Arid Zone Settlement Plan

ed Golany

Gideon

17 Irrigation in Arid Zones: The Israeli Case*

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> "For the land, whither thou goest in to possess it, ... where thou sowdst thy seed, and wateredst it, with thy foot, as a garden of herbs."
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> (Deuteronomy, 11:10)

Many definitions and criteria have been suggested to describe an arid zone. All of them take into account some or all of the following factors: rainfall, temperature, humidity, evaporation, radiation, soil types, flora and fauna. The various definitions reflect the interest of the persons involved and their fields of research. (1) Since we are dealing mainly with irrigation in this chapter, we define an arid zone as an area of land which, only by the use of irrigation, allows the harvest of crop yields needed to support a modern standard of living.

Such a definition describes extreme arid zones, excluding regions where farming practices are possible without irrigation during the rainy seasons. In Israel the region south of the 200 mm isohyet (a line of equal average annual rainfall), near Beer Sheva is an arid zone according to the definition stated above (See Fig. 16.1.) This part of Israel, the Negev, is a wide region and has a significant agricultural potential and Israel is continually facing the challenge of finding a solution which would enable the establishment of modern agricultural settlements there. Several settlements had been established prior to the declaration of Israel's independence in 1948. Since then, however, tremendous efforts have been made to increase the number of agricultural settlements, mainly in the Arava Valley, a strip along the

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eastern border with Jordan, and in the northwest coastal region west of Beer Sheva. Extensive agricultural experience has been accumulated in these settlements with regard to the agricultural practices and production most suitable under extreme arid conditions. This experience clearly shows that when irrigation water restrictions are released, even the most extreme arid regions can provide significant agroeconomic advantages over Israel's intensive agriculture in the semiarid zones north of the Negev. Based on this experience, a large new project, the Southern Project, is now being developed to establish more than a hundred new agricultural settlements in a 35 thousand hectare region southwest of Beer Sheva.

The purpose of this chapter is to describe the climate, soil and water conditions of the Negev and the agricultural practice developed to overcome the difficulties they impose. We will concentrate on the Arava Valley since it presents both the most extreme arid conditions and, at the same time, a significant agricultural success. Among other factors, drip irrigation is probably the major technological reason for this success and will, therefore, be described in detail.

CLIMATE, SOIL AND WATER

Climatic Conditions

Rainfall

In the Negev, the annual amounts of rainfall vary from 200 mm near Beer Sheva to 25 mm near Elat. (See Fig. 16.1.) The annual rainfall, however, should not be the only measure of rainy conditions for agriculture. Another important measure is the variance, or the standard deviation, of the rainfall, since for crop growth this is probably as important as the total amount of precipitation. In the Negev, the variance in rainfall is very large, reflecting its sporadic nature. The following example emphasizes this variability. (2)

Nineteen rain gauges were installed in a ten hectare area near Avdat in the center of the Negev. The mean, $\overline{X}$, of one rainfall was 5.21 mm while the variance V, calculated from the 19 measurements, was 2.79 mm^2 and the standard deviation, σ, was 1.67 mm. The coefficient of variation, which is the ratio $\frac{\sigma}{\overline{X}}$, was about 32 percent. In general, when extrapolated, such a value reflects a very high degree of nonuniformity, particularly when it represents only one rainfall on a very limited area.

The rainfall intensities and the number of rainy days are additional factors to express the rainy pattern in the Negev as presented in Table 17.1. From probabilistic considerations, rainfall exceeding 25 mm is expected once in two years while rainfall exceeding 50 mm is not expected at all. Less than 20 days per year of rains exceeding 2.5 mm are expected, where 2.5 mm of rain is considered to be the minimum of rain required for significantly affecting soil moisture content. Therefore, it is quite obvious that rainwater could not be considered as a sufficient and reliable source for direct watering of crops.

TABLE 17.1. Average Number of Days per Year with Rainfall Exceeding Specified Amounts

Rainfall (mm/day)	Beer Sheva	Central Negev
0.1	35.1	15.8
1.0	27.3	12.1
10	5.9	2.7
25	1.2	0.5
50	0	0

Source: Michael Evenari, Leslie Shanan, and Naphtali Tadmor, The Negev: The Challenge of a Desert (Cambridge, Mass.: Harvard University Press, 1971), p. 33.

Temperature and Humidity

Averages of monthly relative humidity and daily minimum and maximum temperatures are presented in Fig. 17.1. The data from Tel Aviv represent central Israel's semiarid conditions, and those from Elat represent the Negev's extreme arid conditions. For Tel Aviv, the maximum daily temperatures during wintertime, October to April, vary from 17 to 27°C, and the minimum daily temperatures range from 3 to 17°C. During the months December to March, the daily temperatures do not exceed 10°C, and chills or frost are often experienced. These low temperatures are the reason for not growing vegetables in the northern part of Israel during winter. In Elat, however, the daily temperatures during the winter months are always above 10°C; frost is never expected, thus allowing vegetables to be grown during the winter

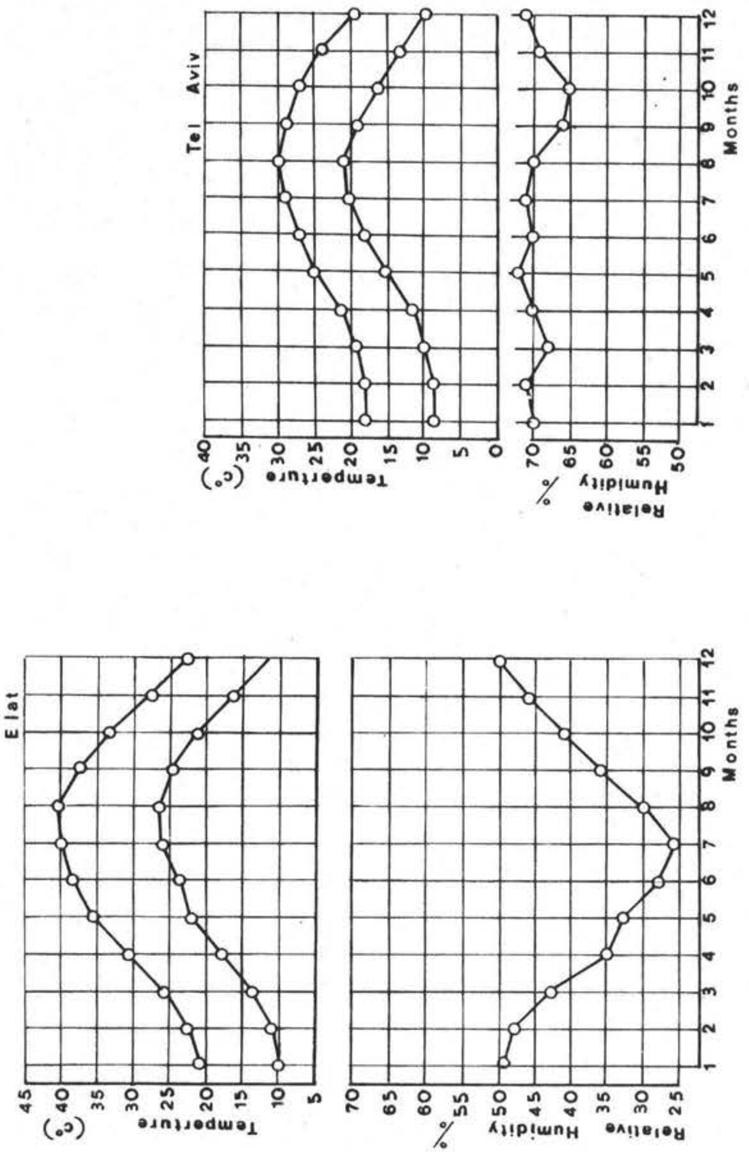

Fig. 17.1. Averages of monthly relative humidity and daily maximum and minimum temperatures in Elat and Tel Aviv.

Source: J. Katsnelson, "Climate of Israel by Regions," Israel Meterological Service.

In Tel Aviv the relative humidity is almost constant, around 70 percent, while in Elat it varies considerably, from 50 percent in the winter to 25 percent in July. Humidity affects intensive agriculture mainly because of pests and plant diseases. Humid areas, in general, require more insecticide sprays than dry areas. On the other hand, humidity might reduce the amount of irrigation water needed. In most cases, humidity is of a secondary significance for irrigated agriculture, provided that the crop varieties are chosen properly.

Evaporation

Figure 17.2 presents the average annual evaporation measured by a class A evaporation pan. The values of annual evaporation in the Negev vary from 1,700 mm near Beer Sheva to 2,700 mm near Elat. In Tel Aviv, however, the annual evaporation is less than 1,400 mm. But such a comparison between Tel Aviv and Elat does not reflect the true evaporation conditions for agriculture since, as previously mentioned, the major growing seasons in these two places are different. Surprisingly, if one compares the evaporation in Tel Aviv during the spring and summer to that of the autumn and the winter in Elat, one finds that the totals are quite the same. Such a comparison is presented in Table 17.2 with the author's own data.

TABLE 17.2. Average Monthly Evaporation in Tel Aviv and Elat During Their Vegetable Growing Seasons (In mm)

Elat		Tel Aviv	
Month	Evaporation	Month	Evaporation
September	292	April	104
October	216	May	143
November	135	June	169
December	108	July	182
January	81	August	169
February	108	September	156
March	135	October	104
Total	1075	Total	1027

Since during the summer there are no rains in Tel Aviv and the amount of rainfall during the winter near Elat is negligible, the evaporation is a good measure for water deficits. Moreover, it should be noted that the growing season for most of the vegetable crops is slightly shorter near Elat than in Tel Aviv. Therefore, even though the totals are equal, the actual water deficits are even smaller in Elat than in Tel Aviv for the same crops at their different growing seasons.

Solar Radiation

The amount of solar radiation in Israel is relatively high and varies from 182 Cal/cm^2/year (Cal = kilogram calories) in the north to 201 Cal/cm^2/year in Elat. (3) A typical distribution of solar radiation during a year is presented in Fig. 17.3. Solar radiation flux is of great importance in determining the potential yields of agricultural crops due to its effect on photosynthesis and temperature. This is one of the main reasons for developing agricultural settlements mainly based on greenhouses in the northern Negev. It is felt that the greenhouses use the solar radiation efficiently while providing protection for the crops against hazards caused by low temperatures and winds existing in this region.

Climatic Phenomena Characteristic of the Negev

Khamsin

The khamsin is a dry desert wind which blows in Israel mostly from the east and southeast direction, passing over the Arabian or Sinai peninsulas. The wind is extremely dry, and the relative humidity drops rapidly to 10 percent. Temperatures are high and may reach 48^{o}C in the Arava Valley. Khamsin days are prevalent in almost all the regions of Israel, mainly during March and April and September and October. These dry and hot days impose difficulties on people, animals, and crops in general and the vegetable crops in particular. In the mountain areas of northern Israel, 100 khamsin days are usual, while in the coastal region and in the Arava Valley only 30 to 40 khamsin days occur every year.

Dew

Dew is one of the most important factors in maintaining arid flora and fauna in the wild since it is the only source of water during the summer. In Avdat, located in the central Negev highlands, the average annual amount of dew is 35 mm, totaling 185 dew nights. For modern intensive agriculture, however, dew amount is a very small factor in the water balance and, therefore, is of small importance. (See Chapter 12 for another view.)

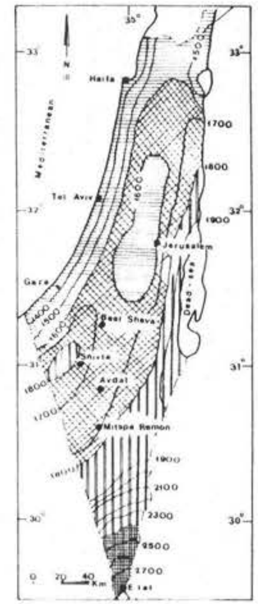

Fig. 17.2. Map of annual evaporation in Israel (measured with class A evaporation pan). Contours are lines of equal annual evaporation (mm).
Source: Atlas of Israel (Israel Department of Survey, 1956).

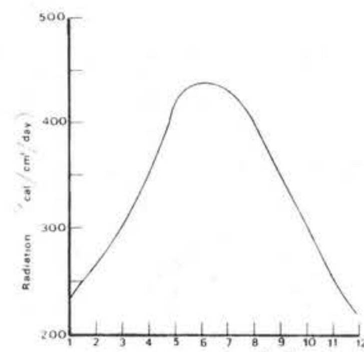

Fig. 17.3. Average daily solar radiation fluxes throughout the year in Israel.
Source: J. Katsnelson, Chief, Division of Climatic Documentation, Israel Meteorological Service, 1969.

Sand and Dust Storms

In the Negev, including the Arava Valley, sand and dust storms occur mainly from February to May. Such storms carry several million tons of dust and sand over the Negev and are a potential hazard to the crops, especially to the quality of the fruit. This is still a major problem awaiting a technical solution.

Winds

The wind regime in the Arava Valley is different from that of the rest of the country. The winds follow the direction of the valley and normally blow from the north and occasionally from the south. The average velocity is 20 km per hour, and cases of standstill or heavy wind storms are rare. In the Arava Valley windbreaks 25 meters high are used and are usually located 40 to 50 meters from each other. These windbreaks were found to be a good means for reducing wind damage. In fields where no steps had been taken to break the force of winds, crop yields were reduced by 40 to 100 percent depending on the crop, its growing stage and the location of the field.

Soils

The Negev is comprised of many types of soils and those currently used in agriculture are sandy and loess (Fig. 17.4).

Sandy soils

Sandy soils can be classified into three main groups: (1) coastal sand dunes found in area II; (2) sandy regosols, a mixture of coastal sands and loess materials, area I, and (3) coarse desert alluvium as found in area VI - the Arava Valley. The advantages of these sandy soils for agriculture are related mainly to the ease with which accumulated salts can be leached out of the root zone.

Loess soils

Loess soils cover extensive areas in the Negev and appear in various mechanical gradations from sandy to clayey loesses. These soils are made of eolian deposits, the origin of which is not very clear. They are characterized by a deep uniform profile and by their tendency to form impermeable crusts on the surface during rains.

Water

The main factor in the agricultural development of the Negev is water. Regarding the water resources, the Negev could be divided into two regions: the northern Negev which, at present, gets its water through the National

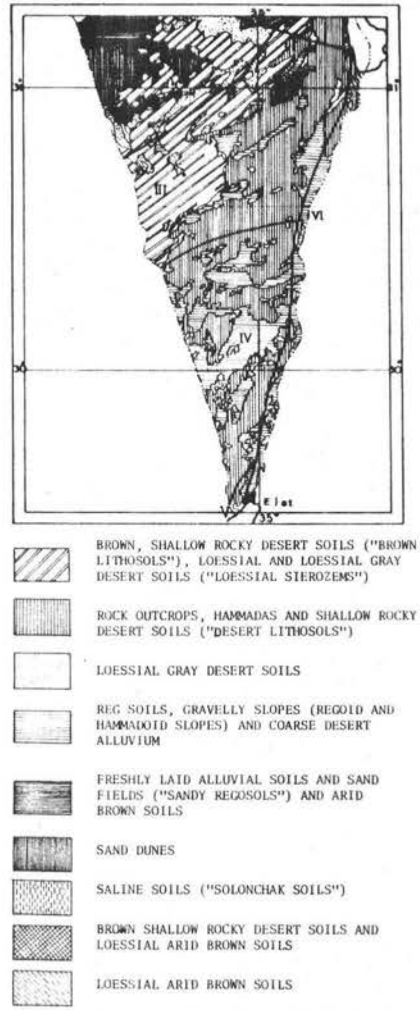

Fig. 17.4. Soil map of the Negev, showing the main regions: (I) coastal strip (northern Negev); (II) northwestern plains and foothills (northern Negev); (III) central highlands (central Negev); (IV) lower sedimentary Negev (central Negev); (V) igneous southern Negev (southern Negev); (VI) the Arava.

Source: Michael Evenari, Leslie Shanan, and Naphtali Tadmor, The Negev: The Challenge of a Desert (Cambridge, Mass.: Harvard University Press, 1971) p. 40.

Water Carrier from the north of Israel; and the Arava Valley which is dependent on local water resources.

In the Arava Valley, in spite of its being an extreme arid zone at present, a large amount of water is accumulated in underground aquifers. A survey of water resources in the Arava Valley is presented in the data summarized in Table 17.3.

TABLE 17.3. Estimated Underground Water Stored in the Arava Valley

Storage Water	Quantities (million m^3)
Total underground storage	1300-1850
Year recharge	10-65
Yearly amounts to be-harvested for 30 year period	
under 600 mg chlorine per liter	25-35
600 - 100 mg chlorine per liter	35-45
1000 - 4000 mg chlorine per liter	33-44
above 4000 mg chlorine per liter	2-4
Water amount used in 1974	35

Source: Finkel and Finkel, Master Plan to the Arava Valley (Haifa, Israel: The Jewish Agency, 1974).

From Table 17.3 one can see that 35 million m^3 of water were used in 1974 (see also Chapter 18, Table 18.2). This amount is almost the entire quantity of relatively good quality water potentially available. The yearly potential of water under 1000 mg chlorine per liter is estimated to range between 60 million to 80 million m^3. This situation calls for an extensive use of saline water for further agricultural development.

Recently, a large aquifer of good quality water was found in the north of the Arava Valley (not included in Table 17.3 totals). Two other sources are also currently being developed, namely, desalination mainly for drinking water and recycling sewage water. These two sources are quantitatively marginal at present.

IRRIGATION

The Past

In ancient times human settlements flourished in the Negev. (4) Israeli scientists have drawn on the past to reconstruct runoff collection systems. (5) The so-called microcatchment method, Negarin in Hebrew, is worthwhile describing as a unique approach based on ancient Nabatean technology. This method was suggested and experimentally carried out during the years 1961 to 1967. A typical microcatchment is schematically shown in Fig. 17.5. (See Arava Valley example in Chapter 18.) It was found by Evenari, Shanan, and Tadmor that, within certain limits, the smaller the catchment the higher the relative water yield per unit of surface area. (6) An area of 2.5 hectares was chosen for microcatchments, reflecting a typical loess plain in the Negev highlands near Avdat. This area was divided into 117 microcatchments ranging in size from 16 to 1000 m^2. The average annual yield obtained in the microcatchments of saltbush (Atriplex halimus), a highly salt-resistant pasture plant, was 660 kg/ha fresh matter (400 kg/ha dry matter). This yield is equivalent to about 160 to 170 feed units per hectare with 40 kg protein per hectare. The control areas without the microcatchments produced only 5 to 20 feed units per hectare under the same conditions. It was also found that this irrigation method efficiently leached the soluble salts down to a level which actually caused no hazards even to medium salt-resistant plants. After six years of irrigation the total soluble salts dropped from an average of 1.02 percent to 0.08 to 0.12 percent.

Such methods, as ingenious as they are, cannot, of course, be the basis of modern agriculture for several reasons. First, machinery cannot be efficiently used. Next, fields are very sparsely planted; thus proper management becomes a difficult task and requires a very high degree of skill. Finally, the cost of constructing microcatchments is economically unjustified. In other words, outdated concepts and techniques could not compete with modern cropping technology and practices and, therefore, could not support a modern standard of living.

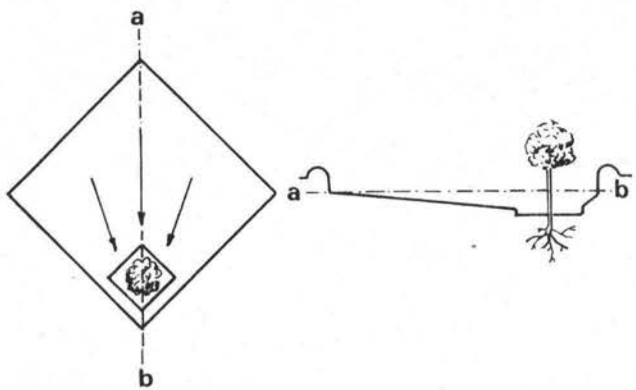

Fig. 17.5. Top view and cross-section of a microcatchment (Negarin) plot. Arrows indicate direction of runoff flow.

Source: Evenari, Shanan, and Tadmor, The Negev: The Challenge of a Desert.

Modern Irrigation Methods

Background

About 90 percent of the 200 thousand hectares of irrigated land in Israel is irrigated by pressure methods, mainly sprinklers, and some by drippers. In general, these methods provide several basic technological advantages: (1) the amount of water and the application rate can be adapted to given field requirements and can be easily controlled; (2) the hydraulic network can be adapted to the shape and the topography of the plots to be irrigated; and (3) the operation of the systems is relatively simple.

It should be emphasized that water in Israel is firmly controlled by the government through the 1959 Water Law. This law states that "water resources are public property, subject to the control of the State, to be used to provide for the needs of the population and the development of the country." (7) The principal responsibility for all the aspects of water supply is borne at the national level by the Ministry of Agriculture and the executive authority is vested in the Office of the Water Commissioner. Water allocation for agricultural purposes is based on a system of annual license procurement

by the farmer, using norms and maximum quantities of consumption related to the various agricultural crops. Such a central administration enables the efforts concerning all water aspects to be firmly directed and controlled. This is, perhaps, one of the main reasons that Israel has been able to develop advanced irrigation technology and methods to face her demographic needs.

Agronomical Aspects

The general objective of irrigation is to control the water variable in the dry matter production process. This variable affects the dry matter production process through its influence on the crop water deficit. The water deficit develops in the crop as a result of the delay between water absorption by the roots and the evapotranspiration through the leaves. Normally, crop water deficits develop as a result of the gradual drying out of the soil.

In arid zones, however, short-term transpirational water losses are even more significant in the development of water deficits than the gradual drying of the soil. The factors which affect the high amount of transpiration in arid zones, namely temperature, humidity, and radiation, are also those which can result in record high dry matter production rates and, consequently, crop yields. This can only be achieved if other variables such as water and nutrients are maintained at sufficient levels. The sandy soils, which are preferred for agriculture in arid zones for reasons previously discussed, are characterized by low water and nutrient storage capacity. The properties of the sandy soils call for frequent water and fertilizer applications in order to maintain optimal levels, requiring a fresh approach and a high degree of sophisticated irrigation technology.

Surface irrigation cannot be used efficiently to solve the problem of frequent irrigation. Using the border and furrows methods, if at all possible, would require highly excessive quantities of water. Sprinkler irrigation, in principle, can be applied as frequently as required. However, when the irrigated water is saline, as is normally the case in the Arava Valley at present (and it will be more likely in the future), sprinkler irrigation cannot be frequently practiced because of leaf burns which result in considerable yield losses. The method of drip irrigation is ideally suited to the combination of hot weather, sandy soils, and saline water. It is, therefore, due to the development of drip irrigation that modern agriculture has been made possible under such unfavorable conditions as exist in the Arava Valley.

Drip Irrigation, Theory and Practice

Drip irrigation is basically a controlled furrow irrigation method. The water flows through a plastic pipe into which equally spaced water emitters are introduced. As a result, the soil water distribution along the line is made up of a series of wetted circles as can be seen in Fig. 17.6. The wetted volumes, characteristic in drip irrigation, are of onion shape (Fig. 17.7). The dimensions of the "onions" depend on the type of soil, the flow rate or discharge of the emitter, and the amount of water applied. During the water application, the soil is saturated close to the emitter. The soil moisture gradually decreases radially due to the soil diffusivity and conductivity and due to the gravitational force. Generally, the diameter of the wetted soil increases with the discharge of the emitter and with the decrease of infiltration capacity of the soil. The depth of the wetted soil volume increases with the increase of both the quantity of water applied and the infiltration capacity of the soil. The latter depends mainly on the soil texture.

The wetted volume characteristics of the drip irrigation method are presented in Fig. 17.7. As can be seen in this figure, optimal conditions for root growth exist only in zone B in which the soil is moist and well aerated. In zones A and C, however, root growth conditions are poor because of excessive wetting or even saturation and high salt accumulation conditions, respectively. Experiments show that the root density in the onion-shaped wetted volume follow these three zones, and in zone A very few roots have been found.

Drip irrigation has further advantages over other methods as far as the efficiency of water distribution in the soil is concerned. Efficiency of an irrigation method can be defined as the ratio between the water available to the roots and the total amount of water applied. The losses of water are caused mainly by wind, evaporation, and deep percolation below the root zone. Since drip irrigation wets the soil directly, wind drag losses are entirely eliminated. Evaporation is reduced because only a small portion of the soil surface is wetted. Deep percolation is still a problem, but it can be partly controlled and diminished by frequent and low-rate application. For a given amount of water, when compared to furrow irrigation methods, the deep percolation due to the drip method is significantly smaller, since the uniformity of soil wetness along laterals is higher.

Consequently, drip irrigation can be regarded as a very efficient means of irrigation, particularly when applied in the Arava Valley. The resulting success of the drip irrigation methods and its advantages over sprinkler and furrow irrigation in the Arava Valley can be seen in Tables 17.4 and 17.5. Table 17.4 presents the results of an irrigation experiment conducted in the Arava Valley during the growing season from September to December. They

Fig. 17.6. Typical view of drip irrigated field in the Arava Valley.

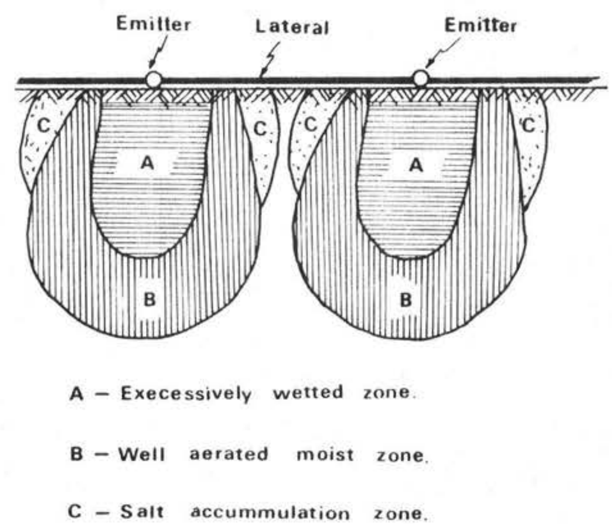

Fig. 17.7. Schematic representation of typical zones in the onion-shaped volume wetted by an emitter with drip irrigation.

TABLE 17.4 Effects of Irrigation Methods on Muskmelon Yields

Irrigation Methods	Yield (tons per hectare, t/ha)	
	Total	Export Grade
Sprinkler	23.8	13.0
Furrows	24.2	16.7
Drip	43.0	35.0

Source: D. Goldberg, B. Gornat, and D. Rimon, Drip Irrigation (Kfar Shmaryahu, Israel: Drip Irrigation Scientific Publication, 1976). Published with permission.

TABLE 17.5 Effect of Irrigation Methods on the Yield of Tomatoes and Cucumbers

Crop	Arava Valley			El Arish (Coastal Sand Dunes)		
	Growing Season	Yield (t/ha)		Growing Season	Yield (t/ha)	
		Drip	Sprinkler		Drip	Sprinkler
Tomatoes	Sept.-March	65.3	39.0	Sept.-March	79.0	30.0
Cucumbers	Nov.-Feb.	39.0	0	Apr.-June*	1.5	3.6

* Summer growth - out of season in this region

Source: D. Goldberg, B. Gornat, and D. Rimon, Drip Irrigation (Kfar Shmaryahu, Israel: Drip Irrigation Scientific Publication, 1976). Published with permission.

show that under drip irrigation the yields of muskmelons were essentially doubled when compared to the other irrigation methods. The quality of the muskmelons, as measured by their export grade, was even more responsive to drip irrigation than the total yields.

The advantages of drip irrigation over the sprinkler irrigation method in other vegetable crops is demonstrated by the experimental results from the two main regions in the Negev as presented in Table 17.5. The yield of tomatoes was significantly higher under drip irrigation than under sprinkler irrigation in both regions. Under sprinkler irrigation with saline water in the Arava Valley, no yield of cucumbers was harvested, since the leaves of this crop are very sensitive to saline water. (See Chapter 13 for a discussion of this topic.)

The extreme conditions of high radiation flux and temperatures, sandy soils, and saline irrigation water call for a highly controlled intensive agriculture. In practice, this means daily irrigation using the drip method and daily fertilizer application, mostly nitrogen, with the irrigation water. The overall result is relatively high yields during seasons when normal agriculture is practically dormant because of the weather. Typical average yield results in the Arava Valley, compared with the average yield received in the north of the country, are presented in Table 17.6.

From Table 17.6 one can see that several crops, denoted by dashes in the last column, are grown and marketed exclusively in the Arava Valley during the late autumn and winter and, thus, provide considerable economic advantage. For others, the average yields in the Arava Valley are greater than those achieved in other zones (late autumn tomatoes and trellising tomatoes). For onions, both sprinkler and drip irrigation systems are used. The yields achieved clearly favored the drip irrigation system, although sprinkling provides some operational advantages and requires lower capital investment than dripping.

Drip Irrigation, Technology

Drip or trickle irrigation is a system for supplying water and fertilizers directly to the soil. Water and fertilizers are delivered through an extensive pipe network to each plant by emitters. The emitters dissipate the pressure in the pipe by means of either small orifices or long paths. These pressure-reducing means allow for small discharges of only a few liters per hour. Figure 17.8 shows a long spiral path emitter of two liters per hour, commonly used in drip irrigation systems.

A typical drip irrigation system is shown in Fig. 17.9 consisting of the following main components: water supply source, control head, main pipe, submain pipes and laterals with emitters.

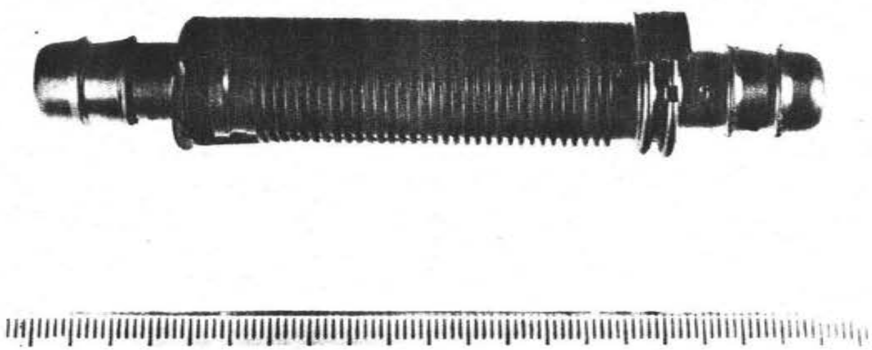

Fig. 17.8. Long spiral path emitter for drip irrigation. (Scale in mm.)

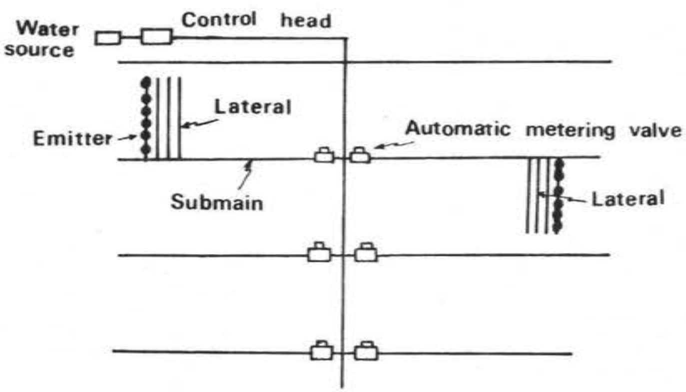

Fig. 17.9. Schematic layout of drip irrigation network.

TABLE 17.6. Average Data for Crops in the Arava Valley and in Israel at Large

Crop	Arava Valley				In Israel at Large[a]
	Growing Season	Crop Yield (t/ha)	Water (1,000m^3)	Marketing Season	Average Crop Yield (t/ha)
Tomatoes (autumn	Aug.-Dec.	50	5-6	Nov.-Dec.	50
(winter)	Sept.-March	60-80	7.5	Jan.-March	40-50
(trellising)	Sept.-March	120-180	9	Dec.-March	80-100[b]
Cucumbers (autumn)	Oct.-Dec.	30-40	6	December	-[c]
(winter)	Jan.-March	25-30	4.5	March	25
Eggplants	Aug.-April	50-70	9	Nov.-March	-
Peppers	Aug.-April	40-70	9	Dec.-March	40-70[b]
Muskmelons (autumn)	Aug.-Dec.	30-40	6	Nov.-Dec.	-
(winter)	Jan.-April	30-40	4.5	March-April	30[b]
Watermelons	Jan.-April	40-50	4	March-April	50[d]
Onions (sprinkled)	Sept.-March	30-50	8	Jan.-March	-
(dripped)	Sept.-March	50-80	8	Jan.-March	-
Sweet corn	Jan.-April	15	5	April	-
Palms	All year	10	20	Sept.-Oct.	9
Grapes	All year	40	12	April	-

[a] Excluding the Arava Valley

[b] In the Negev's coastal dunes (El Arish).

[c] Denotes out of growing season.

[d] Under plastic.

Source: M. Uzrad, the Volcani Center, personal interview, July 1977.

Control Head

The control head is comprised of water metering devices, valves, automatic flow rate and pressure controllers, filter and a fertilizer tank (Fig. 17.10). The filter is installed as a result of one of the main problems of the drip system, emitter clogging. As mentioned above, all types of emitters are made up of small water passages which require water free of suspended solids. This is accomplished by filters of various types such as gravel packs, screens, vortices and others. The filters have to be cleaned regularly, and this is done either manually or automatically. In many cases mechanical filtration is not sufficient to prevent clogging. In these cases, a chemical washing is applied through the entire piping network using different soluble acids. However, all of these devices do not solve the problem of clogging entirely, and the problem still remains.

Main Pipe

The main water supply line connects the water source to the submains through the control head. Its diameter varies from 75 mm to 200 mm (3 to 8 inches), according to the total discharge to be delivered; it is usually buried under the soil surface.

Submains

The submain lines connect the main line to the laterals, usually laid on the surface. In most systems an automatic water metering valve is installed near the main line. This automatic valve enables the setting of a predetermined amount of water to be applied through a group of laterals, all irrigating at the same time and connected to this submain. The diameters of the submains vary from 50 mm to 100 mm (2 to 4 inches), and they are usually made of plastic.

Laterals

Laterals are the pipes which include the emitters and are responsible for distributing the water in the field. Depending on the crop and its spacing along the row, laterals are commonly placed along the row in the arrangements shown in Fig. 17.11. Type one is commonly used for vegetables, while types two through four are mostly used for orchards. The spacings between the laterals vary from 0.5 meter to 2.0 meter for vegetables to a few meters long for orchards.

The lengths and the diameters of the laterals are determined by the following contradictory considerations: to provide maximum discharge

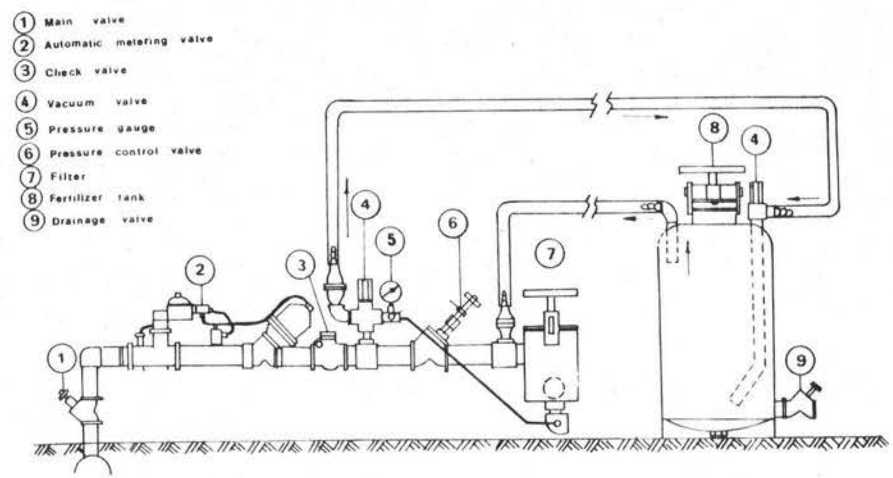

Fig. 17.10. Schematic diagram of control head for drip system.
Source: Israel Center of Waterworks Appliances, Tel Aviv: The Standards Institute of Israel, 1969.

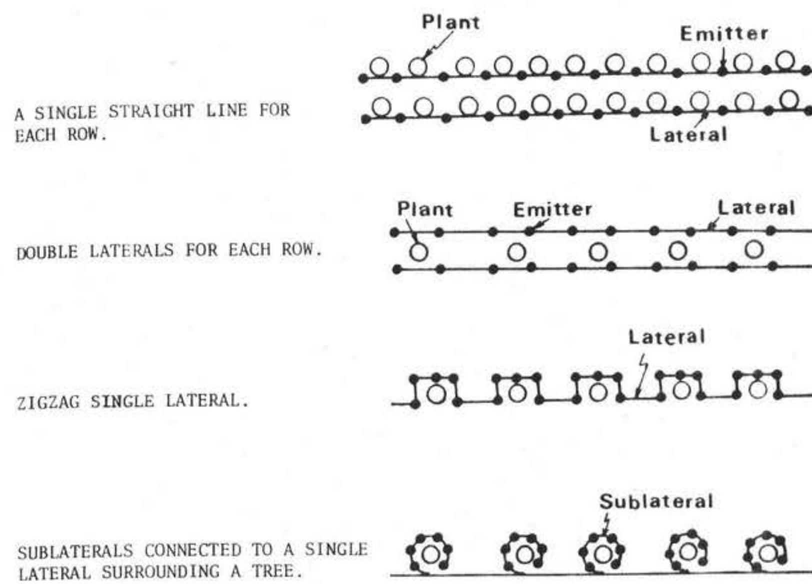

Fig. 17.11. Common layouts of drip laterals.
Source: D. Karmeli and J. Keller, Trickle Irrigation Design (Glendora, Calif.: Rain Bird Sprinkler Manufacturing, 1975), used with permission of Rain Bird Sprinkler Manufacturing Corp. Copyright U. S. A., 1975 by Rain Bird Sprinkler Manufacturing Corp.

uniformity of water distribution along the lateral, and to minimize the cost of the system. Thus, it requires an appropriate hydraulic design, as will be explained.

The uniformity of discharges along the lateral, the main factor of an irrigation system, depends on the length, diameter, and material of the pipe and the topography along it. Pressure head decreases with the length of a given pipe line and can be calculated by multi-exit pipe hydraulic formulas such as: Heizen-Williams, D'Arcy-Weisbach and Chezy, adapted to multi-exit pipes by coefficients which depend on the number of the exits. (8) Therefore, the flow rate of an emitter depends on its location on the lateral meeting the following equation:

$$Q(X) = CA[\Delta H(X)]^m$$

where:

- $Q(X)$ = the flow rate of an emitter located at the distance X from the beginning of the lateral
- C = a coefficient which depends on the type of the emitter
- A = the area of the exit
- $H(X)$ = the difference between the pressure head existing at the X location and the atmospheric pressure
- m = a coefficient, the values of which range from 0.5 to 1.0

Typical flow rates as a function of pressure heads are shown in Fig. 17.12. In order to control the uniformity of flow rates along the lateral, one must minimize the difference between the pressure heads at the beginning and the end of the lateral. In Israel the most common practice is to limit the flow rates along the lateral to the range of 90 percent, that is, $Q_e \geq 0.9\ Q_b$ by meeting the constraint of $H_e \geq 0.85 H_b$ where Q_e, Q_b, H_e and H_b are the flow rates and pressure heads at the end and the beginning of the lateral, respectively.

It is therefore clear that for a given length of a lateral, the larger the diameter the better the uniformity of flow rates. But, at the same time, the cost of the lateral increases with the diameter. As a result, optimal lengths of laterals are called for in order to maintain the flow rate uniformity limits achieved by minimal lateral diameters. A typical design data for recommended lengths of 12 mm (1/2 inch) diameter lateral is presented in Table 17.7 for two emitter types and various emitter spacings along the lateral. The lengths of laterals in Table 17.7 maintain the flow rate uniformity constraint of $Q_e \geq 0.90\ Q_b$ mentioned above. Detailed nomograms, graphical aids) and computerized routines for lateral calculations are available for the designer. (9)

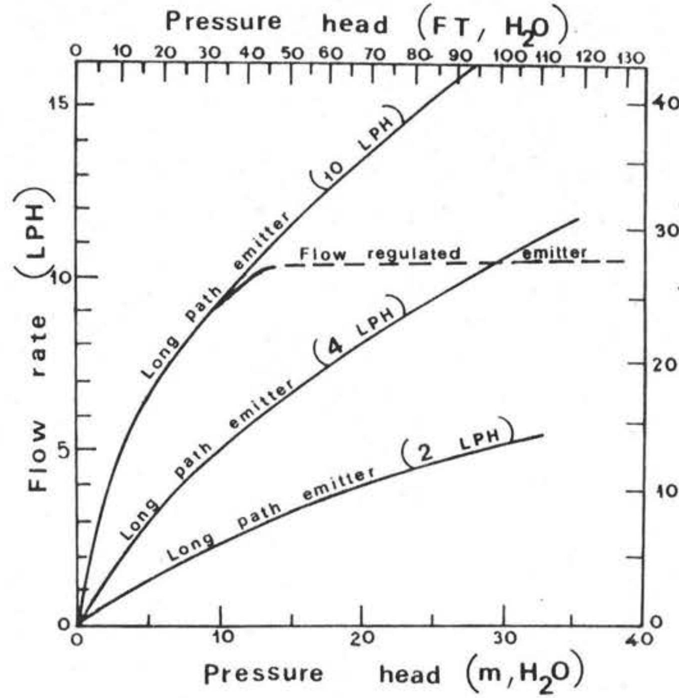

Fig. 17.12. Flow rate as a function of pressure head for various long path emitters (drip irrigation).

Source: D. Karmeli and J. Keller, Trickle Irrigation Design (Glendora, Calif.: Rain Bird Irrigation Manufacturing Corp., 1975), used with permission of Rain Bird Sprinkler Manufacturing Corp. Copyright U.S.A., 1975 by Rain Bird Sprinkler Manufacturing Corp.

Emitter

Many different types of emitters are available. All of them dissipate pressure heads so as to achieve small flow rates ranging from 2 to 15 lph (liters per hour). The mechanisms for reducing pressure heads are different: long spiral path, orifice, vortex orifice, twin wall tubing and porous tubing. The latter is made of a porous material through which water leaks into the soil. A long spiral path 2 lph emitter is presented in Fig. 17.8 as previously discussed.

TABLE 17.7. Recommended Lengths of 12 mm Diameter Laterals (In Meters)

Flow rate of emitters (liters per hour)*	Spacing between Laterals (m) 0.5	0.6	0.75	1.00	1.25	1.50	2.00
2	45	50	60	80	90	110	140
4	25	30	35	40	50	60	90

* At pressure head of 10 m (H_2O).

Operational Considerations

The irrigation regime for a given field is determined mainly by the crop requirements. These requirements vary during the growing season of the crop according to the growing stage, the depth of the main root zone, soil, and climatic conditions. Once the hardware of the system (that is, the type of emitter, the lateral spacing, length and diameter) are determined, the irrigation regime can be controlled by (1) the amount of water per application, (2) the emitter flow rates by varying pressure head, and (3) time intervals between applications.

The second factor above is rarely used, while the other two are the main decision variables to be altered from time to time. The amount of water is automatically controlled by means of the metering valve. The third decision variable, the time intervals, involves additional considerations related to the degree of the portability of the laterals. With regard to portability, three types of drip systems are commonly used: stationary, semiportable, and fully portable laterals. A stationary lateral system is one in which laterals are not shifted during the irrigation season. A semiportable system refers to a technique by which laterals and sublaterals are manually moved only a few times from one place to another. With the fully portable system, a group of laterals is dragged manually, or mainly by a tractor, along the crop rows. When short time intervals (one to three days) between applications are required, stationary laterals are preferred. For longer intervals, the semiportable and the fully portable systems can be used. All of these techniques are practiced where labor-cost exchange considerations determine which one should be applied.

CONCLUSION

In the Arava Valley there are at present about 20 kibbutzim and moshavim. Their agricultural production activities are comprised of livestock, orchards, vegetable crops, corn and animal food crops.

Table 17.8 demonstrates the high level of agricultural intensity achieved in the Arava Valley and presents a production plan for three kibbutz settlements near Elat for the year 1973 which was to be carried out by 180 family units. This plan required 6 million m^3 of water, 750 thousand m^3 of which were recycled sewage water.

From Table 17.8 one can see that 6 million m^3 of water is required to irrigate the 575 hectares of land. About 90 percent of the income is derived from irrigated crops of which 73.1 percent are vegetables. The yearly amount of water per hectare, 10,500 m^3 in the Arava Valley, is about the same as for the rest of the country. Another measure is the amount of water per family unit per year, the value of which is 33 thousand m^3 for both the Arava Valley and the state's average. A significant difference arises concerning the gross income. The annual average gross income per urban employee family in Israel was 17,500 I₤ for the year 1973. (10) The plan in Table 17.8, however, presents an annual gross income of 24,890 I₤ for that year in the Arava Valley, which is 42 percent higher than the state's average.

The Arava Valley presents extreme arid zone conditions imposing severe difficulties on human existence. However, as far as agriculture is concerned, it has been definitely proven that these extreme conditions provide significant advantages and enable a modern high standard of living when water is available and appropriately used.

Even though Israel is unique in type of settlers, efforts directed toward the development of its arid zone by governmental agencies and other factors make the conditions as well as the technological difficulties and solutions and the economic successes presented here sufficient to arouse interest, especially of planners who must face similar conditions.

TABLE 17.8. Production Plan of Three Kibbutz Settlements near Elat, 1973

Activity	Level		Income (I£)[a]		(%)
	Unit	Amount	Per Unit	Total	
Cows	head	300	790	237,000	
Calves	head	308	320	98,560	
Eggs	10,000	490	300	147,000	
Total livestock	–	–	–	482,560	10.8
Palm trees	hectare	21	8,500	178,500	
Other orchards	hectare	64	8,500	544,000	
Total orchards	–	85	–	722,500	(16.1)
Vegetables[b]	hectare	170	12,000	2,040,000	
Onions	hectare	210	4,750	997,500	
Muskmelons	hectare	15	7,200	108,000	
Corn	hectare	50	2,600	130,000	
Total row crops	-	445	-	3,275,500	(73.1)
Animal food crops	hectare	45	-	-[c]	-[c]
Total irrigated crops	hectare	575	-	3,998,000	89.2
Total	-	-	-	4,480,560	100.0

[a] I£ is Israeli pound, 1 I£ ≈ 0.25 U.S. dollar.

[b] Tomatoes, cucumbers, eggplants and peppers.

[c] Included in livestock income.

Source: A Proposal for Developing Agricultural Settlements in the Arava Valley (Tel Aviv: Israel Ministry of Agriculture, 1973).

NOTES

(1) W. Koppen and R. Geiger, Handbuch der Klimatologie (Stuttgart: Gebruder Borntraege, 1930), and C. W. Thornwaite, "An Approach Toward a Rational Classification of Climate," Geographical Review 38 (1948), pp. 55-94.

(2) Michael Evenari, Leslie Shanan, and Naphtali Tadmor, The Negev: The Challenge of a Desert (Cambridge, Mass.: Harvard University Press, 1971), pp. 32-33.

(3) G. Stanhill, "Solar Radiation in Israel," Bulletin of the Israel Research Council 11G (1962), pp. 34-41.

(4) Evenari, Shanan, and Tadmor, p. 33.

(5) Ibid., p. 40.

(6) Ibid., p. 220-228.

(7) S. Arlosoroff, Irrigation Equipment and Methods - Trends and Forecast (Tel Aviv: United Nations Food and Agriculture Organization, 1976).

(8) A. Benami, "New Headloss Table for Sprinkler Laterals," Proceedings of American Society of Civil Engineers 94, (1968), 185-197.

(9) D. Karmeli and J. Keller, Trickle Irrigation Design (Glendora, Calif.: Rain Bird Sprinkler Manufacturing Corporation, 1975); and D. Goldberg, B. Gornat, and D. Rimon, Drip Irrigation (Kfar Shmaryahu, Israel: Drip Irrigation Scientific Publication, 1976), p. 32.

(10) Statistical Abstracts of Israel, No. 24 (Tel Aviv: Israel Central Bureau of Statistics, 1973), p. 345.

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