Bedouin shepherd stopped working with us. His payment was very high, and his two wives and his children relieved him of guarding our flock. We also gave him water and food for his flock outside the fenced-in area, and we got on with him very well. Despite all these advantages he just did not want to go on working. The stress of having to work for some hours at a specific time every day bothered him and deprived him of his personal freedom. He is ready to work on the farm as a day-labourer, but only when *he* likes to.

The research and the practical work on the two experimental farms of Avdat and of Shivta were carried out by the Hebrew University of Jerusalem.

Prof. Dr. M. Evenari of the "Department of Botany", and Prof. Dr. N. Tadmor of the same department, as well as the water engineer L. Shanan started to work as a team in 1958. The research was subsidized by the "Ford-Foundation" from the beginning, later on also by the "Rockefeller Foundation" and the "Hillson Foundation" of New York.

Four progress reports, including photographs, charts, and tables, give an account of the work done in Avdat and in Shivta to the foundations and to scientists all over the world. (Report I, 1958—1962; Report II, 1962/63; Report III, 1963/64; Report IV, 1964/65, 1966/67.)

A detailed book, summarizing all the results of these investigations was published by the above mentioned team. Its title reads: "*The Negev, the Challenge of a Desert*" (see bibliography). Due to the international connections of Professor Evenari, especially with organizations of the UNO such as UNESCO and FAO, the results were made known to a wide circle of interested experts.

We shall mention only some of the many contacts which stimulated the work and lead to immediate practical application of the Avdat/Wadi Mashash method.

Australia

In 1968 the Australian water engineer Philip R. Mudie visited the farms of Avdat and Shivta. In a letter of December 1968 he tells us that he has started, together with his colleagues in a firm for survey and irrigation work, to experiment with runoff-farming. He writes as follows:

"The country is situated about 500 miles inland from Sydney just east of Bourke and is typical of a belt of land 150 miles north to south and 100 miles east to west. Soils are generally deep red loams running to sandy loams in the south with patches of clay loam in the north . . . The country has been used solely for the range grazing of sheep . . . and carries flocks of 3000 to 15000 sheep.

The average annual rainfall is 12"

Bedouin family in Wadi Mashash. They are our shepherds and workers on the farm.



Generally the rainfall is evenly distributed between summer and winter. No precipitation for as long as 18 months straight and a total of 36" in one year are the extremes recorded.

We have gone ahead with the establishment of the first 70 acres. . . . In this first year we will try to grow — lucerne (alfalfa), Phalaris, barley, wheat and a small area of Sorghum. The microcatchment orchard will contain about forty trees — apricots, plums, peaches, nectarines, almonds, olives and some grapes.

Catchment areas of 200, 300, and 400 square yards will be used. No irrigation supply can be made available to our area."

In February 1973, Mr. Mudie writes again:

"We planted a wide range of fruit trees and although not now properly tended it does seem that we can expect good results from the microcatchment idea.

I hope eventually to concentrate on almonds and some softwoods . . . Lack of financial support has caused us, however, to discontinue the work at this time."

Republic of Botswana, Africa

We have been in regular correspondence with the research station of the ministry of agriculture of the Republic of Botswana, and we are therefore well informed about their experiments with microcatchments. The responsible expert in Gabarone gave us the following information in a letter of 21th July, 1973:

"The annual precipitation at the farm is 518 mm with a variability of 35%. The total rainfall in 1971/72 was 622.1 mm, producing 229.1 mm of runoff, that is 37%.

The catchments have three sizes: 9 m x 9 m, 9 m x 18 m, 9 m x 27 m. 98 trees were originally planted in two blocks. They were all apricots. The average failure for the first planting was 62%, and of the 61 trees that were replanted 10% died . . . There has been no severe flood damage yet. Unfortunately the tree program is not progressing well at present due to lack of personnel . . . I realize that we could run a much more intensive program of runoff farming with trees, pastures and



Botswana, Africa: Apricot trees in microcatchments.

arable crops and could probably simplify our system using contour strips as was suggested by Mr. Shanani . . . I am sure that the technique could have wide application in Botswana but it needs much care in planning, adequate supervision and training of local staff. This may sound rather obvious but the facilities and personnel to carry this out are not here at present."

In a letter of 9th September, 1973 the reasons for the high failure rate were given as the following:

1. The trees were planted rather late when temperature rose rapidly.
2. Evaporation rates were very high.
3. Attempts to shade and protect the trees resulted in too great a restriction of air movement and they were probably 'cooked'. We have since determined the optimum time for planting and how to protect the trees while maintaining free air movement."

Afghanistan *)

Since 1971 an intensive exchange of thoughts has taken place between the German organization "Bundesstelle für Entwicklungshilfe" (BfE and GAWI), in Frankfurt and the farms in the Negev.

For many years the Federal Republic of Germany, in cooperation with the State of Afghanistan, has been carrying out an extensive development program in the plain of Khost, in the province of Paktia.

Apart from agriculture the experts there also help with the regulation of rivers, the forest administration, the building up of home-worker organizations, and the initiating of educational projects.

In February 1971 Dr. H.-J. Wald published a detailed article about "Sturzwasser-Bewässerung in Khost (Afghanistan)" (Runoff-farming in Khost [Afghanistan]), in the periodical "Zeitschrift für Bewässerungswirtschaft". In this article Dr. Wald obviously refers to the publications of Prof. Evenari in the journal "Umschau in Wissenschaft und Technik", (No. 15 and No. 16, 1964), and in the

*) The "Bundesstelle für Entwicklungshilfe" (BfE), Frankfurt-Eschborn, has authorized these informations about the project in Paktia.

periodical, "Nova Acta" Leopoldina (Leipzig, 1966, Bd. 31, Nr. 176).

That is what Dr. Wald writes:

"The formation of a flood of runoff water depends on a number of inter-related factors. The importance of these factors and their interdependence was experimentally investigated by M. Evenari and his team in the Negev desert. In the Nabatean period a prosperous agriculture on the basis of runoff irrigation had already existed. For the purpose of these investigations some ancient farms were reconstructed, with archeology rendering assistance. I shall repeatedly refer to the results of Evenari in the text that follows..."

Dr. Wald concludes his article with this résumé:-

"In spite of the research begun in the Negev it must be assumed that the conditions and the possibilities of runoff irrigation are almost unknown. Anyway, it has been proved that this method of irrigation enables agriculture under extreme arid conditions, and under more favorable conditions (Khost) it plays the

role of an important agricultural complementary function."

After the head of the agricultural project in Khost, Dr. Christoph Häselbarth personally had visited the farms in the Negev, he was followed by numerous experts of the same project who came for short consulting visits to Israel. In a letter, dated from 20th February 1972, Dr. Häselbarth writes:

"We have successfully imitated the terrace irrigation for the growing of cereals and other field crops and the microcatchments for the raising of fruit trees and useful trees as you (Evenari) have suggested, and we have recommended it to the farmers. We especially strived to improve the pasture by means of your system.

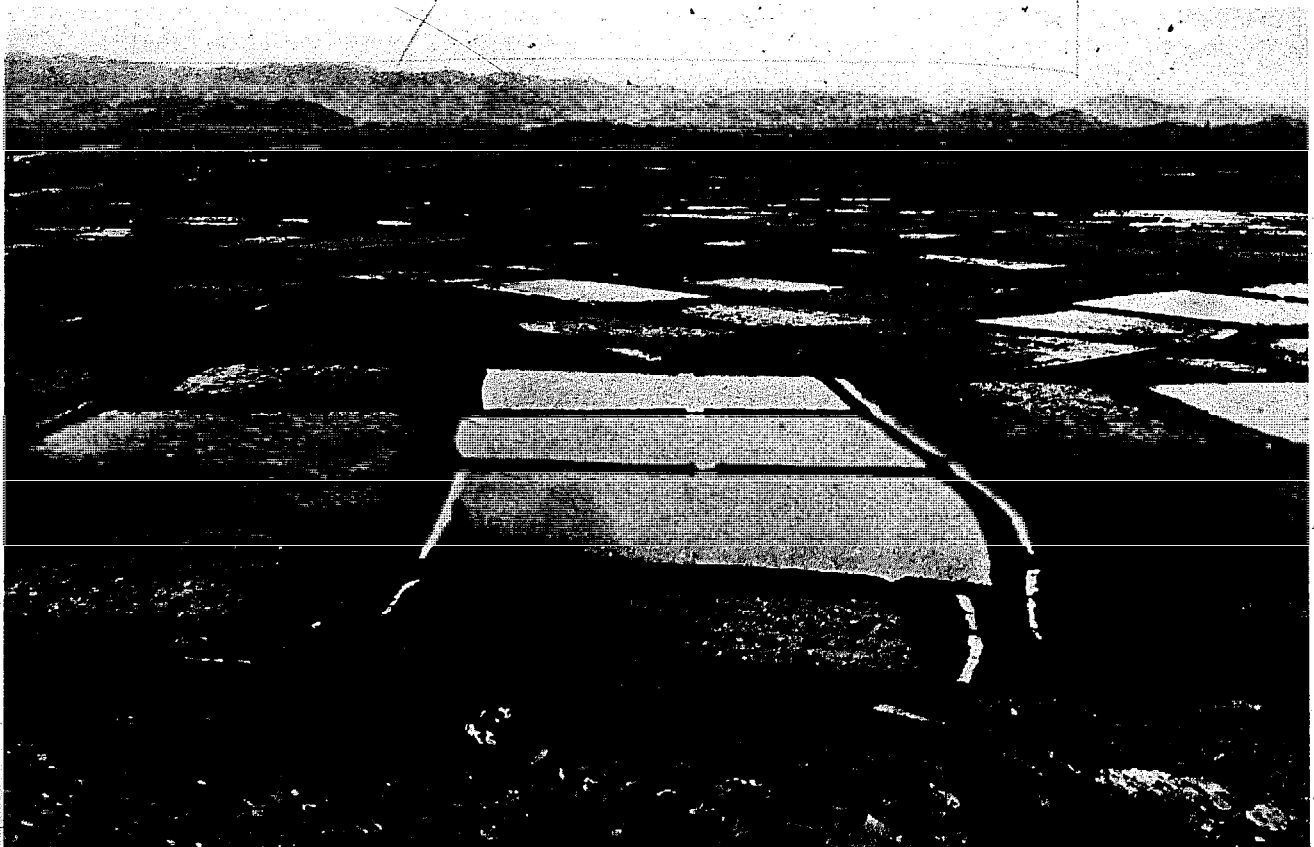
I am fully convinced that your ideas and recommendations can attain economic importance for developing countries with arid regions. In those countries land and personnel are available, as well as the will to work, provided the professional instruction is given.

I see in your suggestions the possibility — I myself have demonstrated that — of cultivating large steppe areas, which are threatened by erosion and formation of Karst, with trees and bushes and of utilizing them for agriculture again, and all that with a minimum of investments."

In spring 1973, Mr. Nessler and Mr. Schenk visited Afghanistan and could see for themselves the wide range of application of the runoff irrigation. The agricultural engineer Dietrich Gebauer, who had especially worked on the construction of the terraced fields, was our guide through the plain of Yakuby/Paktia, in Afghanistan. We quote from one of his reports, from May 1972: "Advantages of the improved runoff irrigation:

While up to now only a small part of the runoff could be used, this new system enables us to lead most of the runoff water to the field and there make good use of it. The water collected on the fields has enough time to penetrate through the soil and to wet it well. This

Afghanistan: Flooded fields laid out in terraces.





Afghanistan: Spillway made of piled-up stones. The remaining part of the dams is made of earth.

In the Indian deserts the population density is about 5 people per one square kilometer. Though the rainfall amounts to more than 300 mm in summer, the water supply is a big problem.

Sahel Zone in Africa

With the assistance of the sponsor organizations of Wadi Mashash, WELTFRIEDENSDIENST and HEKS, and of other organizations such as EIRENE, we collected some informations about the drought regions in Africa. A trend to settle down could be observed with nomads in Niger who had lost their flocks. Within the frame of a project for agriculture and afforestation it is planned to use the runoff-farming method of Wadi Mashash. Direct contacts have been made, experts visited the project, and two German members of the project are supposed to have completed the basic investigations by the end of 1974.

humidity suffices to supply the plants with water over a long period of drought. It was ascertained that 4 months after a damming up of 30 cm the soil was still wet down to 1 m of depth. Thus, every field has the function of a reservoir.

The construction of the dams, the inlets and the spillways can be carried out by the farmers themselves according to instruction. This system of improved runoff irrigation has been practiced here for one year (since 1971). All given data, therefore, must be considered approximate data only. On the other hand the results we obtained by means of this system in so short a time are so satisfactory that it is certainly justified to use this system in regions where it can be applied.

The System of the Improved Runoff Irrigation

The fields to be irrigated are being surrounded by a solid earthen dam.

The size of this dam:

dam basis 1.50 m (diameter)
dam crest 0.50 m
dam height 0.50 m

1000 m² proved a good size for the fields. At one point of the dam an outlet with a spillway was constructed. The dry-masonry spillway worked well at a breadth of 2 m, and it is 0.20 m to 0.30 m high. The spillway and its side walls in particular must be carefully built of field stones.

The actual spillway consists of small steps which have to retard the water running over the spillway.

India

When we visited the "Central Arid Zone Research Institute Jodhpur" in the state of Rajasthan in India we could see with our own eyes that the desert agriculture of the Negev was known even there and that the leading agriculture expert of the institute was carrying out experiments with runoff-farming. Microcatchments were also planned.

We may chose the example of the Sahel zone to speak more generally about problems of aid for developing countries:

The conditions for a successful transfer of the Wadi Mashash method to the Sahel zones exist. The people concerned — nomads in a transitional state before settling down, and small farmers — are exactly those for whom the Wadi Mashash method is most suitable.

The readiness of the industrial nations to sponsor the transfer of this method is great; that is true for financial help as well as for the sending of personnel. Furthermore it is easily possible to introduce runoff-farming into a project which has already been run for some time. It would not even have to be an agricultural project.

In the Footsteps of the Ancient Farmers

German Organizations

Apart from the direct sponsors of the Wadi Mashash project — these are mainly "Not für die Welt" the "Evangelische Kirche in Hessen und Nassau", and the "Hillson Foundation", a good and quite intensive cooperation developed with other German organizations such as the national "Deutscher Entwicklungsdienst", the catholic "Arbeitsgemeinschaft für Entwicklungshilfe", and the protestant "Dienste in Übersee".

On a mission for the organization "Dienste in Übersee" the farmer Klaus Schäfer visited the farm of Wadi Mashash in 1972 and gave a report part of which we quote here:

"... What is most attractive concerning the Wadi Mashash method is its simplicity, if not to say its ingenious primitiveness. No technical installations are required. Once being set up this system functions with only a minimum of maintenance work. Natives, of non-agricultural background even, can adopt this method without giving up their traditional way of life. Since this system is so simple and cheap one can make it known to a great number of people without investing much money (only the payment of the personnel and their transport).

As all the installations can be built by the natives themselves costs arise only for the initial outfit with seed-corn and plants.

The conditions for the application of the system are clear: the method can be applied in all regions where soils exist with a relatively high water holding capacity. It can however not be decided from far away whether a specific area is suited for the application of this method. In fact, such a decision can be arrived at only by an expert on the spot who knows the limits of the method.

"... At first sight it might look as if only farmers could learn the Wadi Mashash method. But, as a fact, this technique is so simple and so logical that every intelligent person with a bit of scientific interest can transfer the basic ideas. Whoever doubts this assumption that non-farmers may understand this method in its entirety, must be told that the Wadi Mashash farm in itself has been erected and run exclusively by non-farmers. Prof. Evenari

e. g. is a botanist, and the good results are doubtlessly due to the fact, that the work has been done without any professional blinkers!"

We cannot close this chapter without touching upon the question of the origin of the ancient runoff agriculture. Who invented it? Where was it invented?

How old is it? We will consider here only the old world and will not discuss runoff agriculture in the new world.

One way of answering the questions raised is to find out what the main geographical areas are where runoff agriculture was once carried out and to try to trace any connections between them.

As far as our region is concerned ancient desert runoff agriculture was practiced not only in the Negev but in all of Southern Transjordan and in great parts of Sinai.

Another such region is Southern Arabia.

Travellers of the nineteenth and early twentieth century (Glaser, Freya Stark, Thompson and Gardner, Philby) described extensive traces of ancient runoff agriculture in Hadhramaut, and remains of a large dam near Marib, today a small village but once the capital of the ancient Sabaeen kingdom.

We know of the Sabaeans from the Bible. It says in Kings I, 10, 1-10: "And when the queen of Sheba heard of the fame of Salomon . . . she came to Jerusalem with a very great train, with camels that bore spices and gold very much and precious stones . . .

And she gave the king a hundred and twenty talents of gold, and of spices very great store, and precious stones; there came no more such abundance of spices as these which the queen of Sheba gave to king Salomon."

This visit of the queen of Sheba took place in the tenth century B. C., and we learn from the Bible that already at this early time in history the Sabaeen kingdom must have been a mighty and rich one. The Sabaeans were prosperous because the caravan trade of frankincense (gum resin obtained from certain species of Boswellia) and myrrh (gum resin from various species of Commiphora) was in their hands, a trade which much later was taken over by the Nabateans. This was apparently one of the reasons why the Sabaeen kingdom declined in power in the last centuries of the first millenium B. C. But the Sabaeans were not only masters

of the overland caravan trade to the North — as witnessed by the Bible and a number of Roman historians and geographers — they were also masters of the desert runoff agriculture.

This was clearly shown by R. LeBowen who in 1950–52 investigated the ancient agricultural practices in Southern Arabia and the famous dam of Marib.

These agricultural remains with their fields, channels and sluice gates are an exact counterpart of what we found in the Negev, and are almost identical with e. g. the agricultural remains we described for Nahal Lavan. Bowen writes: "... the ancient South Arabians never attempted to store water behind dams for irrigation (this was the erroneous opinion of Philby), but built their systems to break up the soil (Arabic for flash flood) and distribute it over as large an area as possible ..."

Concerning the dating of these desert runoff agricultural systems Bowen writes that they cannot be older than the second millennium B. C.

The dam of Marib was part of such a water spreading system. It was an enormous construction with solidly stone built, gigantic sluice gates at both of its ends. It was dated to c. 750 B. C. and, in the words of Bowen "... it is reasonable to suppose that it may even antedate this". One can only marvel at the hydrological and technical knowledge of its builders.

It was not built to store flood water but to raise the flood water of the large wadi Dhana in which it is situated to such a level that the water could flow through the two sluice gates to fields lying along both flanks of the wadi (the "two gardens" of the Quran). The dam functioned for about 1300 years.

The Quran reports its destruction. "A sign there was to Saba, in their dwelling places — two gardens, the one on the right hand, and the one on the left".

"Eat ye of your Lord's supplies, and give thanks to him: Goodly is the country, and graceous is the Lord".

But they turned aside: so we sent them the flood of Iram; and we changed their gardens into two gardens of bitter fruit and tamarisk and some few jujube-trees". Nothing could describe better the desertification of good agricultural

land in an arid area the moment the runoff system is destroyed.

The destruction of the dam of Marib by a colossal flood must have happened c. in 575 A. D.

A third region with innumerable remains of ancient runoff agriculture are the desert fringes of North Africa especially in Southern Algeria and Tunisia.

Already the early French explorers of this area were struck by the fact that according to the still visible remains very large areas which today are desert were once cultivated. Some of them also recognised that the fertility of these areas in ancient times was not due to a better climate (Discussion on this in Despois 1955) but to ingenious use of the runoff waters. Some like Carton (1888, 1909) even thought that these methods could be usefully applied in modern times in recreating the fertility of the once flourishing countryside because he found the ancient methods most adapted to the local conditions, most efficient and cheap.

How large the area was which was once runoff cultivated can for South Algeria as an example best be seen when looking at the many air photographs taken and published by Barradez, a colonel in the French Air Force who discovered from the air the trace of the "Fossatum Africae", a Roman defensive frontier trench (fossé frontiere) extending over hundreds of kilometers.

All along the "fossatum" are found many fortresses, fortified towers, terraced wadis, diversion systems, large runoff fields, runoff cisterns, villages etc., and all this in a region which today is completely desolate, a fact which Barradez stresses many times: "The contrast between the traces of what once existed and the aspect of what remains today is dreadful. The region is terribly devastated ..."

The "fossatum" was started by the Roman emperor Hadrian (117–138 A. D.) and garrisoned by "limitanei", the same type of soldier-farmers we mentioned already as garrisons of the Negev towns; and exactly as there they, their families and their dependants were the ones who farmed the land.

The runoff farming in Roman times was certainly not restricted to the

"fossatum Africae". Wherever in North Africa the Romans ruled and wherever the rainfall was insufficient and no other water sources like e. g. chain of wells were possible there was extensive runoff farming by terracing wadis, building runoff farms, runoff fields and constructing diversion systems. (Carton, Despois, Tixeront, Renaud, Gsell).

This type of farming was certainly one of the reasons for North Africa becoming the "corn chamber" of Rome, providing $\frac{2}{3}$ of its grain requirements.

The vast hydrological knowledge of the North African water engineers ("aquilegi" in Latin) must have been highly appreciated by the Romans because Cassiodorus (Roman historian c. 490–585 A. D.) tells us that "a hydrologist came to Rome from those regions in Africa where — because of the dryness of the land — this art through which one can provide water for an arid region is cultivated to such a degree that dried out areas can be made advantageously habitable".

But were the Romans the first to practise runoff agriculture in North Africa? They certainly developed this "art" there to its highest peak, but they were not the first to apply it. We know from various sources (Gsell, Despois L'Afrique du Nord) that Phoenician navigators visited North Africa already around 1200 B. C. But the impact of the Phoenicians on North Africa and its agriculture became really important only after c. 814 B. C., the date Carthago was founded by the Phoenicians. The Phoenicians introduced the culture of grape vine and olive into North Africa and a Carthaginian agronomer by the name of Mago wrote a treatise on rational agriculture and agricultural economy which was famous in Roman times but is lost to us.

We know of it only because it is mentioned with great esteem by many Roman authors as e. g. Columella (*De re rustica* I, 1, 16). It is therefore quite possible that the Phoenicians already practised runoff agriculture in North Africa before the Romans. But Tixeront, one of the French authors trying to trace the history of agriculture in North Africa, goes even one step further back.

He claims that long before the founding of Carthago, sometimes in the second millennium B. C. people from Canaan migrated to Tunisia by sea or overland,

and that these Canaanites implanted the principles of runoff agriculture into Tunisia which naturally presupposes that runoff agriculture was known in Canaan already in the second millennium B. C.

What can we learn from all this regarding the origin and age of runoff agriculture in general and its history in the Negev? It is obvious that what can be said on this point is no more than a working hypothesis and has to be taken cum grano salis. Such a hypothesis must be based on the following facts.

1. Agriculture has been invented in the fertile crescent in the pre-pottery Neolithic period between c. 7000–5000 B. C. It existed already at this time in Jericho (Kenyon).

2. Runoff agriculture in the Negev was practiced at the latest in the 10.–9. century B. C. It may be older and go back to c. 2000 B. C. (M. B. I period).

3. Runoff agriculture in South Arabia, may be dated to some time in the second millennium B. C.

4. In North Africa it existed in the early centuries of the first millennium B. C. but may be older.

But was agriculture when it was first invented a kind of dry farming i. e. agriculture using rain when and where it falls or was it irrigation agriculture?

Though it may seem logical to presuppose that dry farming as the more primitive method preceded irrigation farming, "primitive" in cultural history does not necessarily mean "earlier". It is important in this respect that Kathleen Kenyon tells us that the system of agriculture of the pre-pottery Neolithic A-settlement in Jericho was based on irrigation using the water of the nearby spring Ain es Sulran. She even makes it probable that the early Jericho people used already irrigation channels.

She writes; "At a stage when the expanding population required a large area of fields, irrigation channels must have been constructed to carry the water of the spring farther afield.

The successful practice of irrigation involved an elaborate control system.

A system of main channels feeds subsidiary channels watering the fields, when the necessary sluice gate is closed."

Disregarding the question if dry farming preceded irrigation farming, it seems permitted to assume that people who knew how to use channels to carry water from a spring to fields and how to use sluice gates knew also how to use these technical means for collecting runoff into channels and how to divert flood water from wadis to farm land.

This must be especially true for a place like Jericho, the southern most and most arid tip of the fertile crescent.

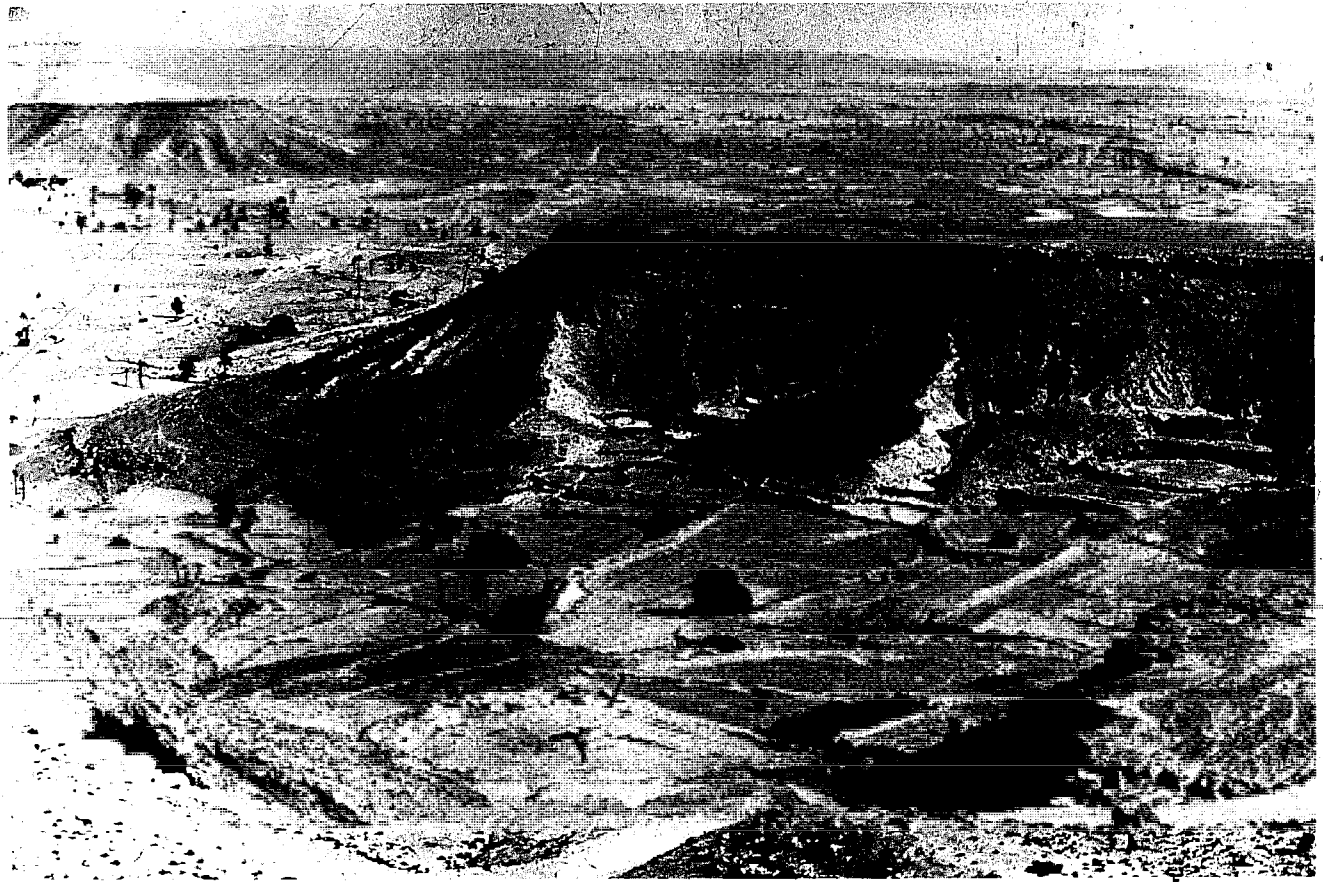
Jericho is an oasis in an arid environment, where floods occur as e. g. in Wadi Kelt, which opens into the plain of Jericho, and where it must have been easy to apply the techniques used to divert spring water to the diversion of flood waters. We come therefore to the conclusion that the same fertile crescent where agriculture was first invented in pre-pottery Neolithic times was also possibly in its more arid part the birthplace of runoff agriculture.

If so, runoff agriculture would be the offspring of irrigated agriculture. This knowledge must then have spread from there to South Arabia and to North Africa, perhaps really by the Canaanites of Tixeront. This would also make it more probable that the MB I population of the Negev already carried out runoff agriculture as suspected by Kochavi, and that the Israelites (Israelite period II–III) only built their runoff systems upon older MB I structures.

All this is in the realm of speculation, it is an educated guess. But if we already speculate, an operation which is always necessary when trying to close a gap in knowledge by formulating a working hypothesis as a basis of further research, we may add one more speculation.

It is certain that there were contacts between the Judaeans and the ancient Sabaeans kingdom. At that time runoff agriculture was already highly developed in Sheba. Could it be that this Sabaeans knowledge was transmitted to the kings of Juda, perhaps by the queen of Sheba during her famous visit to king Salomon, and used by them either to apply or to improve runoff agriculture in the Negev?

Report on a Journey to Tunisia and Niger



Tunisia: A view from the Berber settlement of Chenini in South Tunisia to terraced dry watercourses. In an ingenious way fields for olives, dates, almonds, figs, pistachios, vegetables and cereals have been built. In the background one can identify in the wide plain numerous farm units planted with olive trees and palm trees. This kind of plantations can also be found in the vicinity of the cave-settlement of Matmata. The climatic conditions and the soils are similar to those in the Negev. Some data of Chenini: altitude: about 500 m; mean annual temperature: 20,2°C; winter rain: 129 mm. Some data of Avdat/Negev: altitude: 550 m; mean annual temperature: 18,1°C; winter rain: 80 mm.

Tracing the remains of the ancient desert agriculture we were trying to find the answer to these questions: Who invented the desert agriculture and how old is it? A number of sign-posts pointed to Carthago, to Tunisia of today. Obviously the contemporaries of the Negev farmers, the North African farmers, were great masters of runoff-farming. Who, then, was the first to reach the skill to the other? That is an interesting, yet unsolved question. Does the farmer of today think about these questions while he is engaged in repairing an impressive spillway on a field below the ancient cave-settlement of Matmata? We do not know. Much more than by the past, we were, however, fascinated by the impressive present of the Tunisia of November 1974.

On a 10-days excursion through wide regions of desert agriculture Udo Nessler and Otto Schenk could see for themselves that busy and inventive people in arid zones can live by the skill of the ancient desert farmers, even in the 20th century. They build terraces in wadis and harvest almonds, olives, dates, and figs from the small terraced fields. On slopes they build dams following the contours, with simple but suitable spillways, and behind them they grow cereals and vegetables after a flood. In large plantations they grow olives which receive their water from *microcatchments*. All the time we were reminded of the Negev: The soil, the plants, and the system of working the fields let us not forget the relationship. This "living" desert confirmed our

opinion that the chances of a successful application of the runoff farming of the Negev in wide regions of the drought zones of Africa are considerable. Does it pay, is it profitable?

The nomads of Tunisia do not ask this question, they *live* simply by their skill of coercing yields out of the desert. The improvements of the dams and the expertly repaired cisterns show clearly that the farmers are being helped and advised.

Can the Wadi-Mashash-Method be of Any Help in the Hunger Area of the Sahel Zone in Africa?

Television and broadcasting services as well as the press have fully informed

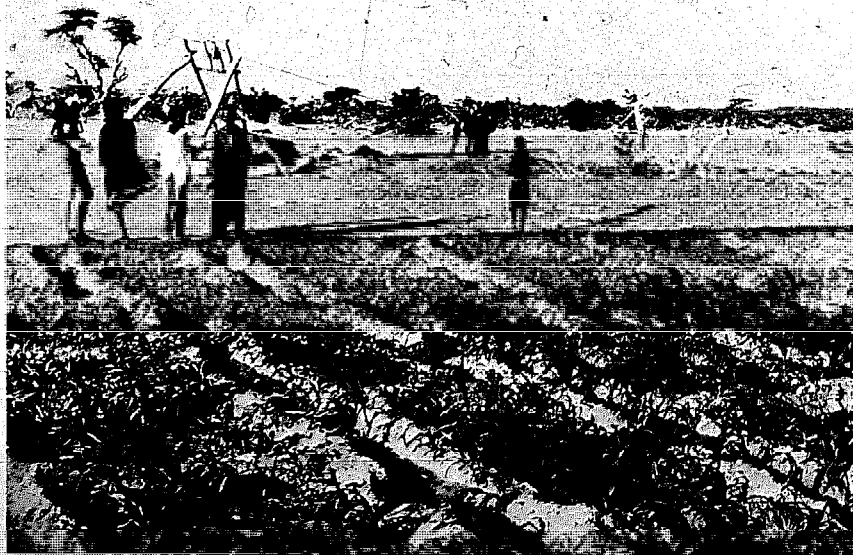


Tunisia: Spillway on a farm lying at the foot of the village of Chenini (the cave-dwellings are on top of the hill on the left). These solid and well built stone walls reach in some places a height of 2–3 m. They border small terraces which sometimes are planted with one very big tree only. Larger and more gently sloping areas serve for the growing of crop.

Near the settlement of New-Matmata a large plantation is set up with olive trees growing in microcatchments (basin 5 x 5 m; catchment area about 20 x 20 m). The single catchments are not separated by border checks, however:

It is especially remarkable that not even the new plantations are fenced-in to hold off goats and sheep and that they nevertheless look well.

Sahel zone, NIGER: The Tuareg nomads have for years laid out gardens of a size of 1000–2000 m² along the big wadis. They draw the water out of shaft wells (5–10 m deep) usually by means of an ox — here in the picture it is a camel — and then lead it to small fields. They grow maize, tomatoes, beans, and melons. Due to the continuous irrigation the Tuaregs can harvest several times a year. They never have thought of using the flood water of the wadis. Anyhow, these nomads are used to agricultural work.



the world about the drought catastrophe in the Sahel zone. On the whole, can any long-term help be given in these areas on the edges of the desolate Sahara desert?

Some church organisations trying to find any means of help, asked us to examine whether an application of the Negev agriculture would be possible, at least in some parts of the drought area.

Thus, Udo Nessler and Otto Schenk started for a two-weeks intensive information trip to the Republic of Niger, to the region where the Tuareg nomads live. Agadez (520 m above sea level, 28.7° C mean annual temperature, 128 mm summer rain) is the capital of this region and has about 10 000 inhabitants, who live in clay huts or plaited bast-huts. The local market and recently the distribution of food have increasingly attracted many

Tuaregs to pitch their tents at the outskirts of the town.

A Missionary Station Engages in Desert Agriculture

For many years the missionary station of Tschirozerine, lead by French Catholics, has run a school for Tuareg children and a small hospital. When the drought period began they started to concentrate on more immediate help for the nomads. Père Antoine has been the head of the station since 1972 and he has initiated agricultural experiments and labour-programs for the Tuaregs. The station lies at a distance of one hour by car (landrover) from Agadez and is situated at the foot of the Air-mountains. Near the station a wide wadi — here it is called kori — runs past which in good years (1974) is flooded up to 17 times, and even in the drought years had been flooded thrice at least. In the rainy season in summer, from June to August, immense torrential floods rush through this dry water-course for some hours. According to estimates more than 4.8 million m³ ran off in 1974! Exact data of the rainfall in the area of the station are not yet available, but 100–150 mm are estimated. No soil analysis has been made yet, either. It seems to be composed of clay, loam and sand. Important is however, that it builds a crust. The deep shaft wells in the area show a layer of soil as deep as 5–10 m. Notwithstanding the lack of an exact soil analysis the kind of vegetation growing in the area permits some conclusions concerning the soil.

Numerous acacia trees, many bushes and in some places even continuous growth of grass after the rainy season indicate that the soil gives good yields provided enough water is available. Such a conclusion seems even more justified, if one takes into account the yields of tomatoes and maize in the artificially irrigated gardens.

In 1972 Père Antoine started to build dams and terrace walls in the dry watercourses. It is planned to give 20 Tuareg families a living by diverting at one place the water of the wadi and thus supplying the fields with sufficient water.

A member of the "Internationaler Friedensdienst EIRENE" got acquainted with the project of Père Antoine, and also visited the farms in the Negev, he then developed a program for the Tuaregs in a valley not far from the missionary station.

Runoff-farming for the Steppes Around Agadcz/Niger

In its letter of October 1974, EIRENE describes the EIRENE-BROT-FÜR-DIE-WELT project in the plain of Tschin Tebiskin as follows:

"This method of Prof. Evenari of the Negev desert shall be adapted to the conditions in Niger and shall be applied in a modified form. This runoff-farming consists of:

- the building of small stone dams in koris (wadis) in order to slow down the water flowing over the crusted soil surface, and thus to facilitate its infiltration into the soil. (Raising of the ground-water level.)
- Construction of large stone dams which divert the water to fields beside the wadi. These fields are surrounded by small earthen border checks, and therefore can store the water (flooded areas.)
- Raising border checks on gently sloping areas, each of which surrounds a plot (sized 250 m² in the Negev). At the deepest point of the plot a tree will be planted."

A beginning has already been made to attain this aim. But costly mistakes were made by wrong constructions of dams or selection of unsuitable areas. But the combination of the experiments of Père Antoine with the Negev method might produce a fruitful solution. The possibilities of long-term aid programs exist at the missionary station as well as in the German project.



Sahel zone, NIGER: A stone dam for the purpose of retarding the floods in a wadi bed near the missionary station of Tschirozerine (near Agadcz). Such dams are being set up by paid teams of workers who are supposed to tend them later on. Often the force of the floods was underestimated and the dams broke. Now, a new program was started to dam up the water of small wadis in order to improve the natural vegetation and to utilize the flooded areas for agriculture.

Mariental, South-West Africa: Contour catchments aid the regeneration of pasture-grounds.

"The soil consists of fertile, deep loam/sand, and it is rich in nutrients. Water could not penetrate because of the formation of a crust of foamlike structure, and thus desert-like conditions developed. The furrows were dug in 1968/69 and are 60 cm deep. In 1974 they were levelled. Today this area can again be used as a good pasture for sheep. —"

(Quoted from a letter of 3rd November, 1974 from Prof. Völk, University of Würzburg.)



Bibliography

Aharoni, Y., Evenari, M., Shanan, L.,
Tadmor, N. H.:
Ancient Agriculture in the Negev
Science 11 (1961), p. 979-996

Charlesworth:
Distribution of Periglacial Loess
E. Arnold, London, 1957

Dregne, H.:
Arid Lands in Transition
American Association for the Advance-
ment of Science
Washington D. C., 1970

Elias, M. K.:
Loess and its Economic Importance
American Journal of Science, May 1945

Evenari, M., Koller, D.:
Ancient Masters of the Desert
Sci. Amer. 194 (1956), p. 39-46

Evenari, M., Shanan, L., Tadmor, N. H.:
The Negev - The Challenge of a
Desert
Harvard University Press, 1971
Hebrew, 1975

Evenari, M., Shanan, L., Tadmor, N. H.:
The Ancient Agriculture of the
Negev III. Early Beginnings
Israel Explor. J. 8 (1958), p. 231-268

Evenari, M., Shanan, L., Tadmor, N. H.:
Runoff-farming in the Negev Desert
Progress Report I-IV
Public. Nat. and Univ. Inst. of Agric.,
Rehovoth, 1963-1970

Evenari, M., Shanan, L., Tadmor, N. H.:
Moisture Use of Young Peach and
Apricot Trees in a Desert Environment
Journal of Agronomy, 1967

Flint, R.:
Loess in North America
Chapman & Hall, London, 1955

Glueck, N.:
Rivers in the Desert
Farrar, Strauss and Cahardy, New York,
1958

Greene, H., Snow, O. W.:
Soil Improvement in the Sudan Gezira
J. Agric. Sci. 29: 1-34 (1939)

Hillel, D., Tadmor, N. H.:
Water Regime and Vegetation in the
Central Negev Highlands
Ecology 43: 33-47 (1962)

Hillel, D.:
Studies on Loessial Crusts
Public. Nat. Univ. Inst. Agric.
Rehovoth Bull. 63, 1-87 (1959)

Keilback:
Das Rätsel der Lößbildung
Zeitschrift DGG, 1928

Lowdermilk, W. C.:
The Use of Flood Water by Nabateans
and the Byzantines
Israel Exp. J. 4: 50-51 (1957)

McGinnis:
Deserts of the World
The University of Arizona Press, 1970

Monod, T.:
Les Déserts
Horizons de France, 1973

National Academy of Sciences:
More Water for Arid Lands
Washington D. C., 1974

Palmer, E. H.:
Der Schauplatz der vierzigjährigen
Wüstenwanderung Israels
Gotha, 1876

Rathjens, C.:
Löß in Tripolitanien

Reifenberg, A.:
The Struggle between the Desert and
the Sown
The Rise and Fall of Ancient Agriculture
in the Levant
Mossad Bialik Publ., Jerusalem, 1955

Scheidig, A.:
Der Löß und seine geotechnischen
Eigenschaften
T. Steinkopff, Leipzig, 1934

Shanan, L., Evenari, M., Tadmor, N. H.:
Rainfall and its Variability in the Negev
Israel Expl. J., 1967

Shanan, L., Tadmor, N. H., Evenari, M.:
The Ancient Desert Agriculture of the
Negev - II. Utilization of Runoff from
Small Watersheds in the Abde (Avdat)
Region
Ktavim 9 (1958), 107-128

Shanan, L., Tadmor, N. H., Evenari, M.:
The Ancient Desert Agriculture of the
Negev - VII. Exploitation of Runoff
from Large Watersheds
Ktavim 11 (1961), 9-31

Shanan, L., Evenari, M., Tadmor, N. H.:
Ancient Technology and Modern
Science in the Desert Agriculture
Science and Technology, 1967

UNESCO
The Problems of the Arid Zone
Proceedings of the Paris Symposium
1962

Pictures:

Page 6 top right	K. O. Hundt
Page 7 bottom	K. O. Hundt
Page 13 top left	Mrs. L. Evenari
Page 28	D. Gibbons
Page 29	D. Gebauer
Page 30	D. Gebauer
Page 36 bottom	O. Volk
all the others	U. Nessler

