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irrigation of field and orchard crops under semi-arid conditions

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ABOUT THE INTERNATIONAL IRRIGATION INFORMATION CENTER

The International Irrigation Information Center (IIIC) is a non-profit corporation established in 1975 by the International Development Research Centre of Canada, and the Ministry of Agriculture of Israel. The IIIC offices are located at the Volcani Center of Israel's Agricultural Research Organization.

The objective of the Center is to collect and analyze information on different aspects of irrigation appearing in technical and scientific literature throughout the world. This information will be disseminated among those concerned with irrigated agriculture, particularly in semi-arid regions, by means of various periodicals and publications.

ABOUT THIS REVIEW

Irrigation of Field and Orchard Crops Under Semi-Arid Conditions is a summary of field experiments conducted in Israel during the period 1954-1974. The purpose of the experiments was to establish the optimum irrigation regime for various field and orchard crops and to increase water use efficiency. The studies were carried out in the five main ecological regions of Israel, under a variety of soil and climatic conditions. The climatic conditions were characterized by a warm, dry summer and a cool, rainy winter, with a mean August temperature range of 23 to 32°C, a mean August potential evaporation range of 7 to 10 mm/day and a winter (November to April) rainfall range of 230 to 620 mm.

For each crop, data is given on the production function of yield vs. water application, evapotranspiration rate, optimum irrigation regime and pattern of water uptake from the root zone.

The applicability of the information obtained in Israel to other ecological regions depends mainly on the possibility of taking climatic variability into account.

An appendix is provided which demonstrates that data from the various ecological regions of Israel can be normalized on the basis of a single climatic variable. Thus, production functions obtained in Israel may be applied to other areas.

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Introduction

The appropriate design of irrigation systems and the judicious application of irrigation water in the field demands reliable information on the irrigation requirements or consumptive use of the particular crops. The irrigation requirement of a crop may be defined as the minimum amount of water, applied at appropriate intervals, which will result in an optimum yield in quantity and quality.

Several methods are available for estimating the water requirements of a crop, based on meteorological variables (net radiation, temperature, relative humidity, wind) and soil and plant variables (integrated moisture stress, preirrigation moisture stress, leaf water status, stomatal aperture). The applicability of these methods depends on their calibration against the direct measurements of yield as a function of irrigation water application, deduced from carefully designed and conducted field experiments.

This report is an attempt to present a concise summary and analysis of the results of water requirement experiments carried out in Israel during the past 20 years. Data are given for the following crops: field crops – wheat, sorghum, corn, cotton, sugar beets, peanuts, alfalfa and tomatoes; orchard crops – citrus (orange and grapefruit), avocado, apples and bananas; miscellaneous crops – lawngrass, greenhouse roses, poplar and sisal.

The summary includes: (a) production functions of yield vs. water application and/or consumptive use (b) the daily course of evapotranspiration (E_t) based on monthly or semi-monthly means, as well as Class A pan evaporation (E_0) (c) tables of recommended (optimum) irrigation regimes including irrigation intervals, depth of soil wetting and yields (d) water uptake as a function of soil depth and (e) climatic and soil conditions at the experimental sites.

Presentation methods

1. *Production functions*

Production functions are presented in graphic and algebraic forms in terms of relative yield and net or gross water application. The use of relative rather than absolute yield offers a simple way of presenting data from different locations and years in a uniform manner. The maximum yield in each experiment was considered as 100%; it was generally high, compared with accepted averages, and is reported in each case.

Net water application is the actual amount of water added to the soil following an irrigation, rather than the amount actually delivered. Use of this parameter reduces variability due to application efficiency and soil conditions. By correcting for irrigation efficiency, the data obtained may also be applied to conditions other than those of the experiments. In all experiments reported, efficiency was 80-90%. Water distribution in orchards is generally very poor; although this is not critical in terms of water availability – as each tree receives water in at least part of its root zone – it does make estimation of the net water application difficult. Consequently, the yield of orchard crops was reported relative to the total water applied. Since water was usually applied to wet less than the full rooting depth, deep seepage was slight and thus the difference between the net and total amounts of water applied was minimal.

A linear regression was applied to the data of most field crops in the range of zero to 95% yield. The fit was generally good, except for orchard crops for which a regression analysis was not possible.

2. *Daily evapotranspiration* (E_t)

The daily course of E_t as a monthly or semi-monthly mean is given for the optimum treatment, i.e. that which gave a close to maximum yield with the least amount of water. By superimposing a number of such curves for various crops, the irrigation schedule for an entire farm may be computed. Whenever possible, Class A pan evaporation (E_o) and E_t/E_o are also reported.

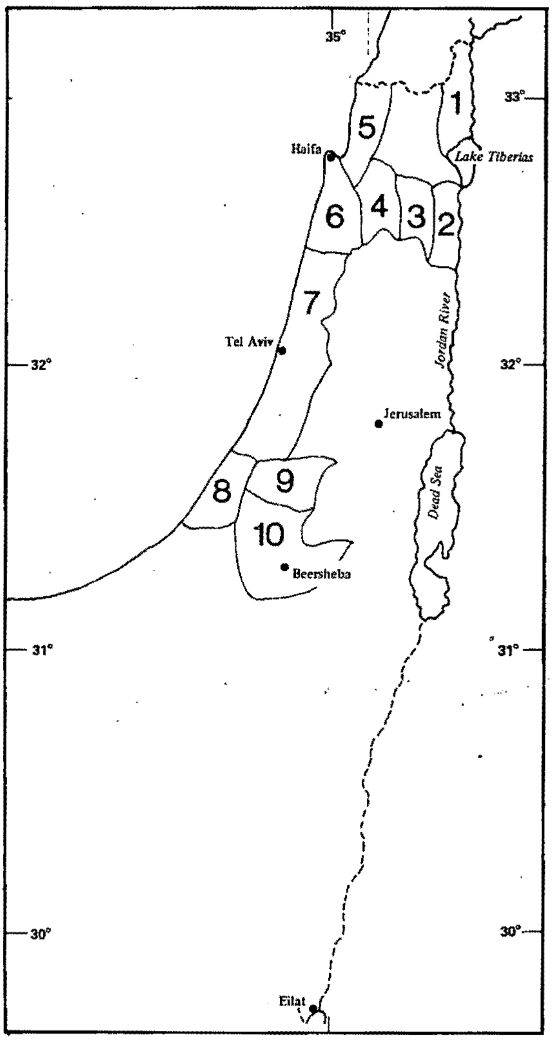
3. *Optimum irrigation regimes*

The optimum irrigation regime was chosen arbitrarily as that which results in a yield not lower than 90% of the maximum in any particular experiment, with the least amount of water. The optimum recommended irrigation frequency is also reported for each crop. (High frequency irrigation was not tested in most of the experiments.)

The values for consumptive use (evapotranspiration) may be computed from the data on net irrigation water requirements by adding the amounts taken up from storage, which range between 150 mm and 200 mm for a rooting depth of 120 cm in medium and heavy-textured soils.

4. *Water uptake as a function of soil depth*

Whenever data were available, water uptake as a function of depth was reported for the optimum treatment and occasionally for other treatments as well. These data may be used to decide on partial root zone wetting for water conservation, provided accumulated salts may be leached out by winter rains or by periodic overirrigation.



Regions
1 Upper Galilee
2 Bet Shean Valley
3 Eastern Jezreel Valley
4 Western Jezreel Valley
5 Western Galilee
6 Northern Coastal Plain
7 Central Coastal Plain
8 Southern Coastal Plain
9 Lakhish Region
10 Northern Negev

Figure 1. Schematic location map of the various irrigation requirement experiments.

5. *Experimental locations*

Production functions were computed for distinct ecological regions. (Fig. 1) Climate was uniform, but soil properties varied within each region. The climatic characteristics, main soil properties, and Class A pan evaporation are indicated in Tables, 1, 2 and 3, respectively. There may have been more than one experimental site within each region; such sites are marked by Roman numerals.

Table 1. Location description, and climatic characteristics of the various experimental sites

No.	Location	Coordinates		Mean temperature (°C)			Relative humidity	Rainfall
		Long. °'E	Lat. °'N	Apr.	Aug.	Dec.	Aug. (%)	(mm)
1.	Upper Galilee	3536	3308	17.6	26.6	13.7	59	430
2.	Bet Shean Valley	3530	3229	20.4	30.4	15.4	49	270
3.	Eastern Jezreel Valley	3517	3236	18.3	27.6	14.6	59	440
4.	Western Jezreel Valley	3512	3243	17.8	26.9	15.0	63	580
5.	Western Galilee	3506	3526	17.3	26.4	15.4	69	630
6.	Northern Coastal Plain	3457	3227	17.6	26.0	15.1	67	560
7.	Central Coastal Plain	3449	3156	17.4	25.6	14.5	67	535
8.	Southern Coastal Plain	3432	3129	17.6	25.1	13.0	67	360
9.	Lakhish Region	3451	3134	17.8	25.7	15.0	64	350
10.	Northern Negev	3439	3119	18.6	26.8	14.8	60	240

Table 2. Soil characteristics of the various locations

Location No.	Soil type	Field capacity by weight (%)	Wilting point by weight (%)	Bulk density (g/cm^3)
1.	Vertisol (Clay)	33	23	1.20
2.	Protogrumusol (Clay)	27	17	1.35
3.	Vertisol	35	23	1.30
4.	Vertisol	37	23	1.20
5.	Vertisol	36	26	1.30
6.	Vertisol	26	15	1.45
7.	Sandy brown Hamra	18	8	1.60
8.	Loessial soils	22	11	1.45
9.	Loessial soils	22	11	1.45
10.	Loessial sierozem	18	8	1.45

Table 3. Mean monthly Class A pan evaporation (E_o) in mm/day

	Location	Month												Total
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	(mm)
1.	Upper Galilee	2.2	2.5	4.1	5.2	7.7	10.2	9.8	9.9	7.3	5.0	3.7	2.8	2140
2.	Bet Shean Valley	2.2	2.6	4.1	6.3	9.0	10.9	11.1	10.5	8.9	6.1	3.9	2.4	2380
3.	Eastern Jezreel Valley	2.4	2.8	3.6	5.1	7.6	9.1	9.4	8.9	7.4	5.7	4.0	3.0	2100
4.	Western Jezreel Valley	2.5	2.7	3.5	4.3	6.3	8.2	8.8	9.2	7.3	5.6	3.1	2.5	1950
5.	Western Galilee	1.7	2.4	3.3	4.0	4.9	6.1	6.2	7.2	5.4	4.3	2.6	2.0	1540
6.	Northern Coastal Plain	2.2	2.7	3.7	4.9	6.5	7.5	7.4	7.0	6.1	4.9	3.8	2.7	1810
7.	Central Coastal Plain	2.2	2.6	3.8	5.4	6.8	8.0	8.0	7.5	7.0	5.0	2.9	2.2	1870
8.	Southern Coastal Plain	2.5	2.7	4.0	5.1	6.7	7.8	7.7	7.3	6.6	4.7	3.7	2.8	1880
9.	Lakhish Region	2.7	3.1	4.2	5.9	7.8	9.0	9.0	7.9	7.2	5.4	4.1	2.9	2110
10.	Northern Negev	2.9	3.4	5.0	6.8	8.6	9.5	9.5	8.9	7.5	6.0	4.4	3.2	2300

Experimental methods

Most of the experiments included at least five irrigation treatments (generally involving irrigation frequency), with five to six replications. The irrigation treatments ranged from dry (infrequent irrigation) to wet (frequent irrigation). Frequencies were chosen such that the dry treatment resulted in a substantial yield loss while the wet treatment yield was either in the yield plateau or even reduced due to overwetness.

Evapotranspiration and irrigation efficiency were determined by frequent soil moisture measurements, using gravimetric sampling in the early experiments and neutron moderation in the more recent ones. In all cases, irrigation was always applied to wet the soil to its predetermined water holding capacity (field capacity). Depth of wetting was a variable in some experiments and a constant in others. In some experiments, critically sensitive phenological growth stages were also determined.

All inputs other than water were kept at a high technological level and the yields obtained were thus generally high. The predominant irrigation method used was sprinkler, except in those experiments where drip and furrow methods were used.

Plot size for field crops was usually 24 x 24 meters, of which the center 12 x 12 meters was used for sampling and yield analysis. In orchards, plot size was determined by tree spacing. In most cases, 16 trees were included in each plot, of which the center four were used for yield analysis.

field crops

Wheat

The wheat (*Triticum aestivum*) type most commonly grown during the winter in the eastern Mediterranean region is spring wheat. It is usually planted in dry soil in November, and its germination therefore depends on early winter rains or irrigation. The optimum date for germination is late November – earlier germination may result in midwinter maturation when low temperatures may damage the spikelets, while late germination may result in sluggish early vegetative development and a truncation of the growing season. Plants which germinate in late November enter the winter with good vegetative cover and resistance to low winter temperatures.

Spikelet differentiation starts about 30 days after germination. Heading occurs in most varieties during the first half of March.

Spikelet development depends upon four main factors:

a. Date of germination: Early germination results in early heading. On the other hand, late germination does not delay heading beyond a date determined by varietal characteristics.

b. Water supply: Lack of water during vegetative development may hasten maturation. Earlier deficiency affects both the timing of heading and the date of germination.

c. Nitrogen supply: Nitrogen deficiency hastens heading.

d. Temperature: Low winter temperatures delay heading.

Grain filling begins following heading. Water deficiency during this stage will result in shriveled grains.

The results summarized below are based on a series of experiments conducted throughout Israel during the period 1954-1971.[1] Most of

[1] D. Shimshi, principal investigator; S. Gairon, J. Rubin, M. Khilfa and Y. Khilmi, coinvestigators.

the principal experiments were carried out in the Northern Negev region (Gilat). Supplementary experiments were conducted in the Lakhish region, the Jordan Rift and the Bet Shean valley. In the early experiments, the common variety tested was Florence x Aurore. Later on, locally-bred semi-dwarf varieties were used. (N. 46, Miriam, Lakhish and 1177)

Mean rainfall ranged between 240 mm and 350 mm, and the temperature in April between 18.5°C, and 20.5°C (Table 1). The water holding capacity of the soils to a 100 cm depth ranged between 120 mm and 150 mm, despite the variability in soil type (loess to fine-textured vertisols). (Table 2)

Since wheat is grown during the rainy season, the experimental design was kept flexible in order to account for varying rainfall amounts and distribution. The principal experiments in the Northern Negev included six treatments, four of which had predetermined irrigation scheduling: (i) no irrigation; (ii) one early irrigation immediately following seeding; (iii) one late irrigation during spikelet formation or somewhat earlier, depending on rainfall and (iv) two irrigations, one early and one late. The remaining two treatments were determined on the basis of rainfall conditions. Supplementary experiments included only four treatments (i-iv). The sowing date in all experiments preceded November 20th. The date of germination depended on the timing of the early rains or irrigation. The soils ranged from loess (F.C. = 18%) to vertisols (F.C. = 32%).

Approximately thirty experiments were carried out on the various varieties, at different locations and in different years. Variability in weather and soil conditions from year to year and from location to location resulted in considerable variations in results; nevertheless, some general conclusions may be drawn. The conclusions reported below are based on the results of ten experiments in which the maximum yield exceeded 450 kg/1000 m^2.

Results and conclusions

1. *Water consumption, yield and change of water uptake with time and depth*

Table 4 presents typical evapotranspiration data for the semi-dwarf variety N.46 under favorable soil moisture conditions. During the early months of wheat crop development the consumptive use is about 50% of pan evaporation (E_t/E_o = 0.5); during the peak of vegetative development, in March and April, the ratio reaches 0.8, and during maturation it falls to about 0.2. When the root system is fully developed in March, 90% of the water is taken up from the 0-90 cm layer. Under conditions of frequent but light rains, the pattern changes so that 90% may be taken up from the 0-60 cm layer and 60% from the 0-30 cm layer without any yield reduction. During moderately dry years more water may be absorbed from deeper layers, again without any yield reduction.

Table 4. Monthly water consumption (E_t) for wheat (Var. N. 46) in the Northern Negev (Gilat) under a favorable irrigation treatment[1] (two irrigations totalling 224 mm)

Soil layer (cm)	E_t, (mm per month)							E_t (% of 0-120 cm layer)
	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total	
0- 30	40	32	38	52	34	11	207	47.4
30- 60	5	14	27	41	35	14	136	31.2
60- 90			10	22	22	14	68	15.6
90-120				4	13	8	25	5.7
Total E_t (mm)	45	46	75	119	104	47	436	
Rain (mm)	108	75	41	64	0	2	290[2]	
Class A pan evaporation (E_o) (mm/month)	86	86	92	146	192	250		
Et/E_o	0.52	0.52	0.81	0.82	0.55	0.19		

[1] The yield of this treatment was 619 kg/1000 m^2.

[2] In addition, 10 mm had fallen during the months of October and November.

To produce a maximum yield, the wheat crop requires 400-450 mm of water (Fig. 2 and Table 5); with less water, a yield reduction may be expected. The mean maximum yield obtained in the Northern Negev and Lakhish regions was 540 kg/1000 m^2 while in the Jordan Rift and the Bet Shean Valley the yield was 500 kg/1000 m^2.

2. *Irrigation timing*

It is essential that at the early stages of development there will be sufficient moisture stored in the soil for wheat crop development. In

Table 5. Irrigation regimes, irrigation quantities and optimum wheat yields at various locations

Location	Year	Variety	Rainfall (mm)	Total water application (mm)	Time of irrigation[1]	Yield[2] (kg/1000 m²)		kg(1000m²/ mm)[3]
Northern Negev I	1965-66	N.46	186	350	P+H+M	501	(100)	1.35
	1966-67	N.46	300	150	P	473	(95)	0.76
	1967-68	N.46	318	224	P+H	619	(100)	1.59
	1970-71	1177	237	286	P+H	649	(100)	1.06
	1971-72	1177	363	150	P	588	(94)	1.28
Northern Negev II	1967-68	N.46	298	240	P+H	464	(100)	1.02
Lakhish	1969-70	Miriam	291	180	P+H	454	(100)	1.60
	1971-72	1177	518	100	H	471	(94)	0.37
Bet Shean Valley	1970-71	1177	471	100	P	486	(98)	1.12
Jordan Rift	1971-72	1177	353	240	P+H	504	(100)	1.43

[1] P = after planting; H = shortly before, or at heading; M = at milk stage.

[2] In parentheses: relative yield expressed as a percent of the maximum yield in the same experiment.

[3] Marginal return, calculated by subtracting the yield obtained with no irrigation from the total yield, and dividing by the water applied. Yields obtained with no irrigation are not given in the table.

65% of the experiments there was a marked response to the early irrigation. For example, in the Northern Negev (Gilat), Variety 1177 irrigated with 150 mm of water right after seeding yielded 550 kg/1000 m^2 as compared with 440 kg when irrigated with 150 mm water at heading. In Lakhish, Variety Miriam yielded 380 kg/1000 m^2 when irrigated early, compared with 210 kg when irrigated late. Early irrigation was usually found to be advantageous in years when irrigated wheat germinated at least two weeks before non-irrigated wheat, because of a delay in the first effective rains.

The mean yield response to the four basic irrigation regimes is presented in Table 6. There was a 10% yield difference between early and late irrigation (456 and 409 kg/1000 m^2, respectively). Since the mean rainfall was higher than the long-term mean, during the experimental years, the yield without irrigation was higher than the yield expected under average rainfall conditions.

Table 6. Wheat response to four irrigation regimes (mean of 10 experiments with maximum yield better than 450 kg/1000 m^2)

Treatment	Rain (mm)	Gross water application (mm)	Relative yield (%)	Marginal return[1] (% per mm water)
No irrigation	330	–	51	
Early irrigation	330	129	86	0.27 (0.21)
Late irrigation	330	132	76	0.19 (0.13)
Two irrigations	330	244	100	

[1] Values without parentheses refer to response to a single irrigation; those in parentheses refer to an additional irrigation.

The marginal return for an early irrigation when given as the only irrigation was 1.40 kg/1000 m^2 per mm water, while the return for a single later irrigation was only 1.02 kg/1000 m^2. The difference between early and late irrigations, when applied in succession, was even larger (1.09 kg/1000 m^2 and 0.65 kg/1000 m^2 per mm water, respectively) than the difference when each was given as a single irrigation.

A water application of about 150 mm at the time of seeding is sufficient to carry the wheat crop until the end of January without impairing its yield potential. Under Northern Negev conditions, there is a high probability that midwinter rains will be sufficient to bring the crop to maturation with high yield. At heading time, the soil should have 150 mm of available water stored; if not, additional irrigation will be required, although this may contribute not more than 20% to the final yield, provided sufficient water was applied at seeding time.

3. *Production functions*

Despite the large variability among years, and the differences in response to early and late irrigations, it is possible to obtain a general response function for wheat. The function was computed for two distinct regions using data from all experiments with maximum yield exceeding 450 kg/1000 m² (Fig. 2).

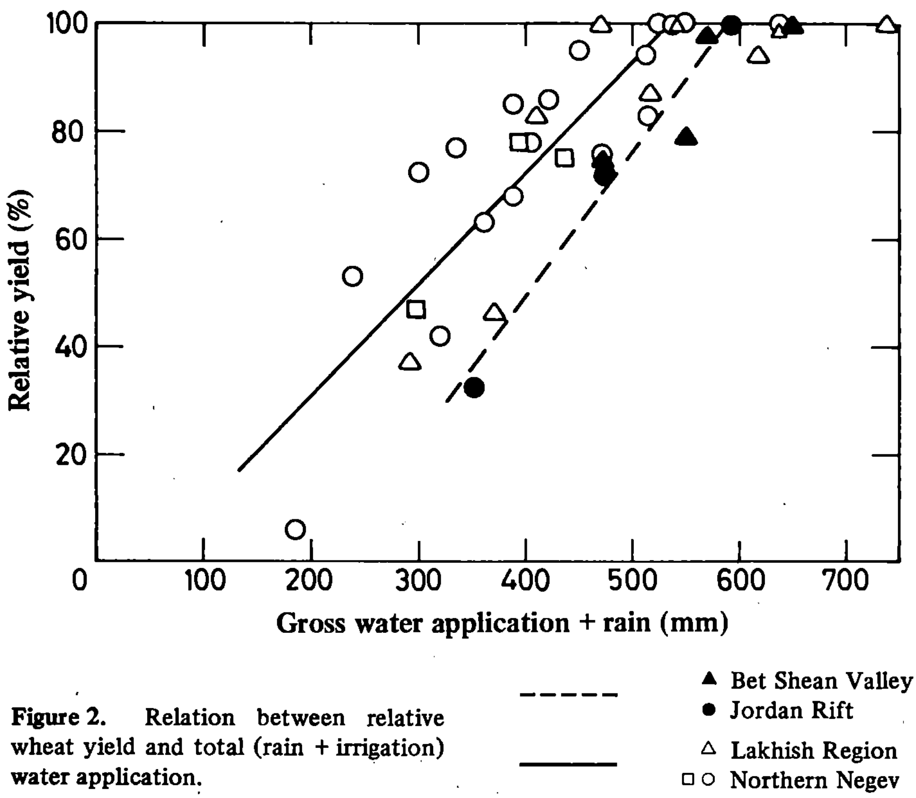


Figure 2. Relation between relative wheat yield and total (rain + irrigation) water application.

The relationship of the total amount of water (irrigation + rain) (x) to the estimate of relative grain yield ($\hat{y}$) for the Northern Negev and Lakhish regions may be described by the following linear equation (in the 200-550 mm water range).

$$\hat{y} = -10.7 + 0.208\,x; \qquad r^2 = 0.767$$

According to this equation, the mean increase in yield for each mm of water is 1.12 kg/1000 m^2, provided rainfall distribution is favorable. In an average year (240 mm rain) the expected yield without irrigation is 39% (210 kg/1000 m^2) of the maximum yield.

In the Jordan Rift and the Bet Shean Valley, the linear equation is (in the 250-600 mm range):

$$\hat{y} = -58.3 + 0.268\,x; \qquad r^2 = 0.933$$

According to this equation, the mean increase in yield for each mm of water applied is 1.34 kg/1000 m^2. The expected yield without irrigation is 22% (110 kg/1000 m^2) of the maximum yield, which is about half the yield obtained in the Northern Negev. The most likely cause for these regional differences is temperature, especially during the spring months.

The marginal return for irrigation water was 2.7 kg/mm in dry years, 2 kg/mm in average to moderately wet years (up to 320 mm rain) and nil in wet years (over 400 mm rain). Under dryland conditions, the yield may range between 32 and 360 kg/1000 m^2, depending largely upon the early rains. For a given rainfall quantity, the yield decreases substantially, as seed germination is delayed beyond mid-December due to delayed rainfall.

Comparison of the low-yielding variety Florence x Aurore with the high-yielding dwarf varieties shows no increase in water requirement with the substantial yield increase (Table 7).

4. *Irrigation effects on yield components*

Under arid Mediterranean conditions, there are no phenological stages of growth during which wheat is particularly sensitive to water deficiency. Early irrigation influences the number of seedlings, and thereafter affects the number of ear-bearing tillers. For example, during a winter with 360 mm rain, an early irrigation of 150 mm increased the number of seedlings from 268 to 349 per m^2 and the number of ears from 344 to 403 per m^2 as compared with the yield with no irrigation. Late irrigation had no effect on the number of ears. Larger differences may be expected if the first rains are late, resulting in late seedling emergence.

Table 7. The effect of irrigation treatments on yields of Florence x Aurore (F.A.) and N.46 wheat in the Northern Negev (Gilat, 1966 and 1967)

Irrigation Treatments: dates and amounts (mm)	Total water (mm)	Yield ($kg/1000\ m^2$)	
1966: 186 mm rain, beginning in February		F.A.	N. 46
No irrigation	0	45	32
Nov. 25 (150)	150	254	391
Jan. 5 (86)	86	131	154
Jan. 5 (86); March 5 (112)	198	183	276
Nov. 25 (150); Feb. 2 (68); March 10 (130)	348	314	501
1967, 318 mm rain, beginning in November			
No irrigation	0	154	262
Dec. 8 (86)	86	336	482
March 13 (150)	150	360	463
Dec. 8 (86), March 17 (138)	224	420	615

Water deficiency during and after heading results in shriveled seeds; irrigation during these periods results in a substantial increase in 1000 seed weight. For example, the 1000 seed weight of Variety 1177 was 34.1 g without irrigation, 37.8 g with early irrigation only, 42.8 g with late irrigation only and 39.8 g with two irrigations. This advantage in seed quality may compensate for the lower yields usually obtained with late irrigation only.

5. *Recommendations for irrigation*

(in regions with approximately 250 mm annual rainfall)

a. Plant in dry soil in November and apply 150 mm water shortly thereafter. In case of substantial rain before planting, irrigation should be applied to bring the upper 60 cm of soil to field capacity.

b. Second irrigation should be applied when the cumulative water deficit in the top 100 cm of soil reaches 100-120 mm. In average years, there is no need for additional water until heading occurs.

c. If the soil water deficit at heading is less than 20-30 mm, there is no need for irrigation until the milk stage, at which time – if the rains are delayed – the soil water deficit should be replenished to a depth of

60 cm. With over 20-30 mm water deficiency, at least 50 mm of water should be applied at heading. Subsequently, no further irrigation is required.

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Sorghum

Sorghum (*Sorghum bicolor L. Moensh*) originated in Asia and Africa, and is today extensively distributed over wide regions. Its cultivation has increased since the development of high yielding hybrid varieties. The crop can yield reasonably well under adverse conditions of low soil moisture and high temperatures, although it does respond well to irrigation. Its xerophytic characteristics are due to a well-developed and dense root system, a high root-to-top ratio, wax layer over the leaves, small stomata and its ability to roll leaves in dry and hot weather.

The results summarized herein are based on field experiments conducted at three locations:[1] the Northern Negev, the Northern Coastal Plain and the Southern Coastal Plain. The Negev experiments included 5-8 irrigation treatments and two row spacings: 75 and 105 cm in the years 1958 and 1959 and 45 and 75 cm in 1961. Irrigation was applied to wet 180 cm of the soil depth to field capacity. The Southern Coastal Plain experiment, in 1966, included four irrigation treatments and three row spacings: 45, 75 and 150 cm. The Northern Coastal Plain experiments in 1964 and 1965 included 7 irrigation treatments and three row spacings: 45, 75, and 100 cm. In all experiments, the crop was seeded in early to mid-April. The respective soils in the three regions were loess (F.C. = 18%), dark brown soils (F.C. = 22%) and vertisols (F.C. = 26%).

Results and conclusions

1. *Irrigation requirements and yields*

The amount of net irrigation water required for optimum yield (not less than 90% of the maximum) is 380-420 mm in the Northern Negev and 240-270 mm in the coastal region (Fig. 3). The total amount of water required should be adjusted according to local irrigation efficiency. To obtain the total evapotranspiration (E_t), an amount of 230-250 mm of water taken up from storage should be added. The differences in water requirements between the two regions stem from differences in winter

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[1] H. Bielorai, A. Amir and Z. Plaut, principal investigators; A. Blum and I. Arnon, coinvestigators.

precipitation and the consequent soil water storage. The mean maximum yields in the Negev and the coastal plain were 825 kg/1000 m² and 1044 kg/1000 m², respectively.

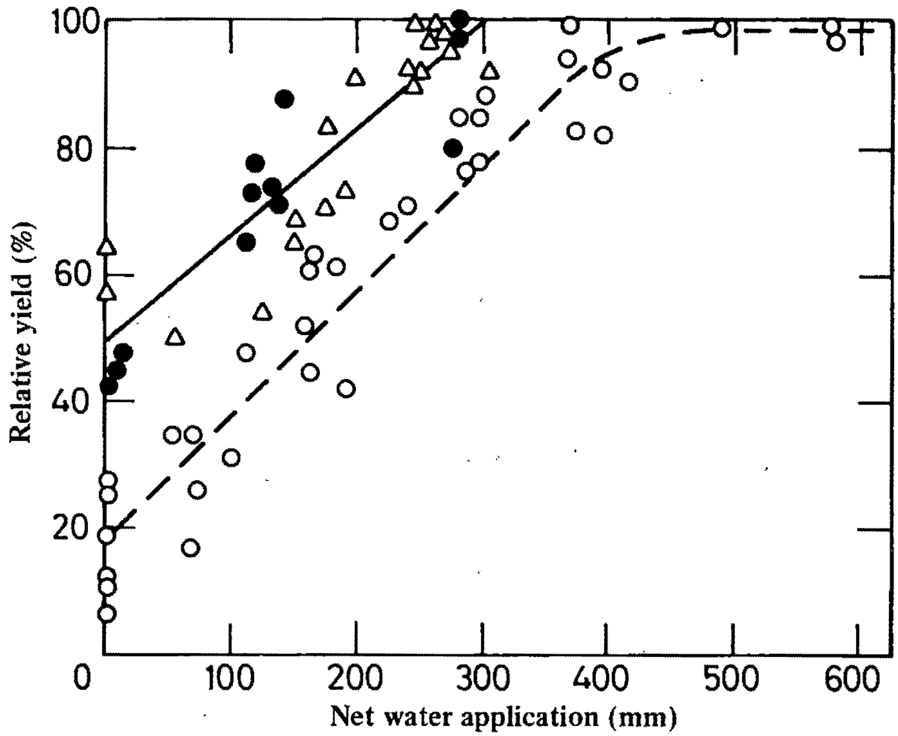

Figure 3. Relation between relative sorghum grain yield and net water application in two regions.

2. *Production functions*

The relation of relative yield estimates ($\hat{y}$) and net water application (x) may be described by the following linear equations for the range of 0-420 mm water:

Northern Negev:	$\hat{y} = 18.0 + 0.202\,x$;	$r^2 = 0.916$
Coastal Plain:	$\hat{y} = 45.9 + 0.169\,x$;	$r^2 = 0.822$

According to these equations, the yield increase per mm water was 1.67 kg/1000 m² and 1.77 kg/1000 m² in the Negev and coastal regions, respectively. Sobotnik et. al. (4) fitted a second order equation to the absolute yield estimates for the Northern Negev:

$$\hat{y} = 1248 + 2.47\,x - 0.00217\,x^2; \qquad r^2 = 0.965$$

According to this equation, the marginal yield increments were 2.0, 1.2 and 0.7 kg/1000 m^2 for water quantities in the ranges of 100, 300 and 400 mm, respectively.

3. *Cultivation under dryland conditions*

Fifty percent of the maximum yield in the coastal region (520 kg/ 1000 m^2) may be obtained without any irrigation, whereas in the Northern Negev only 20% of the maximum (150 kg/1000 m^2) may be expected, provided 180 cm depth of soil is wetted to field capacity prior to seeding. With one supplemental irrigation of 120 mm it is possible to obtain 70% of the maximum yield in the coastal region, while 250 mm of water applied in two or three irrigations is required to obtain similar yields in the Northern Negev.

4. *Number of irrigations*

Three irrigations are required to obtain optimum yields in the Northern Negev, and two irrigations are required in the coastal region, provided the soil profile is wet before seeding. A larger response will result from a single irrigation if it is applied during heading than if applied earlier (Table 8).

5. *Irrigation and row spacing*

The response to row spacing was not consistent in all experiments. Nevertheless, it may generally be concluded that the fewer the irrigations the greater the advantage of wider spacings. With a single irrigation the 105 cm spacing is preferable, while with two irrigations the 75 cm spacing resulted in higher yield and better water use efficiency (Table 9). In the Southern Coastal Plain, with two or three irrigations, increasing the spacing from 100 to 150 cm resulted in a 15% yield reduction.

6. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

The mean daily E_t is given in Fig. 4. Two weeks after seedling emergence the daily E_t was 1.5 mm and increased gradually to 3.5 mm in June; when only one irrigation was applied, the E_t was reduced to

Table 8. Optimum yields and yield components of grain sorghum and water consumption at three locations

Location and year	Number of irrigations	Irrigation interval (days from seeding)	E_t (mm)	Net water application (mm)	Grain yield[1] ($kg/1000\ m^2$)		1000 seed weight (g)	Water use efficiency ($kg/1000\ m^2/mm$)
Northern Negev								
1958	3	38 59 80	522	292	586	(78)	–	1.12
	7	38 48 57 67 77 87 99	678	582	726	(97)	–	1.01
1959	4	37 56 72 87	558	394	871	(93)	27.1	1.38
1961	3	39 58 74	558	364	750	(82)	27.4	1.39
S. Coastal Plain								
1966	3	52 73 91	499	271	1086	(100)	31.0	2.1
C. Coastal Plain								
1964	2	43 82	440	235	1015	(100)	28.0	2.3
1965	2	43 82	460	245	955	(93)	31.1	2.0

[1] In parentheses: relative yield expressed as a percent of the maximum yield in the same experiment.

Table 9. Irrigation regime, row spacing, yield and yield components of grain sorghum in the Northern Negev

Number of irrigations	Irrigation interval (days from seeding)	Net water application (mm)		E_t (mm)		Grain yield (kg/1000 m^2)		1000-seed weight (g)		Water use efficiency (kg/1000m^2/mm)	
	Row spacing (cm)	75	105	75	105	75	105	75	105	75	105
0		85	85	244	250	250	234	16.3	17.9	1.02	0.94
1	38	138	152	322	306	326	318	14.1	14.9	1.01	1.04
1	60	246	244	411	421	589	572	26.9	27.7	1.43	1.35
2	36 57	365	372	535	519	791	713	26.5	27.8	1.49	1.37
2	42 68	388	332	514	460	825	794	27.0	27.5	1.60	1.72
3	36 59 78	502	455	594	535	847	772	26.7	27.1	1.43	1.44
4	37 56 72 87	479	477	520	558	871	768	26.8	26.8	1.68	1.38
6	35 45 55 65 75 85	664	581	710	667	932	741	27.2	27.3	1.31	1.11

1.2 mm/day and with three irrigations it was increased to 6 mm/day in July.

The E_t/E_o ratio rose rapidly from 0.37 in June to 0.66 in July and dropped to 0.30 in August. Thus, it would be difficult to use Class A pan evaporation as an indicator for sorghum irrigation.

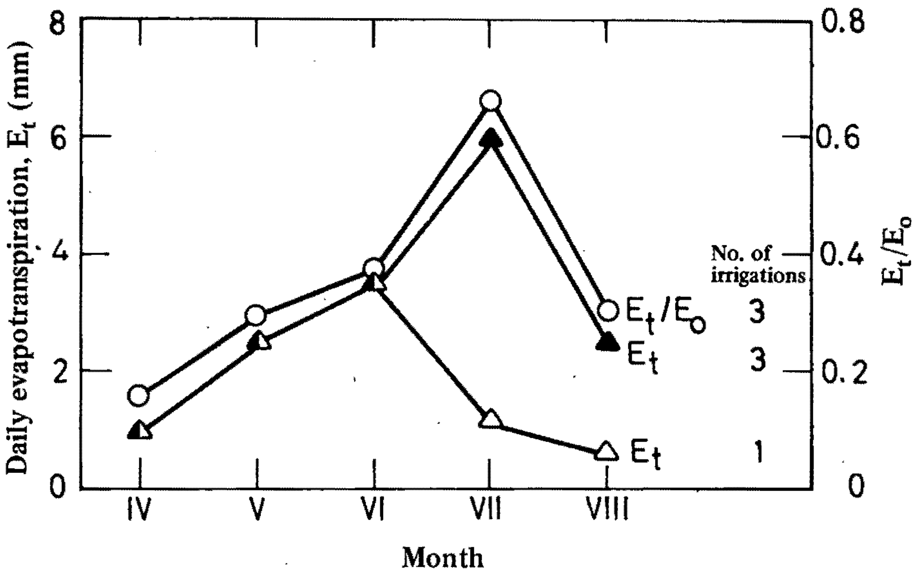

Figure 4. Average daily evapotranspiration (E_t) and E_t/E_o ratio for sorghum in the Northern Negev.

Table 10. Water uptake (% of total uptake) from the various soil layers of sorghum

Number of irrigations	1	3
Total E_t (mm)	244	535
Soil layer (cm)		
0- 30	18.6	20.5
30- 60	18.6	19.7
60- 90	17.5	19.3
90-120	16.7	17.5
120-150	16.4	14.9
150-180	10.3	5.6
180-210	1.7	2.2

7. *Water uptake with depth*

Table 10 presents water uptake with soil depth for two extreme treatments. With one irrigation, 55%-60% of the water was absorbed from the 0-90 cm soil layer. When more frequent irrigations were applied (6-7), 70-75% of the water was absorbed from this layer.

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4. Sobotnik, A., Bielorai, H. and Yaron, D. (1965) Empirical estimates of response functions of some summer crops (sorghum and peanuts) to irrigation intensities. *Volcani Inst. Agric. Res. Bull.* 82 (Hebrew, with English summary)

Corn

Corn (*Zea mays*) is indigenous to the American continent and is cultivated in all countries with a temperate or subtropical climate. It is the highest-yielding grain crop, and is considered to be one of the most efficient crops for high quality forage production. Its ability to produce large amounts of green matter (80-100 tons/ha) and dry matter (16-20 tons/ha) within a short period of time in the summer (90 days) makes it the most efficient in terms of irrigation water use. The growing period of corn for grain is 125-130 days. It is a warm-climate plant in nature; its optimum germination temperature is 16-18°C, although it can also germinate at 12°C. The plant develops well in all soil types, although in order to obtain a satisfactory grain yield, the soil must be fertile. The importance of corn was considerably enhanced with the development of high-yielding hybrids resistant to various diseases and insects.

The corn root system is deep and highly branched. Root spread under favorable moisture conditions may reach beyond a meter in all directions, and the depth of penetration may approach three meters. The roots developing from the seed (seminal roots) at germination extend to a depth of 1.0-1.5 m, but they are relatively sparse. At a later stage, when the internodes elongate, a highly branched system of secondary (adventitious) roots develops from the first node above the seed. The main root zone reaches a depth of 70-80 cm.

Today, corn is grown in Israel mainly for forage and silage. It is sown from the beginning of April to the end of August, and is cut when the ears reach the dough stage. At this point, the accumulation of plant dry matter is at its peak, and the nutritional value for livestock is at its highest. At the beginning of the 1950's, corn for grain production was one of the most important and promising crops in Israel, and consequently numerous irrigation experiments were conducted to determine the plant's consumptive water use. The results presented here are based on studies carried out between 1955 to 1967 in various regions of the country.[1] Investigations to determine the optimum irrigation regime

[1] H. Bielorai, J. Heller, A. Mantell, J. Rubin, D. Shimshi and E. Shmueli, principal investigators; S. Feldman, Y. Leshem, G. Perrugia, E. Rawitz and A. Shlomi, coinvestigators.

for forage corn were few, and the data mentioned here are based on experiments conducted only at one location in the Central Coastal Plain from 1965 to 1967.

Results and conclusions

Grain Corn

1. *Irrigation requirements and yields*

In order to obtain optimum grain yield (no less than 90% of the maximum yield) in all regions of the country, it was necessary to apply a net water application of 450-480 mm (Fig. 5). This quantity does not include the pre-planting irrigation generally required for corn seeded in mid-summer, nor does it include exploitation of soil water reserves. This additional use generally amounts to about 150 mm, so that the total evapotranspiration for achieving optimum yield is about 600 mm. To this must be added an amount to compensate for losses due to irrigation efficiency in accordance with the region, the method of water application and the technological preparation of the farmers. The average maximum grain yield for the different regions was 712 kg/1000 m^2. The results from the Northern Coastal Plain were unusual. High yields (889 kg/1000 m^2) were obtained with relatively low quantities of irrigation water (350 mm), and the reason for this is not clear.

2. *Production functions*

The relation between net water application (x) and relative yield estimate ($\hat{y}$) for all the regions of the country, except the Northern Coastal Plain, may be described by the following linear equation for the range of 100-500 mm water:

$$\hat{y} = 13.4 + 0.183\,x; \qquad r^2 = 0.775$$

According to this equation, the yield increase per mm irrigation water was 1.30 kg/1000 m^2 (at the Northern Coastal Plain, the increase was 2.56 kg/1000 m^2). The yield obtained without any irrigation was about 13% (92 kg/1000 m^2) of the maximum yield. This is not much less than the yield of sorghum obtained in southern Israel under dryland conditions (18% of the maximum yield), despite the fact that sorghum is considered a drought-resistant crop. The equation for the Northern Coastal Plain is:

$$\hat{y} = -1.2 + 0.288\,x; \qquad r^2 = 0.961$$

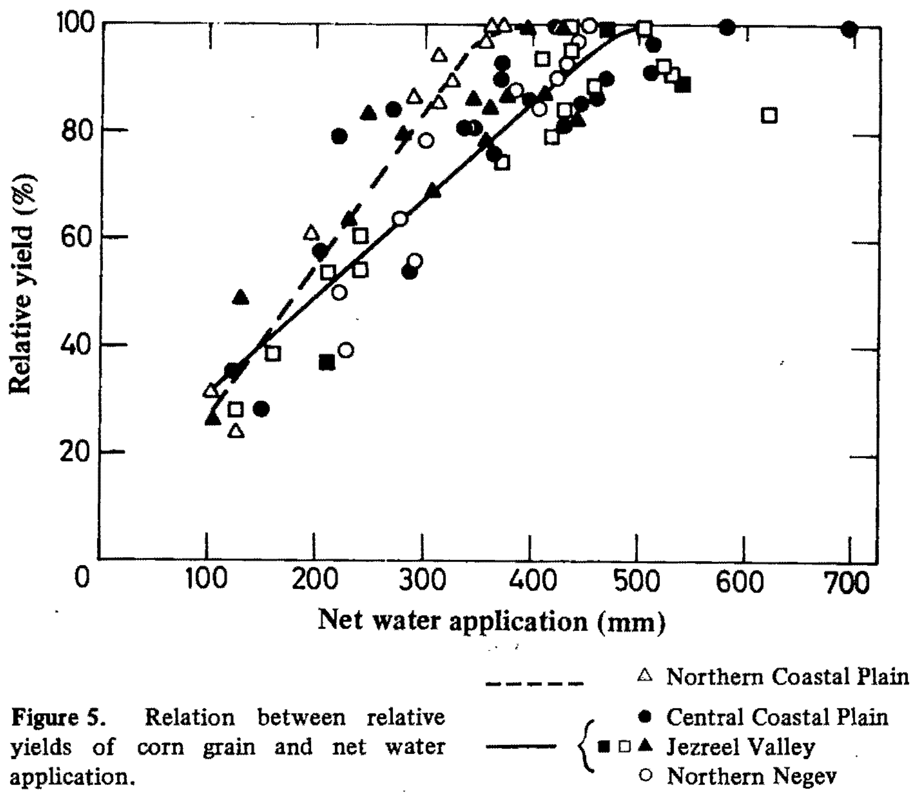

Figure 5. Relation between relative yields of corn grain and net water application.

3. *Frequency and number of irrigations*

The optimum number of irrigations in most regions of the country was 4-6, with the first water application being made 30-35 days after seeding, the second about 2-2½ weeks thereafter, and the succeeding irrigations every 10-14 days until about 45 days before harvest (Table 11). In the Northern Negev, the optimum number of irrigations was 6-7. The most sensitive period is during flowering and pollination, during which time the level of available water in the soil should not be allowed to drop below 30%.

4. *Water uptake with depth*

In most of the experiments the depth of wetting was 120 cm, since about 80% of the water was extracted from the 0-90 cm soil layer (Table 12). It is possible to wet the soil at each irrigation to a depth of only 90 cm, on condition that at the time of seeding the soil profile is at field capacity to a depth of 150 cm.

Table 11. Irrigation treatments for obtaining optimum corn grain yield

Location	Year	No. of irrigations[1]	Irrigation interval (days after seeding)	Net water application (mm)	Grain yield[2] ($kg/1000\ m^2$)	1000-seed weight (g)	Water use efficiency ($kg/1000\ m^2/mm$)
Western Jezreel Valley I	1954	7	25 & every 10 days	433	620 (100)		1.43
	1955	6	29, 42, 50, 60, 68, 76	395	582 (100)	284	1.47
Western Jezreel Valley II	1957	6	33, 55, 67, 79, 87, 101	435	750 (92)		1.73
	1958	6	28, 41, 51, 61, 70, 79	408	762 (94)	295	1.87
Western Jezreel Valley III	1958	5	36, 46, 58, 68, 81	469	955 (100)	331	2.03
Northern Coastal Plain	1958	3	38, 58, 72	310	761 (95)	317	2.45
	1959	6	32, 41, 50, 61, 72, 82	358	974 (100)	365	2.72
Central Coastal Plain	1956	4	25, 57, 70, 92	367	508 (90)	315	1.38
	1957	4	24, 46, 63, 77	368	646 (93)	326	1.76
	1958	6	28, 41, 51, 61, 70, 79	510	806 (97)	336	1.58
Northern Negev	1954	6	28, 40, 55, 65, 76, 86	436	595 (98)		1.36
	1955	8	25, 33, 40, 47, 54, 64, 75, 86	423	629 (100)		1.49
Northern Negev[3]	1959	5E	35, 49, 63, 77, 91	830[4]	904 (89)		1.09
	1959	9E	35 & every 7 days to 91	817[4]	1010 (100)		1.24
	1959	5D	as 5E above	644[4]	764 (76)		1.19
	1959	9D	as 9E above	675[4]	832 (82)		1.23

[1] Depth of wetting at all locations was 120 cm, except Northern Negev in 1959 where it was 90 cm.

[2] In parentheses: relative yield expressed as a percent of the maximum yield in the same experiment.

[3] Irrigation-fertilization interaction experiment. E – high fertilizer level (200 kg ammonium sulfate/1000 m^2); D – medium fertilizer level (100 kg ammonium sulfate/1000 m^2).

[4] Values represent evapotranspiration and not quantity of water applied.

Table 12. Amount of water extracted by grain corn (expressed as a percent of the total water removed) from the various soil depths in optimum irrigation treatments

Soil layer (cm)	Water extraction (%)	
	Central Coastal Plain	Northern Negev
0- 30	27	42
30- 60	32	27
60- 90	17	18
90-120	11	8
120-150	13	5

5. *Interaction between irrigation and fertilization*

The interaction between the irrigation regime and nitrogen fertilization is of the limiting-factor type: as the fertilizer level is increased, the response curve to water levels off at a higher yield (Fig. 6). At the highest fertilizer level of 42 kg N/1000 m^2, the curve had no plateau, indicating that with an increased water application an even higher yield would result. The yield level in this range exceeded 1000 kg/1000 m^2. The evapotranspiration required to achieve this yield was about 820 mm (690 mm irrigation water), with 9 irrigations. Five irrigations produced a lower yield, about 900 kg/1000 m^2.

With a lower fertilizer application of 10.5 kg N/1000 m^2, there was no significant yield difference between 5 and 9 irrigations. The yield obtained was 590 kg/1000 m^2.

It may be assumed, therefore, that the optimum yield obtained in various regions of the country, using normal fertilization practices and at an evapotranspiration level of about 600 mm, could be higher. However, the quantity of irrigation water required would increase. A greater number of irrigations would also be required (9 instead of 6) in order to realize the higher yield potential.

Forage corn

In order to obtain an optimum yield of forage corn in the Central Coastal Plain (at least 90% of the maximum yield) it was necessary to apply about 200 mm gross water, applied in two irrigations at 35 and 60 days from seeding. The dry matter yield produced by this treatment ranged from 14 to 18 ton/ha. Plant water stress imposed relatively early in the season (35-50 days after seeding) resulted in a greater yield decrease than stress imposed at a later stage. The E_t/E_o ratio rose from 0.3 during the first month of growth to 0.7-0.8 during the second and third months.

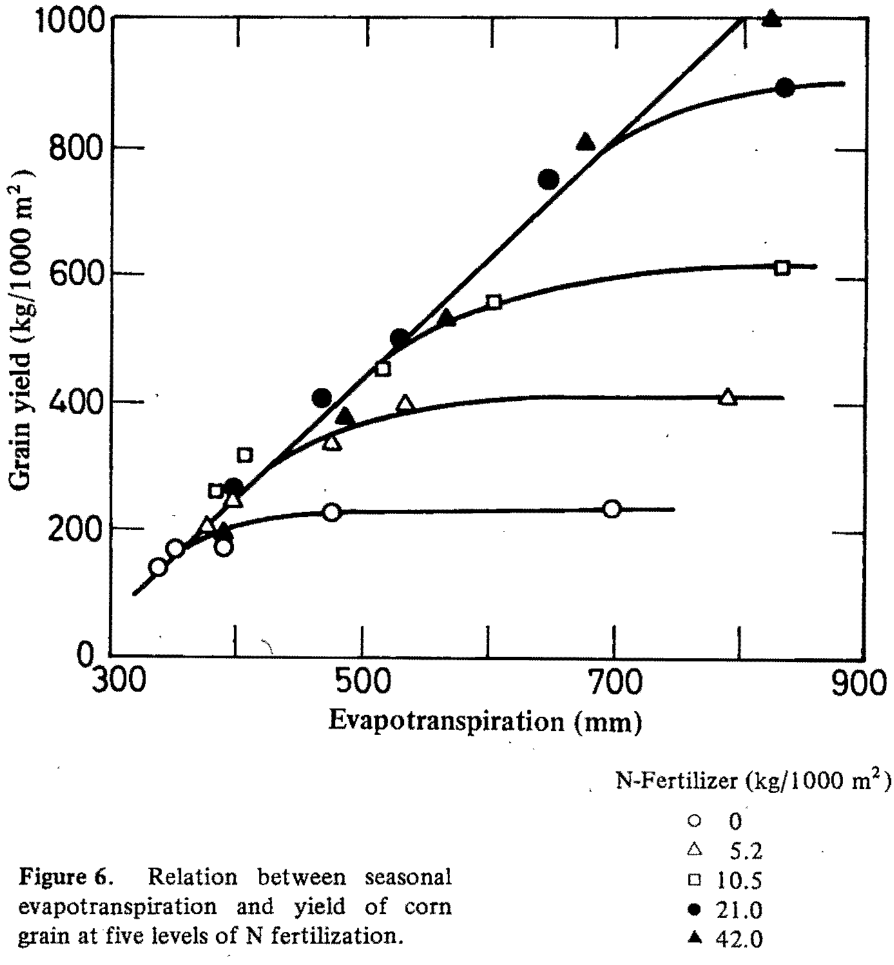

Figure 6. Relation between seasonal evapotranspiration and yield of corn grain at five levels of N fertilization.

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2. Bielorai, H., Rubin, J. and Shmueli, E. (1957) A study of the irrigation requirements and consumptive water use of late hybrid corn in the Northern Negev (Gilat, 1954 and 1955). In: Final Report of the Ford Foundation Israel Project A5. *Agric. Res. Stn. Special Bull.* 6:8-15

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Cotton

The cotton (*Gossypium sp.*) grown at present is a native of Central and South America. It is adapted to regions of high temperature and radiation. The maximum daily temperature during the growth period should not drop below 25°C for optimum yields. Two types of commonly grown cotton are recognized: the short staple upland (*G. hirsutum L.*), whose common varieties are Acala 15-17, 4-42 and S.J.-1 and the long staple American-Egyptian (*G. barbadense L.*) whose common varieties are Pima S-1, S-2 and S-4.

The main root system of the plant is normally found in the 0-60 cm soil layer, although the tap root may reach a depth of 200 cm. Root growth reaches a peak during the flowering period and thereafter starts to decline. Under adverse soil conditions (compact layers and poor aeration), root development may be severely restricted.

Planting is usually carried out during the first half of April. Flowering begins 60-70 days later and continues until growth is stopped due to low temperatures, low soil moisture or insect damage. This occurs at the end of July—beginning of August in most parts of Israel, although in the Bet Shean Valley, flowering continues until mid-September. Boll formation ceases 3-5 weeks after flower initiation, and boll maturation occurs during September and October. A second flowering period occurs in September in the Bet Shean Valley, resulting in a second harvest in November and the early part of December.

The rate of vegetative development is low in the early growth periods, until flowering when it becomes considerably faster. Flower set is dependent on the rate of growth in that both too slow and too fast a vegetative growth will result in decreased flower set. Usually, 50% of the flowers drop before setting, while 60% of the bolls in the Acala varieties and 30% in the Pima varieties drop before reaching maturation.

The following summary is based on 24 field irrigation experiments conducted in most regions over a period of 14 years, since 1957.[1] The

[1] A. Aharoni, A. Amir, H. Bielorai, J. Heller, I. Levin, A. Marani, M. Ophir, Z. Plaut, and D. Shimshi, principal investigators; A. Amirav, Y. Kost, Y. Katan, E. Shmueli and Z. Shtroilicht, coinvestigators.

varieties used in most experiments were of the short staple species (*G. hirsutum*), mainly Acala 4-42, 15-17, and S.J.-1. A few experiments were also conducted with the long staple varieties Pima S-1, S-2 and S-4. All experiments included 6-8 irrigation interval treatments and at least four replications. Irrigation was mostly by sprinkling except for some of the early experiments (pre-1965) where furrow irrigation was used. Seeding was usually during the second half of April.

Cotton normally needs a good moisture supply during flowering and boll setting, but high moisture during the early stages of development results in excessive vegatative growth at the expense of reproductive growth. It is widely accepted in practice that at seeding time, the 180 cm soil layer should be wet to field capacity. In all experiments, if the rains had not been sufficient, a pre-irrigation was provided at the end of the winter. This quantity of water was not included in the net irrigation requirement reported here.

Results and conclusions

1. *Irrigation requirements and yields*

The amount of irrigation water required for optimum yields (not less

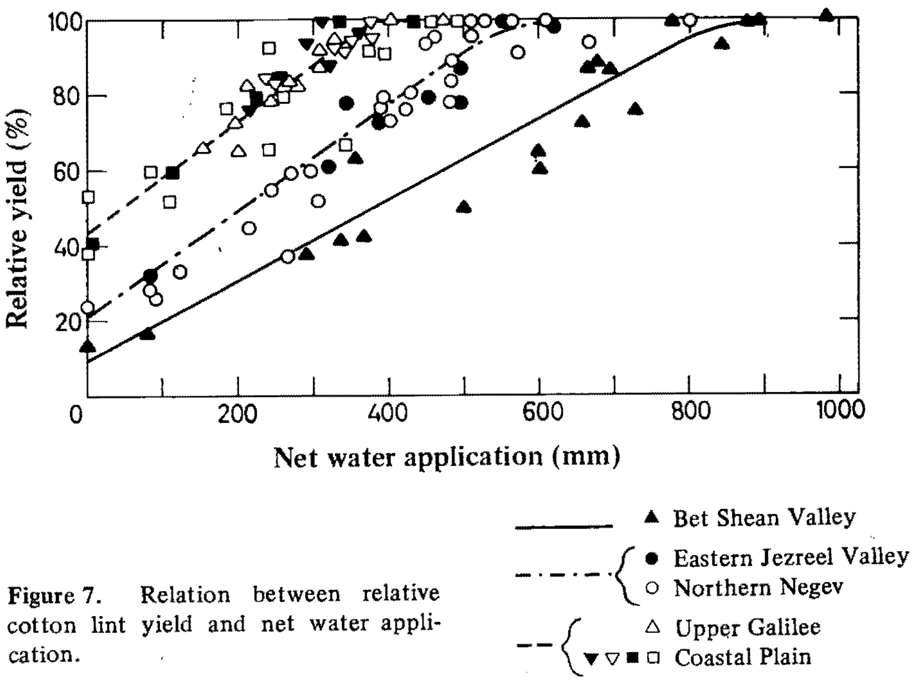

Figure 7. Relation between relative cotton lint yield and net water application.

than 90% of the maximum) depends on the climatic region. The Bet Shean valley, with hot, dry summers (30°C mean August temperature, 49% RH and 10 mm/day pan evaporation) has an irrigation requirement of 780-810 mm. The inland regions of the Eastern Jezreel Valley and the Northern Negev with somewhat cooler summers (27°C mean August temperature and 8.9 mm/day pan evaporation) has an irrigation requirement of 510-540 mm; and in the Coastal Plain region with mild summers (25°C mean August temperature and 7.5 mm/day pan evaporation) as well as the Upper Galilee, the requirement is 330-360 mm (Fig. 7).

The mean maximum lint yields per 1000 m^2 for the three regions, respectively, were 179 kg, 173 kg and 185 kg.

2. *Production functions*

The net water application (x) as a function of relative lint yield ($\hat{y}$), presented in Fig. 7, may be described by the following linear equations:

Bet Shean Valley:	$\hat{y} = 9.1 + 0.103\,x$;	$r^2 = 0.899$
Eastern Jezreel Valley and Northern Negev:	$\hat{y} = 21.4 + 0.138\,x$;	$r^2 = 0.887$
Coastal Plain Region:	$\hat{y} = 43.1 + 0.150\,x$;	$r^2 = 0.895$

These equations apply for water application rates in the range of 0-850 mm, 0-600 mm and 0-400 mm for the three regions, respectively.

The rate of change of yield with irrigation amounts is similar in the three regions, ranging from 11% per 100 mm water in the Bet Shean Valley, to 14% in the Northern Negev and Eastern Jezreel Valley and to 15% in the coastal regions. This is equivalent to 0.19, 0.24 and 0.28 kg/1000 m^2 per mm, respectively.

3. *Cultivation under dryland conditions or supplemental irrigation*

The cotton yield achieved without irrigation depends on climatic conditions. In the hot and dry Bet Shean Valley, a very low yield is obtained (16.1 kg/1000 m^2) while in the inland regions of the Northern Negev and Eastern Jezreel Valley and in the coastal region 37 and 80 kg/1000 m^2, respectively, may be expected. These yields can be obtained provided the soil is wetted initially to a depth of 180 cm as a result of winter rains or pre-irrigation.

In the coastal plain, a supplemental irrigation of 100 mm during the flowering period at the beginning of July will result in a yield of 110 kg/1000 m^2, while two 100 mm irrigations will yield 140 kg/ 1000 m^2.

4. *Number of irrigations and irrigation intervals*

The time of the first irrigation after seeding and the time of last irrigation before harvest determine the number of irrigations required during the season. During the first stage of growth, up to flowering, the rate of evapotranspiration is low and irrigation can and should be delayed until 60-70 days after seeding (mid-June in the coastal region and the Northern Negev and mid-May in the Bet Shean Valley; see Fig. 8). Frequent irrigations during this period may enhance vegetative growth at the expense of lint production (Table 13).

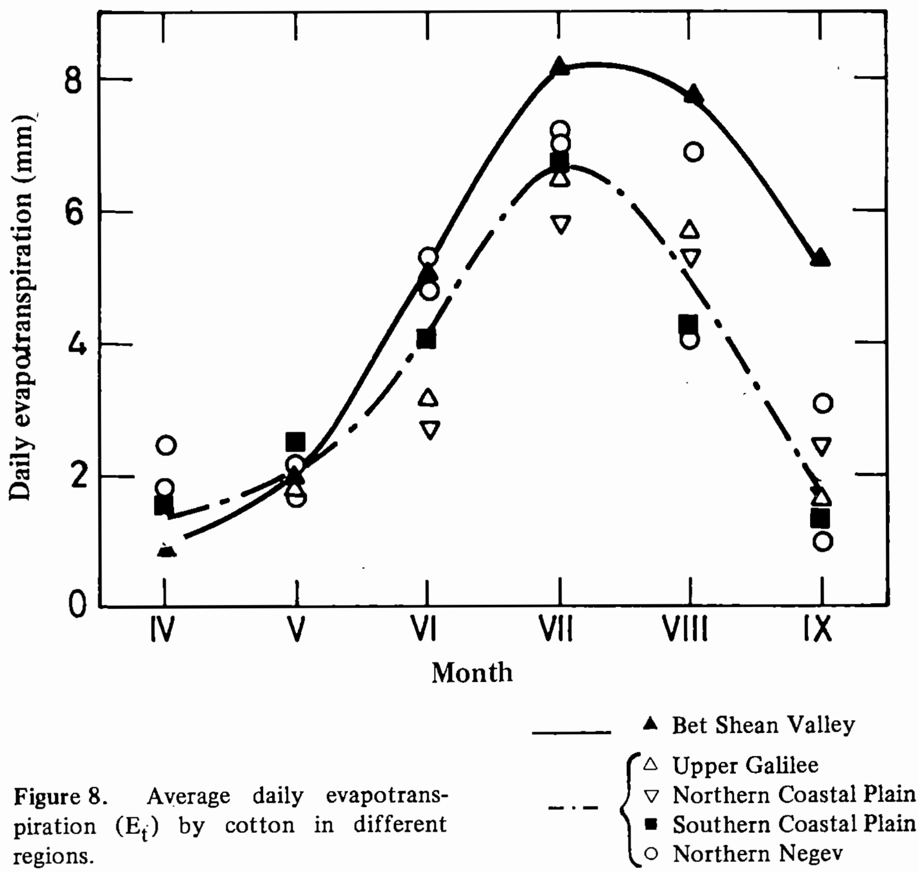

Figure 8. Average daily evapotranspiration (E_t) by cotton in different regions.

Table 13. Irrigation regime, irrigation quantities, and yields of cotton at various locations

Location and Year	Wetting depth (cm)	Number of irrigations	Irrigation intervals (days after seeding)	Net water application (mm)	Yield[1] Cotton (kg/1000 m^2)		Yield[1] Lint (kg/1000 m^2)	Water use efficiency (kg/1000 m^2/mm)
Bet Shean Valley								
1959	150	8	54, 68, 84, 96, 112, 126, 139, 152	1020	495	(100)	185	0.49
1960	120	7	40, 61, 79, 97, 115, 135, 152	665	335	(88)	132	0.50
1966-67	90	6	63, 81, 98, 118, 135, 150	696	492	(100)	176	0.71
Eastern Jezreel Valley								
1960	120	6	55, 71, 88, 104, 119, 133	553	422	(100)	174	0.76
Northern Negev								
1959	60	7	34, 49, 64, 78, 92, 106, 120	573	393	(93)	167	0.68
1960-61	45	7	35, 48, 62, 76, 90, 104, 118	450	362	(95)	148	0.80
1962	90	5	35, 61, 76, 87, 101	399	487	(100)	192	1.22
1965	90	5	64, 80, 94, 112, 130	611	451	(100)	185	0.74
1966	90	4	63, 86, 99, 119	529	411	(100)	168	0.78
1968	80%[2]	9	Every week	510	472	(100)	–	0.92
	100%[2]	5	Every two weeks	486	359	(76)	–	0.74
Southern Coastal Plain								
1964-66	150	3	71, 92, 110	333	479	(100)	187	1.44

Central Coastal Plain							
1965	90	4	70, 97, 118, 137	459	438 (100)	179	0.96
1966	90	3	84, 104, 123	372	470 (93)	188	1.26
Northern Coastal Plain							
1967	90	3	71, 96, 111	310	450 (95)	165	1.45
Upper Galilee I							
1962	90	5	35, 58, 74, 93, 112	475	440 (100)	177	0.93
1963	90	6	53, 70, 84, 98, 112, 125	405	430 (100)	173	1.06
Upper Galilee II							
1971	90	3	61, 79, 100	270	474 (100)	180	1.76
Lakhish I							
1970	90	3	83, 103, 124	330	493 (93)	192	1.49
Lakhish II							
1970	90	3	68, 90, 108	360	492 (100)	166	1.37

[1] In parentheses: relative yield expressed as a percent of the maximum yield in the same experiment.

[2] Drip irrigation: percentage of water deficit in the sprinkler irrigation treatment.

During the second period, when flowering and boll setting takes place, the cotton is particularly sensitive to water deficiency. Soil moisture content should not be allowed to drop below 20-30% available water in the main root zone. In the coastal region, two irrigations at 3-week intervals may be sufficient during that period, while in the Northern Negev and Eastern Jezreel Valley 4-5 irrigations are needed at 2-3 week intervals, and, in the Bet Shean Valley, 6-7 irrigations are needed at 18-day intervals. In Bet Shean, a second flowering period occurs in late August–early September; therefore, the last irrigation should be applied at the beginning of September. A later irrigation is undesirable as it might cause yield reduction by delaying boll maturation.

Some optimum treatments in Table 13 show a larger number of irrigations than applied in practice. In the experiments conducted in the early 1960s, the first irrigation was applied early, in mid-May, and the late irrigation in late August. These irrigations were subsequently shown to be superfluous (Table 14).

Table 14. The effect of irrigation frequency on the water requirements and mean yields of cotton, Southern Coastal Plain, 1964-66. (Seeding date April 20)

Number of irrigations	Time of irrigation (days after seeding)	Net water application (mm)	Consumptive use (mm)	Yield Cotton (kg/1000 m²)	Yield Lint (kg/1000 m²)	Water use efficiency (kg/mm)
0	-	0	237	188	76	0.79
1	70	110	348	277	112	0.80
2	70, 92	208	445	383	150	0.86
3	70, 92, 104	298	535	475	187	0.89
4	67, 88, 109, 125	373	610	480	186	0.79

5. *Depth of wetting*

Seventy to eighty percent of the water is absorbed by the cotton plant roots from a soil depth of 90 cm (Table 15) and hence it is sufficient to wet not more than 60-90 cm of the soil depth and thereby efficiently exploit the water stored in the soil.

6. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

The E_t/E_o ratio ranges betwen 0.65 and 0.70 during the main cotton growing season of June and July. In an analysis by Fuchs and Stanhill

(8) of results from commercial fields, a ratio of 0.63-0.69 was obtained. This ratio may be used in order to estimate irrigation needs.

Table 15. Water uptake (in % of total) by cotton from the various soil layers for the optimum treatment at three locations

Soil layer (cm)	Eastern Jezreel Valley	Northern Negev	Upper Galilee I
0- 30	30	36	38
30- 60	22	24	27
60- 90	16	18	15
90-120	13	14	9
120-150	10	6	7
150-180	9	2	4

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Sugar beets

The sugar beet (*Beta vulgaris* var. saccharina) is indigenous to the Mediterranean region. Botanically, it is a biennial, although it functions agronomically as an annual and is harvested when the storage organ matures. The plant develops a tap root and sugar accumulates in the upper part. The roots may develop to a considerable depth, but the main part of the root system is located in the upper soil layer. Sugar accumulation begins during the early stages of growth, and the rate of storage depends to a great extent on temperature, soil moisture and nitrogen supply. Maximum sugar production occurs in the temperature range 19-22°C, which prevails in Israel during the summer months. For this reason, the sugar content of Israeli beets is higher than in those of many other growing regions, Europe, for example.

Of the total world production of sugar in 1972, about 30% was obtained from sugar beets. The plant is capable of growing under a wide range of soil and climatic conditions (as distinguished from sugar cane), and is thus cultivated in many countries.

The main growing period of sugar beets in Israel occurs in winter, when there is no need to irrigate as long as rainfall distribution is satisfactory. In general, the crop is irrigated only in the fall, in preparation for seeding and germination, and after the winter until the roots are harvested. The quantity of water applied and the frequency of irrigation depends, therefore, chiefly upon the date of harvest, which in Israel may occur between mid-May and the end of July, in accordance with the processing capacity of the refineries. Generally, the beet sucrose content decreases as the harvest date is delayed. It is not customary to begin the irrigation season until the middle of April, except in regions such as the Northern Negev and the Bet Shean Valley where the rainy season is relatively short.

The results presented here were obtained from experiments conducted between 1954 and 1965 in various regions of the country.[1] The

[1] H. Bielorai, J. Heller, A. Mantell, M. Ophir, J. Rubin and E. Shmueli, principal investigators; A. Aharoni, H. Dan, Z. Dor, Z. Ellern, Y. Kost, D. Lachover, J. Leshem and G. Perrugia, coinvestigators.

Zwaanesse III variety was used, and all fields were seeded in October. A pre-planting irrigation was applied to bring the soil moisture content to field capacity to a depth of 150 cm. After seeding, light irrigations were applied as required to assist germination. Thereafter, and until the spring, water was applied only in case of delayed rainfall.

The quantity of water applied at each irrigation was determined according to soil moisture measurements. In the spring, this quantity was calculated to bring the soil moisture content to field capacity to a depth of 90 or 120 cm, depending upon the location of the experiment.

Results and conclusions

1. *Irrigation requirements and yields*

The irrigation treatments which produced optimum sucrose yield (at least 90% of the maximum yield in the same experiment) are presented in Table 16. In most of the studies, the root yield was in the range of 6 to 8 tons/1000 m^2. The sucrose content was in the range of 16% to 20%, and the sucrose yield generally exceeded 1 ton/1000 m^2.

Table 16. Irrigation treatments for obtaining optimum sucrose yield

Location	Harvest date	Spring irrigations			Yield			
		No.	Net water application (mm)	Days from last irrigation to harvest	Tops (ton/ 1000 m^2)	Sucrose (%)	Sucrose (ton/ 1000 m^2)[1]	
Northern	21.5.62	0	0	–	–	–	0.92	(91)
Negev	23.5.61	0	0	–	4.47	20.1	0.89	(88)
	25.5.55	2**	314	55	5.86	20.5	1.21	(94)
	27.5.58	3**	298	34	7.73	18.3	1.42	(93)
	31.5.56	0	0	–	6.29	18.7	1.17	(88)
	27.6.61	1	107	43	6.18	18.0	1.08	(91)
	17.7.61	0	0	–	6.45	19.3	1.24	(93)
	18.7.58	6**	592	31	9.84	16.2	1.59	(95)
Central	4.6.58	0	0	–	4.53	20.1	0.91	(86)
Coastal	18.6.59	1	60	35	6.88	17.2	1.18	(90)
Plain I	20.6.57	1	131	35	7.45	18.6	1.37	(97)
	15.7.58	3	373	22	5.78	16.3	0.94	(93)
	16.7.59	2	207	28	7.60	15.3	1.16	(87)

Table 16. (continued)

Location	Harvest date	Spring irrigations: No.	Net water application (mm)	Days from last irrigation to harvest	Yield: Tops (ton/ 1000 m^2)	Sucrose (%)	Sucrose (ton/ 1000 m^2)[1]	
Central Coastal Plain II	21.6.59	1	135	41	7.38	15.1	1.11	(100)
	19.7.59	1	135	69	7.66	14.1	1.07	(100)
Western Jezreel Valley I	31.5.61	1	97	25	4.33	16.9	0.73	(100)
	2.6.60	0	0	–	5.73	20.6	1.18	(94)
	23.6.60	1	115	43	6.48	20.4	1.32	(90)
	28.6.61	1	97	53	4.41	18.5	0.82	(100)
	12.7.61	2	183	35	4.65	17.4	0.82	(99)
	19.7.60	3	293	43	7.76	18.5	1.43	(95)
Western Jezreel Valley II	22.5.59	1	116	30	6.40	14.3	0.91	(93)
	9.7.59	2	252	35	7.00	15.7	1.11	(95)
Western Jezreel Valley III	22.5.59	0	0	–	6.61	16.3	1.08	(100)
	3.7.59	2	220	40	8.88	13.2	1.17	(100)
Bet Shean Valley I	22.5.59	0	0	–	6.65	16.6	1.10	(93)
	26.6.59	0	0	–	5.86	17.1	1.01	(88)
	16.7.59	0	0	–	6.78	14.9	1.00	(99)
Bet Shean Valley II	11.5.60	1*	125	52	4.95	16.8	1.00	(99)
	18.5.61	0	0	–	6.13	15.2	0.93	(89)
	30.5.60	1*	125	71	6.25	18.1	1.14	(88)
	31.5.65	0	0	–	7.44	15.8	1.17	(98)
	4.6.59	2	276	24	7.45	13.9	1.05	(96)
	9.6.60	2*	250	54	6.48	17.3	1.12	(88)
	14.6.61	0	0	–	6.41	16.1	1.03	(88)
	14.6.65	2	270	26	9.00	15.5	1.34	(100)
	18.6.59	2	276	38	7.64	14.3	1.09	(89)
	2.7.61	2*	173	75	9.34	15.1	1.39	(97)
	15.7.65	3	330	53	9.75	13.6	1.32	(96)

[1] In parentheses: relative yield expressed as a percent of the maximum yield in the same experiment and date of harvest.

*Includes one irrigation on 20.3

**Includes 2 irrigations before the middle of April.

In the case of an early spring harvest (May), there was no need to irrigate after mid-April in most regions; only certain isolated cases required one irrigation of 70-120 mm. When the beets were removed in the middle of the harvest season (June), one or two irrigations totalling 120-170 mm after mid-April were adequate. For a late harvest (until mid-July), 2-3 irrigations totalling 180-250 mm were required after mid-April to achieve optimum yield in most locations. In general, there were no marked differences among the different growing regions regarding the irrigation regime necessary to produce optimum yield. The effect of water application in the spring on relative sucrose yield, in four different regions, is illustrated in Fig. 9. For the early harvest, addition of water caused almost no yield increase. On the other hand, if the yield was harvested late, there was a marked response to water application. The data show that discontinuation of irrigation 30 days or more before harvesting does not reduce sucrose yield.

Table 17. Water uptake by sugar beets (expressed as a percent of the total water removed) from the various soil depths in the spring, for several late-harvest optimum treatments

Location		Northern Negev	Central Coastal Plain I	Western Jezreel Valley II	Western Jezreel Valley III	Bet Shean Valley I
No. of irrigations		6	3	2	2	0
	0- 30	34	45	40	50	27
	30- 60	26	17	29	20	18
	60- 90	19	14	15	12	18
Soil	90-120	15	10	8	11	15
layer	120-150	6	8	4	7	12
(cm)	150-180	–	6	4	–	10
	0- 60	60	62	69	70	45
	0- 90	79	76	84	82	63

2. *Water uptake with depth*

Plants which were irrigated in the spring extracted 60-70% of their total water consumption from the 0-60 cm soil layer, and about 80% from the 0-90 cm layer (Table 17). In some experiments, and in all regions, the effects of wetting depth were studied (i.e. the quantity of water applied at each irrigation). Replenishment of the soil moisture deficit from field capacity to a depth of 60 cm was compared with 90 cm or 120 cm. In all cases, there was no loss in sucrose yield due to shallower depth of wetting, even if the harvest was late. The consequent water saving ranged from 50 mm to 200 mm, depending on the number of irrigations applied in the spring.

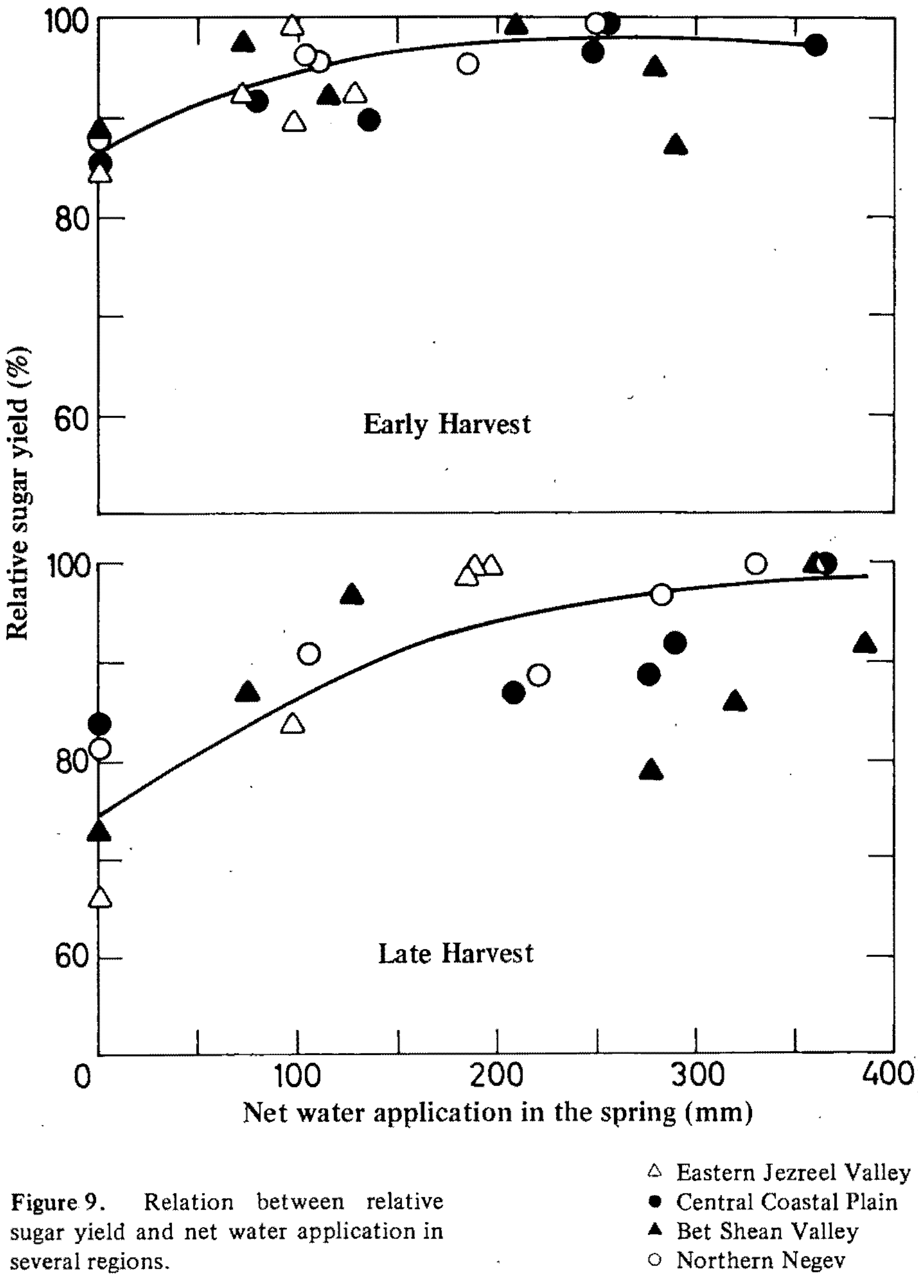

Figure 9. Relation between relative sugar yield and net water application in several regions.

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Peanuts

The peanut plant (*Arachis hypogaea*) is an annual, and is one of the most important world crops for production of vegetable oil and protein. The principal growing regions are Asia and Africa, although the plant grows well in any location with a relatively high temperature, much sunlight and coarse-textured, well-drained soil.

The crop's growing period, from seeding to harvest, is 125-155 days, depending on the variety. Flowering occurs over an extended period – from 5 weeks after seeding until the end of the season, with the peak at 60-90 days. Pods developing from flowers which appear after this date do not reach maturity. Roots develop rapidly and may reach a depth of 180 cm, but the main root zone is in the 0-90 cm soil layer. Three main periods are recognized in the plant's development: a. Seeding to beginning of flowering; b. Flowering and c. Beginning of pod development until harvest.

In most peanut growing regions, there is rainfall during the growing season, and only in the case of delayed precipitation is there a need for supplementary irrigation to replenish the depleted soil moisture. In regions with no rainfall, the crop can succeed only under a full irrigation program.

The results presented here are based on experiments conducted in the Northern Negev and the Central Coastal Plain.[1] Each experiment included 5-6 irrigation treatments, the variety was Improved Virginia Bunch (growing season, about 145 days) and seeding took place in mid-April. A pre-planting irrigation was applied to bring the moisture content in the potential root zone (0-150 cm) to field capacity. All plots were irrigated uniformly after seeding for germination, and again at 35 days. Thereafter, irrigations were applied according to a predetermined schedule. The amount of irrigation water was calculated to replenish the deficit from field capacity in the main root zone (0-90 cm), except in the case of treatments designed to study the effect of other wetting depths.

[1] H. Bielorai, A. Mantell, and D. Shimshi, principal investigators; Y. Alper, Y. Kost, E. Goldin, A. Reiss, E. Rawitz, and J. Schiffman, coinvestigators.

With the introduction of peanut seed inoculation with nitrogen-fixing bacteria as a source of nitrogen, a study was conducted in the Northern Negev to determine the need for frequent irrigation of inoculated peanuts during the first month after seeding.

Results and conclusions

1. *Irrigation requirements and yields*

In both regions the optimum yield (at least 90% of the maximum yield) was achieved with a net water application of 530-560 mm (Fig. 10). The average maximum pod yields at these two sites for all experiments were 484 kg/1000 m^2 and 532 kg/1000 m^2 in the Northern Negev and Central Coastal Plain, respectively.

To this net amount of water must be added the losses due to application efficiency. The quantity of water required to wet the soil profile to a depth of 150 cm prior to planting must also be added. This quantity ranges from 50 mm to 90 mm, net, in the Negev, whereas in the Coastal Plain a pre-planting irrigation is generally not required. Irrigation for germination applied at both sites is not included in the total seasonal application.

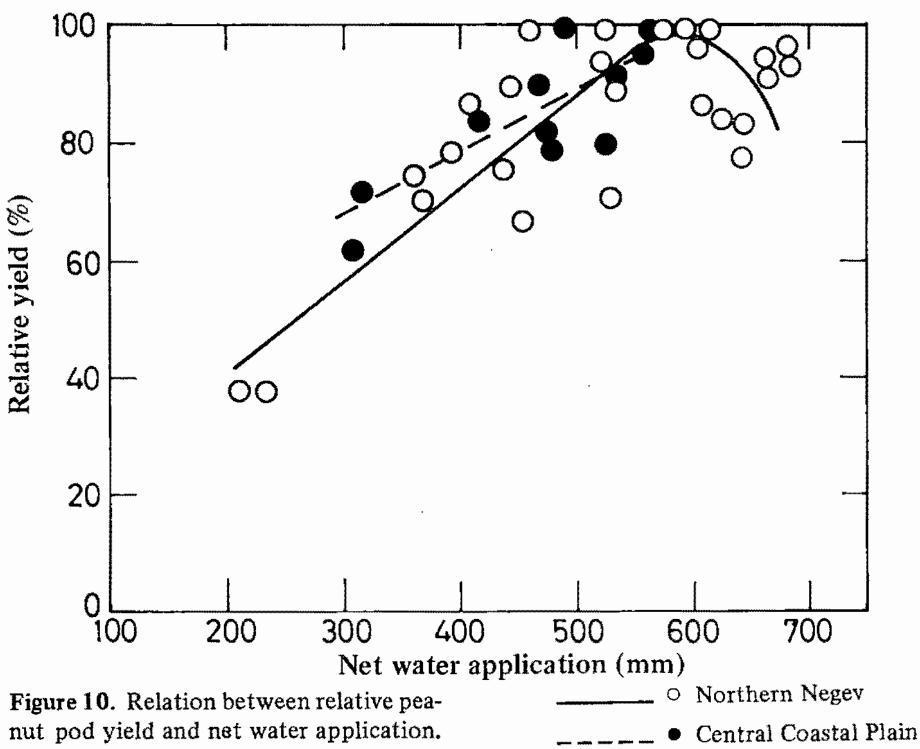

Figure 10. Relation between relative peanut pod yield and net water application.

2. *Production functions*

The relation between net water application after seeding (x) and the estimated relative pod yield ($\hat{y}$) for the Northern Negev can be described by the linear equation (for the range of 200-550 mm water)

$$\hat{y} = 10.29 + 0.158\,x; \qquad r^2 = 0.678$$

According to this equation, the average yield increase per mm of water is 0.76 kg/1000 m^2. Sobotnik, *et al.* (8) fitted the following quadratic equation to estimate the relation between absolute yield ($\hat{y}$) and the net water application (x) for the Northern Negev:

$$\hat{y} = -147.23 + 1.866\,x - 0.00156\,x^2; \qquad r^2 = 0.676$$

According to this equation, the marginal yield increase per mm of water decreases with an increase in water application, from 1.24 kg/1000 m^2/mm in the range of 200 mm water, to 0.62 kg/1000 m^2/mm in the range of 400 mm. In the upper range of 500 mm, the marginal yield increase was 0.31 kg/1000 m^2/mm.

The linear equation (in the 300-570 mm water range) for the Central Coastal Plain is

$$\hat{y} = 37.0 + 0.101\,x; \qquad r^2 = 0.633$$

The average yield increase per mm water was 0.537 kg/1000 m^2.

3. *Irrigation frequency*

In order to achieve optimum yield, 7-9 irrigations were required in the Northern Negev after seeding, at a frequency of 12-14 days and to a depth of 60 cm, on condition that the root zone was sufficiently wet at the beginning of the season. In the Central Coastal Plain, 5-6 irrigations were required, at a frequency of 18-21 days and a wetting depth of 90 mm (Table 18).

Concerning inoculated peanuts, there is no need to irrigate frequently after seeding in order to guarantee adequate plant nodulation. An interval of 35 days after seeding until the first irrigation did not inhibit bacterial development. The yield from the inoculated plants was significantly higher than that obtained from nitrogen fertilized plants irrigated similarly (7 bi-weekly irrigations, beginning 35 days after seeding) and reached 640 kg/1000 m^2.

Table 18. Irrigation treatments for obtaining optimum pod yield

Location	Year	No. of irrigations after seeding[1]	Depth of wetting (cm)	Irrigation frequency (days)	Irrigation interval (days after seeding)	Net water application[2] (mm)	Yield (kg/1000 m²) Hay	Pods[3]		1000-seed weight (g)
Northern Negev	1955	9	90	12	35, 58, 70, 82 94, 106	522	814	454	(94)	
	1956	9	90	11	35, 53, every 11 days until 129	524	807	427	(100)	
	1957	9	60	12	30, every 12 days until 128	461	845	460	(100)	
	1960	7	60	14	35, 50, 64, 78, 94, 108, 122	573	678	410	(100)	
	1964	9	90	14	35, 56, every 14 days	629	692	638	(100)	827
Central Coastal Plain	1959	8	90	14	35, every 14 days until 132	574	995	600	(100)	863
	1959	5	90	21	35, 57, 78, 99 120	469	934	540	9(90)	876
	1960	5	90	21	35, 56, 77, 97, 119	490	908	464	(100)	897

[1] Not including irrigation for germination.

[2] After seeding, the seasonal consumptive use (middle of May to middle and end of September in the Northern Negev and Central Coastal Plain respectively) was 763 mm in the Negev and 675 mm in the Coastal Plain.

[3] In parentheses: the relative yield as a percent of the maximum yield in the same experiment.

4. *Water uptake with depth*

Most of the water from the root zone (80%) is extracted from the 0-90 cm soil layer, while the 0-60 cm layer contributed 65% of the consumptive use (Table 19).

Table 19. Water uptake by peanuts (expressed as a percent of the total water removed) from the various soil depths

Soil layer (cm)	Central Coastal Plain (Irrigation every 21 days)	Northern Negev (Irrigation every 14 days)
0- 30	34	38
30- 60	29	29
60- 90	18	19
90-120	11	8
120-150	8	6

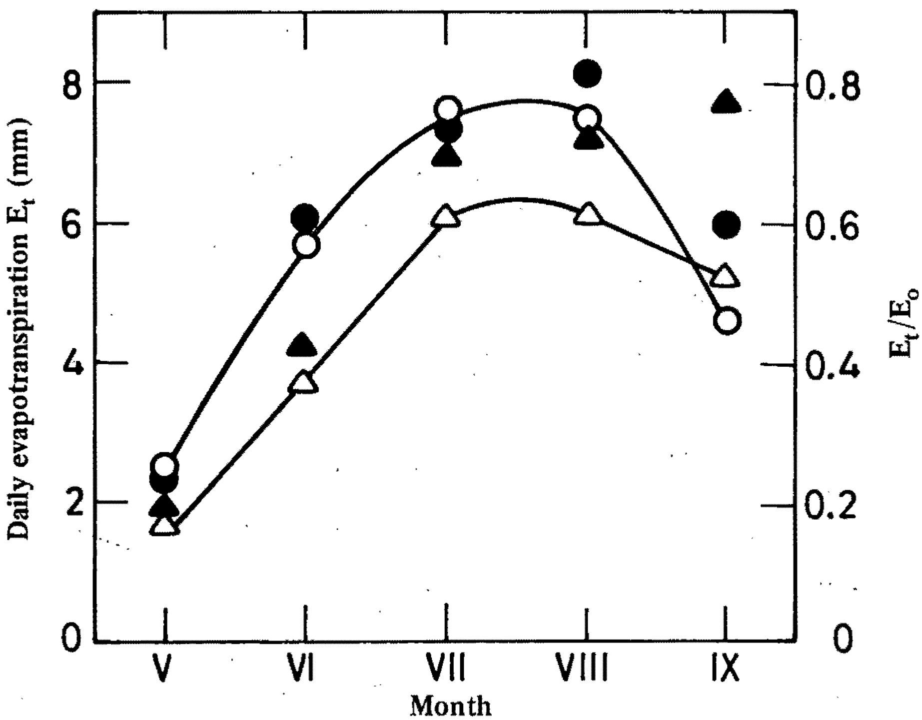

Figure 11. Average daily evapotranspiration (E_t) and E_t/E_o ratio for peanuts.

E_t	E_t/E_o	
○	●	Northern Negev
△	▲	Central Coastal Plain

5. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

Peak consumptive use by the optimum treatment – 6.1 mm/day in the Central Coastal Plain and 7.5 mm/day in the Northern Negev – occurred in July-August. The average E_t/E_0 for the entire irrigation season was similar in the Negev and Coastal Plain (0.60-0.63), and during peak months it was 0.72 and 0.78, for the two regions, respectively (Fig. 11). If pan evaporation is used to estimate irrigation water requirement, it is necessary to differentiate between the initial and final periods of the growing season (June and September) during which a factor of 0.60 should be used in the Negev, on the one hand, and the period of peak flowering during which a factor of 0.78 should be used. Similar results were obtained by Goldberg, *et al.* (5).

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Alfalfa

Alfalfa (*Medicago sativa*) is a perennial legume indigenous to the Near East. The plant has a woody base, or crown, which gives rise to new stems, and a deep root system which, under favorable conditions, may reach a depth of several meters. Alfalfa is capable of adapting to various soil and climatic conditions, and is therefore widely cultivated as a forage plant throughout the world. The crop generally thrives with irrigation and a hot summer. Alfalfa has high nutritional value; it may be grown for meal production, hay or alternate harvesting of hay and seeds. The seed yield compensates for the reduced meal yield, and there is considerable saving in the seasonal water use. This is particularly effective during July and August, which are the peak water consumption months in Israel.

The results presented here are based on experiments carried out between 1956 and 1970.[1]

Results and conclusions

1. *Irrigation requirements and yields*

The relative yields of dry matter as affected by the total water application are presented in Fig. 12. The absolute yield achieved with the optimum irrigation regime in each experiment is shown in Table 20, together with the yield of seeds resulting from the same treatment.

Optimum yield of alfalfa dry matter can be obtained by a gross water application of 620-660 mm in both the Upper Galilee and the Central Coastal Plain. The required depth of wetting is 60 cm. There was no advantage to increasing the water amount beyond this quantity. The relatively large amounts of water applied in the Western Jezreel Valley were due to the greater depth of wetting – 120 cm. In the spring and fall, one irrigation is sufficient between cuttings, while in June, July and August there is some advantage to providing two irrigations.

[1] H. Bielorai, I. Levin and A. Mantell, principal investigators; A. Aharoni, S. Barzelai, Y. Cohen, N. Dolav, A. Dovrat, G. Leitman, E. Rawitz, J. Rubin, S. Sagie, E. Shmueli and I. Shohat, coinvestigators.

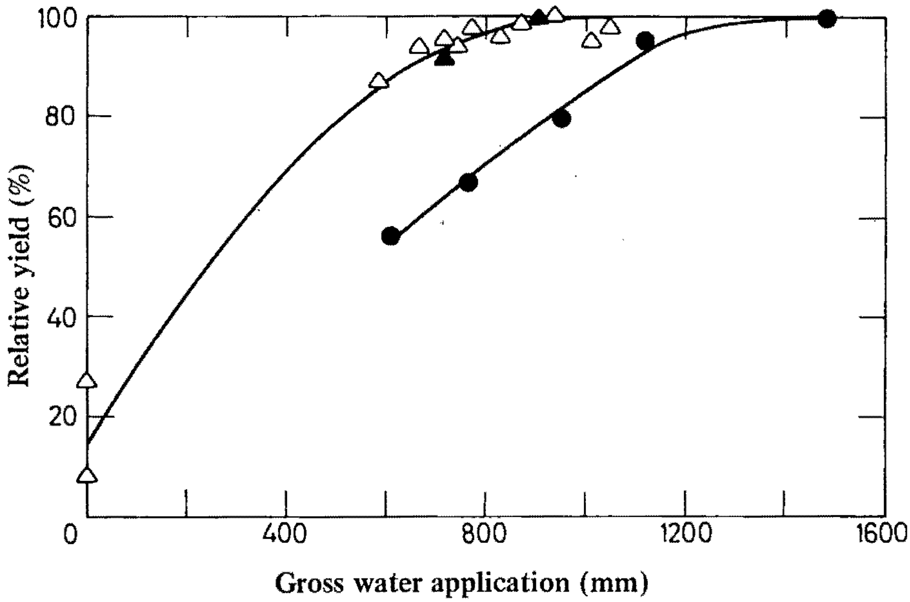

Figure 12. Relation between relative dry matter yield of alfalfa and gross water application.

● Western Jezreel Valley
△ Upper Galilee
▲ Central Coastal Plain

2. *Seed production*

In order to obtain a high seed yield with a low water application, it is desirable to apply one irrigation about 17-23 days after the last hay cutting in the spring (end of May). One irrigation at an earlier date, or even two irrigations, did not produce a better yield and in some cases even had a negative effect. The water requirement may be markedly reduced by 15-20% by growing alfalfa for both meal and seeds. Under such conditions the loss in meal production is approximately 40-55%, but a yield of about 50 kg of seeds/1000 m^2 can be obtained.

3. *Water uptake with depth*

An example of the pattern of water extraction by alfalfa roots which received an optimum irrigation treatment is shown in Table 21. Despite the large depth of wetting, 80% of the water was taken up from the 0-90 cm layer.

4. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

The consumptive water use by alfalfa is relatively low until about 12 days after cutting, and then increases sharply as the plants develop.

Table 20. Water amounts and optimum alfalfa yields in the different regions

Location	Year	Irrigation regime	Depth of wetting (cm)	No. of irrigations	Gross water application (mm)	Yield[1] (kg/1000 m^2) Dry matter	Yield[1] (kg/1000 m^2) Seeds	Water use efficiency (kg/1000m^2/mm) Dry matter	Water use efficiency (kg/1000m^2/mm) Seeds
Western Jezreel Valley	1956	2 irrigations between cuttings	120	12	1120	1034 (90)	–	0.92	–
Central Coastal Plain I	1964[2]	1 irrigation after cutting		7	690	1472 (65)	51 (79)	2.13	0.074
	1965[2]	1 irrigation after cutting		7	755	1393 (65)	81 (95)	1.85	0.107
Central Coastal Plain II	1968	1 irrigation after cutting	60	8	720	1303 (92)	–	1.81	–
	1968[2]	1 irrigation 23 days after last cutting before seed production	120	5	615	774 (54)	48 (100)	1.26	0.078

Upper Galilee	1966	1 irrigation after cutting	60	8	665	2051	(94)	–		3.08	–
	1969	2 irrigations between cuttings	90	10	945	1162	(100)	–		1.23	–
	1969[2]	1 irrigation 17 days after last cutting before seed production	90	5	600	520	(45)	53	(96)	0.87	0.088
	1970[2]	1 irrigation 17 days after last cutting before seed production	120	1	150	–		33	(100)	–	0.220
Bet Shean Valley	1970[2]	1 irrigation 17 days after last cutting before seed production	120	1	175	–		31	(100)	–	0.177

[1] In parentheses: the relative yield as a percent of the maximum yield in the same experiment.
[2] For seed production.

During the initial period it is about 30% of pan evaporation, while during the second stage it reaches 80%. In the Upper Galilee, the average evapotranspiration rate of alfalfa which received optimum irrigation treatment was 63% of pan evaporation (Table 22). In the Bet Shean Valley, the E_t/E_o ratio was 77%.

Table 21. Water uptake (as a percent of the total) from the various soil layers

Soil layer (cm)	0-30	30-60	60-90	90-120	120-150	150-180
Water extraction (%)	42	23	15	10	6	4

Table 22. Evapotranspiration (E_t), pan evaporation (E_o) and the E_t/E_o ratio between two irrigations in the Upper Galilee

Period	Days after cutting	E_t (mm/day)	E_o (mm/day)	E_t/E_o	E_t/E_o (weighted average)
10.6–21.6	0-11	2.9	8.9	0.33	0.63
21.6–15.7	11-35	6.5	8.4	0.77	

Publications

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2. Cohen, Y., Bielorai, H. and Dovrat, A. (1972) Effect of timing of irrigation on total nonstructural carbohydrate level in roots and on seed yield of alfalfa (*Medicago sativa* L.). *Crop Sci.* 12:634-636

3. Leitman, G., Cohen, Y. and Aharoni, A. (1966) Summer irrigation of alfalfa for meal and seed production. *Irrign. Extn. Service, Emek Hefer District* (Hebrew)

4. Summary of alfalfa experiments. Upper Galilee 1969, 1970. Ministry of Agric. Extn. Service and Alfalfa Committee of the Upper Galilee Regional Council (Hebrew)

Tomatoes

Tomatoes (*Lycopersicum esculentum*) raised for processing are usually grown during the summer. The plants may be seeded between April and July, usually in April, and harvested 90 days later. Harvesting is accomplished in one mechanical operation.

The tomato plant is deep-rooted and is not sensitive to moderate moisture stress in the main root zone. The plants are seeded (or planted) into a deeply wetted soil and given a few small irrigations to assure good germination and early development.

The following results are based on eight experiments conducted during the years 1967-1970 in the Coastal Plain region, the Northern Negev and Lakhish region.[1] The experiments included 4 to 10 irrigation treatments; the varieties tested were VF 145/21-4, VP 7879-7B, Roma and Gamad 54; seeding was done in late March to early May. Irrigation was mostly by sprinkler, although, in some experiments, drip irrigation was also tested.

Results and conclusions

1. *Irrigation requirements and yields*

Optimum yields were obtained with 220-240 mm of irrigation water (gross) in the Coastal Plain region and 410-430 mm in the Northern Negev and Lakhish region (Fig. 13). These amounts were applied in addition to germination irrigations and to a pre-seeding irrigation (to wet 150 cm of soil) in drier regions and during years of insufficient rainfall.

The mean maximum yields for the Coastal Plain region and the Northern Negev–Lakhish region were 5780 and 6810 kg/1000 m^2, respectively.

[1] A. Aharoni and D. Shimshi, principal investigators; Z. Shtroilicht, S. Sagie and A. Yagev, coinvestigators.

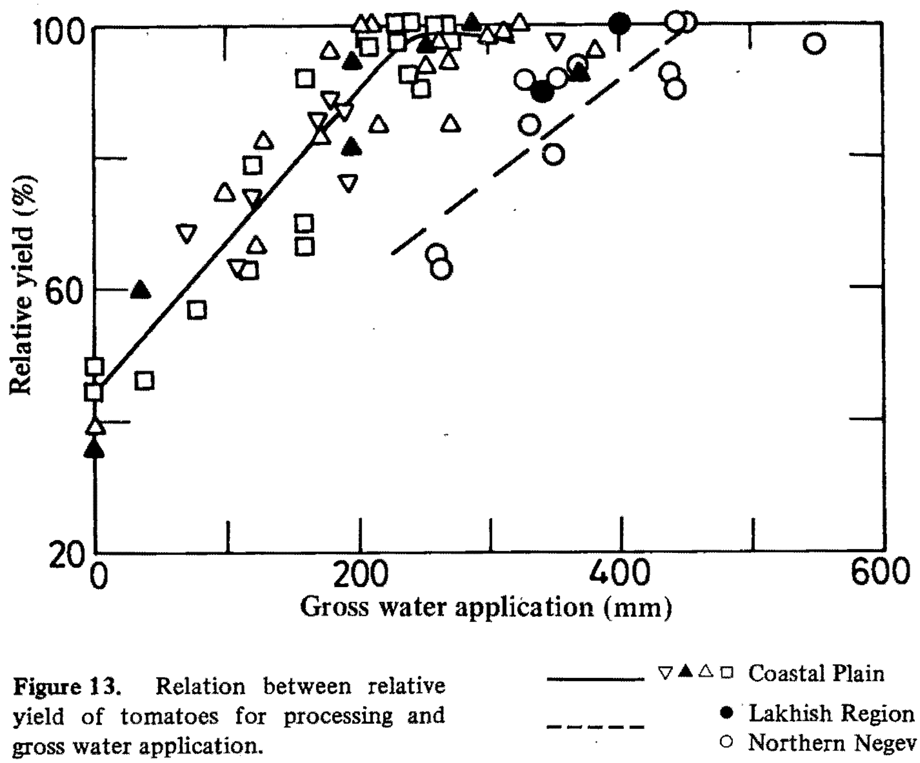

Figure 13. Relation between relative yield of tomatoes for processing and gross water application.

The information on the Coastal Plain was obtained from a large number of experiments specifically designed to determine the timing of the first and last irrigations in order to reduce the seasonal water application. The data for the Northern Negev–Lakhish region, on the other hand, came from only two experiments, specifically designed to test drip irrigation. It is likely that the water requirements thus obtained are overestimated and may be reduced considerably without any sacrifice in yield.

2. *Production functions*

The relation between relative yield estimate ($\hat{y}$) and gross water application (x) (no correction was made for water application efficiency) may be described by the following linear equations:

Coastal Plain:	$\hat{y} = 44.8 + 0.225\,x;$	$r^2 = 0.888$
Northern Negev–Lakhish:	$\hat{y} = 30.2 + 0.158\,x;$	$r^2 = 0.697$

The equations are valid in a water application range of 0-300 mm for the Coastal Plain, 240-450 mm for the Northern Negev–Lakhish region.

According to these equations, the rate of yield increase was 13.0 and 10.7 kg/1000 m^2 per mm of irrigation water for the Coastal Plain and the Northern Negev, respectively. With no irrigation, it is possible to obtain 45% (2550 kg/1000 m^2) and 30% (2032 kg/1000 m^2) of the maximum yield, respectively.

3. *Number of irrigations and irrigation frequency*

Two or three irrigations are required for optimal yields in the Coastal Plain, applied at 12-24 day intervals during flowering and fruit setting. The first irrigation should be applied 8 weeks after planting, at the peak of the flowering season. The last irrigation should be applied at the beginning of pink ripening, 80-85 days after planting (Table 23). Later irrigations usually result in the lowering of fruit dry matter content with no increase in yield.

In the Northern Negev, high yields were obtained with a large number of irrigations (7-day irrigation intervals, first irrigation applied 45-60 days after planting). The possibility of shortening the irrigation season by delaying the first irrigation and advancing the last one was not tested in these experiments.

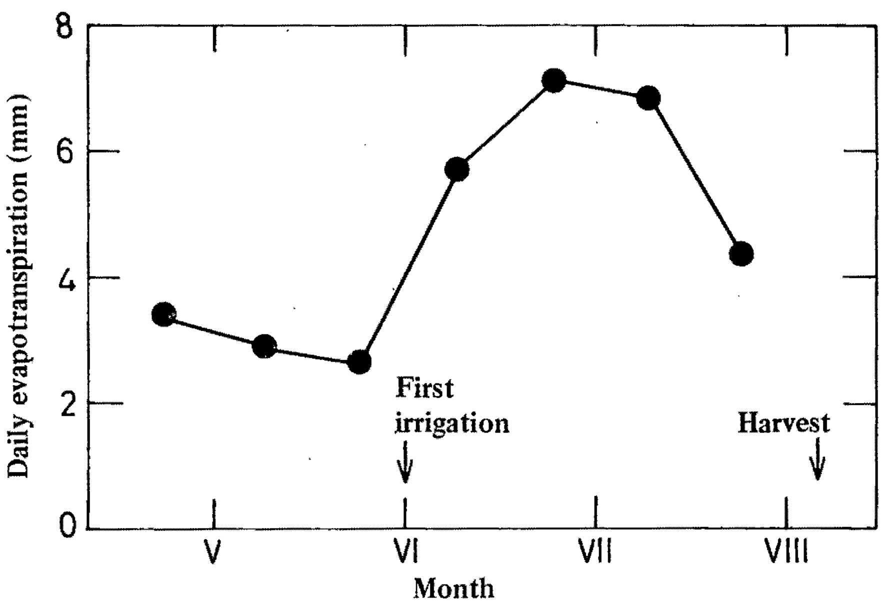

Figure 14. Average daily evapotranspiration (E_t) of tomatoes for processing in the Northern Negev.

Table 23. Optimum irrigation regimes for tomatoes for processing

Location	Year	Irrigation method	No. of irrigations	Irrigation interval (days after seeding)	Gross water application[1] (mm)	Yield[2] ($kg/1000\ m^2$)	Brix index
Southern Coastal Plain	1968	sprinkler	3	61, 76, 88	270	6310 (100)	5.9
	1969	sprinkler	3	62, 73, 84	240	5982 (100)	6.3
	1969	drip	3	62, 73, 84	240	5680 (100)	
	1970	sprinkler	2	60, 84	240	5335 (100)	5.9
	1970	drip	2	60, 84	240	4995 (100)	7.0
Central Coastal Plain	1968	sprinkler	2	60, 84	210	5910 (100)	6.1
	1968	drip	2	58, 83	230	5200 (98)	5.8
	1969	sprinkler	2	62, 89	210	7069 (100)	5.8
	1969	drip	2	62, 89	180	7311 (100)	5.7
Northern Coastal Plain	1968	sprinkler	2	55, 75	210	5160 (100)	5.9
Lakhish Region	1969	drip	7	61 at weekly intervals	400	6100 (100)	5.0
Northern Negev	1968	drip	8	40 at weekly intervals	436	7520 (100)	5.3

[1] Does not include germination irrigations.
[2] In parentheses: relative yield expressed as a percent of the maximum yield in the same experiment.

4. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

The mean daily E_t in the Northern Negev, given in Fig. 14, first shows a gradual decrease at the beginning of the season, due to the delay in the first irrigation, and then increases to 80% of E_o. With similar amounts of water there was a 33% higher yield with drip irrigation (Table 24).

Table 24. Sprinkling and drip irrigation effects on yield and yield components of tomatoes for processing (variety 7879-VF 145), Northern Negev, 1968

Irrigation method	Irrigation interval (days)	Water added[1] (%)	Gross water application[2] (mm)	Yield ($kg/1000\ m^2$)		Single fruit weight (g)
				Total	Red	
sprinkler	14	100	438	8130	5600	70
drip	14	100	438	8280	6800	66
drip	14	80	351	8360	6010	68
drip	14	60	263	6870	4890	61
drip	7	100	545	9340	7380	70
drip	7	80	436	9190	7520	70
drip	7	60	327	7880	6450	65

[1] Expressed as a percent of the measured water deficit in the sprinkled plots.
[2] Does not include germination irrigations.

5. *Water uptake with depth*

Tomato roots penetrate to a depth of over 1.5 m. However, 83% of the water is taken up from the 0-90 cm depth (Table 25).

Table 25. Water uptake from the various soil layers by tomatoes (as percentage of total uptake) for optimum irrigation regimes

Soil layer (cm)	0-30	30-60	60-90	90-120	120-150	150-180
Water uptake (%)	37	32	14	8	6	3

6. *Irrigation and fruit quality*

There is some decrease in the dry matter content and Brix index (solute content) with increase in irrigation quantity and frequency. This is especially strong if the last irrigation is given late (two weeks before harvest). There is no significant effect of irrigation on other quality criteria (acidity and color).

Publications

1. Aharoni, A., (1967) Irrigation of tomatoes for processing – a summary of field trials. *Hassadeh* 48:569-572 (Hebrew)
2. Aharoni, A. (1969) Irrigation of tomatoes for processing. Ministry of Agriculture, Irrigation Field Service (Hebrew)
3. Aharoni, A., Angelchuk, A. and Weis, M. (1967) Irrigation in the Western Galilee. Ministry of Agriculture, Irrigation Field Service (Hebrew)
4. Aharoni, A., Yagev, A., Hirschfeld, A., and Brosh, S. (1967) Irrigation of tomatoes for processing, Southern Coastal Plain. Ministry of Agriculture, Irrigation Field Service (Hebrew)
5. Aharoni, A., Yagev, A., and Sagie, Y. (1968) Irrigation of tomatoes for processing in the Coastal Plain. *Hassadeh* 49:846-848 (Hebrew)
6. Shimshi, D. (1969-1970) Irrigation of tomatoes for processing by the drip method. *Preliminary Report. Institute of Soils and Water, The Volcani Center* (Hebrew)

orchard crops

Citrus

Citrus (*Citrus sinensis*) is a typical mesophyte which grows in tropical and subtropical regions. The leaves are thick, evergreen and relatively resistant to high temperatures and drought. The main growing region is between 20-40° latitude in both the Northern and Southern Hemispheres. The maximum desirable temperature range is 10-35°C, and the optimum 20-30°C. Physiological activity of the citrus tree continues throughout the year, so that delayed precipitation during the rainy season may necessitate irrigation. Consumptive water use by citrus varies in accordance with the climatic growing conditions and the variety.

The physical properties of a soil (structure and texture) are of prime importance in citrus culture; coarse-textured and medium-textured soils are the most suitable. The soil type will determine the water-holding capacity and depth of rooting, and, indirectly, the irrigation regime to be followed.

The typical depth of rooting in a coarse-textured soil is about 150 cm, in a medium-textured soil – 150-200 cm and in a fine-textured soil, only 100-120 cm. Rooting depth is also a function of variety and rootstock. The main part of the root zone is located in the 0-90 cm soil layer.

It is generally accepted that proper water supply is of major importance during flowering and fruit set. A deficit during this period may lead to enhanced abscission of flowers and young fruit and a subsequent loss in yield. Proper water management at this time may indeed reduce flower drop. A second critical period is the time of rapid fruit growth, when a water deficit will influence fruit size. The effects of water supply during the ripening period prior to harvest are uncertain. Throughout the season, irrigation regimes do influence fruit quality, and soil water status has an effect on vegetative growth and root development.

The data presented here are based on the results from a large-scale program of experiments[1] which covered most of the citrus-growing

[1] H. Bielorai, E. Bresler, A. Goell, J. Heller, D. Kalmar, Y. Levy, A. Mantell and E. Shmueli, principal investigators; A. Adri, M. Achituv, A. Altman, M. Aharoni, M.

areas and the three main variety-rootstock combinations: Shamouti orange on sour orange, Shamouti orange on Palestine sweet lime and Marsh grapefruit on sour orange. These combinations represent about 70% of the citrus groves in Israel.

Methods

The program included five main experiments and eight auxiliary ones. In the former, a wide range of irrigation frequencies were studied, from 12 to 42-day intervals, and seasonal water applications from 400 to 1000 mm. The auxiliary trials tested three seasonal water quantities, based on replenishing the water deficit in three different depths of the root zone; the frequency of irrigation was that commonly used for citrus in the region. Details describing the various experiments are presented in Table 26. Experiments 1, 3, 8 and 9 were conducted in relatively high-bearing groves on Hamra soils. Experiments 5, 6 and 7 were in medium-bearing groves on clay soils, while experiments 2 and 4 were in relatively low-bearing groves on clay soils. All grapefruit studies were carried out on medium to heavy-textured soils.

In the main experiments (1, 2, 4, 8 and 10), 5-8 treatments were investigated, with 5-6 replications. The auxiliary experiments consisted of 3-4 treatments replicated 3-4 times.

In all studies, water was applied by low-angle, under-canopy rotary sprinklers. The seasonal water applications mentioned in Table 27 are the gross amounts actually delivered to the plots. The differential treatments generally began in mid-April or at the beginning of May, at the end of the rainy season. In the event of early termination of rains, a uniform irrigation was applied to the entire experimental grove.

Results and conclusions

1. *Water requirements and yields*

A summary of seasonal water applications and number of irrigations producing optimum yields (defined as the yield exceeding 90% of the maximum yield obtained in the same year and location) is presented in Table 27 and in Figs. 15 a, b and c.

Amir, M. Angelchik, I. Brenner, P. Brosh, M. Brum, J. Cohen, Z. Cohen, A. Golomb, I. Hermelin, C. Kurtz, G. Leitman, M. Magen, S. Manor, I. Marchevsky, I. Marnin, C. Nussaiev, A. Ram, N. Ravid, J. Shalhevet, M. Sneh and E. Yagev, coinvestigators.

Table 26. Data on the experimental citrus groves.

Expt. no.	Location	Soil type[1]	Area of experiment (ha)	Year of planting	Planting distance (m)	Chloride in irrigation water (mg/1)	Experimental period[2]
Shamouti on sour orange							
1	Central Coastal Plain I	Sandy loam hamra	3.0	1931	4 x 7	190	1963-1969
2	Central Coastal Plain II	Hydromorphic dark brown, alluvial grumusol	4.5	1956	3 x 6	130-250	1966-1969
3	Western Galilee I	Brown alluvial clay loam hamra	1.1	1956	3 x 6	100	1964-1969
4	Western Galilee II	Non-calcareous grumusol	4.0	1963	4 x 6	60	1969-1972
5	Central Coastal Plain III	Reddish-brown alluvial grumusol	1.5	1955	4 x 7	90-160	1964-1969
6	Southern Coastal Plain I	Dark brown sandy clay loam	1.0	1955	4 x 6	160	1963-1967
7	Southern Coastal Plain II	Alluvial dark brown grumusolic clay	2.0	1957	3 x 6	170-300	1966-1971

Table 26. (continued)

Expt. no.	Location	Soil type[1]	Area of experiment (ha)	Year of planting	Planting distance (m)	Chloride in irrigation water (mg/1)	Experimental period[2]
Shamouti on sweet lime							
8	Central Coastal Plain IV	Non-calcareous sandy hamra	3.0	1956	4 x 6	240	1965-1971
9	Central Coastal Plain V	Sandy loam hamra	0.9	1952	4 x 6	130	1963-1969
Marsh grapefruit on sour orange							
10	Northern Negev	Loessial silty clay	2.1	1959	6 x 6	250	1965-1972
11	Western Jezreel Valley	Calcareous brown grumusol	1.8	1957	4 x 7	110-180	1963-1967
12	Western Galilee III	Non-calcareous alluvial brown grumusol	1.3	1959	4 x 6	50-160	1963-1967
13	Eastern Jezreel Valley	Calcareous alluvial brown grumusol	1.5	1958	4 x 5	230	1966-1967

[1] According to soil tests, and the classification by J. Dan and Z. Raz in "The Soil Association Map of Israel" (Scale 1:250,000) 1970. The Volcani Inst. of Agric. Research.

[2] The period considered here begins after no further changes were introduced in the treatments, and in the young, low-bearing groves, after the yields approached a level typical of mature groves. These years were used to evaluate mean seasonal water application and yield as presented in Table 27.

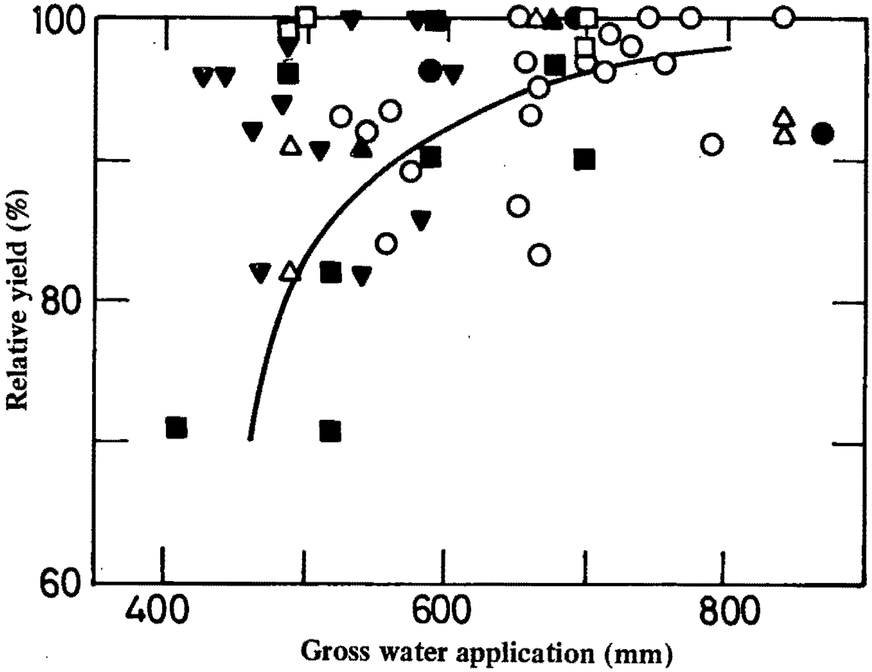

Figure 15a. Relation between relative yield of citrus and gross water application in several regions. Shamouti orange on sour orange.

▼ Western Galilee
□ ▲ Northern Coastal Plain
○ ■ Central Coastal Plain
● △ Southern Coastal Plain

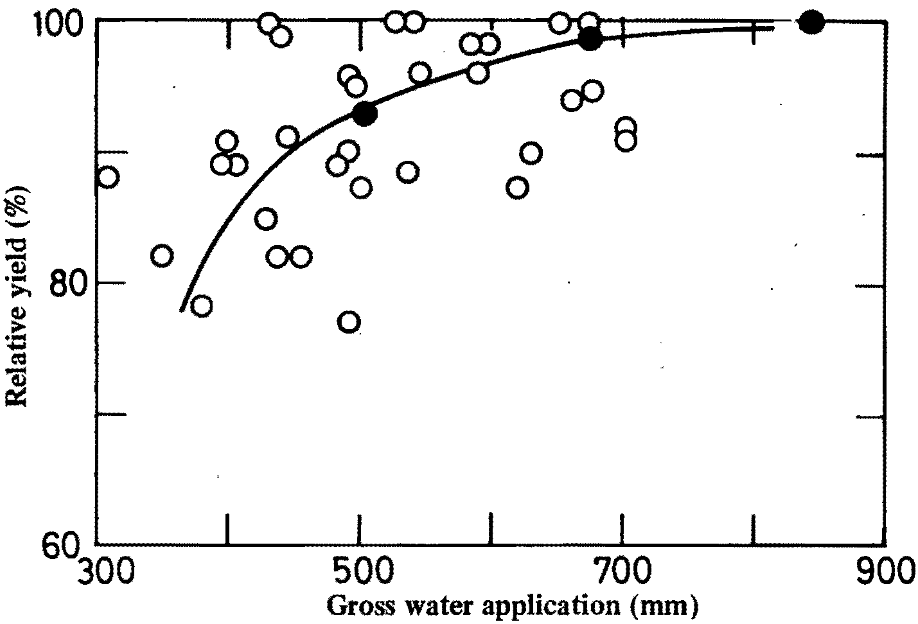

Figure 15b. Relation between relative yield of citrus and gross water application in several regions. Shamouti on sweet lime.

○ ● Central Coastal Plain

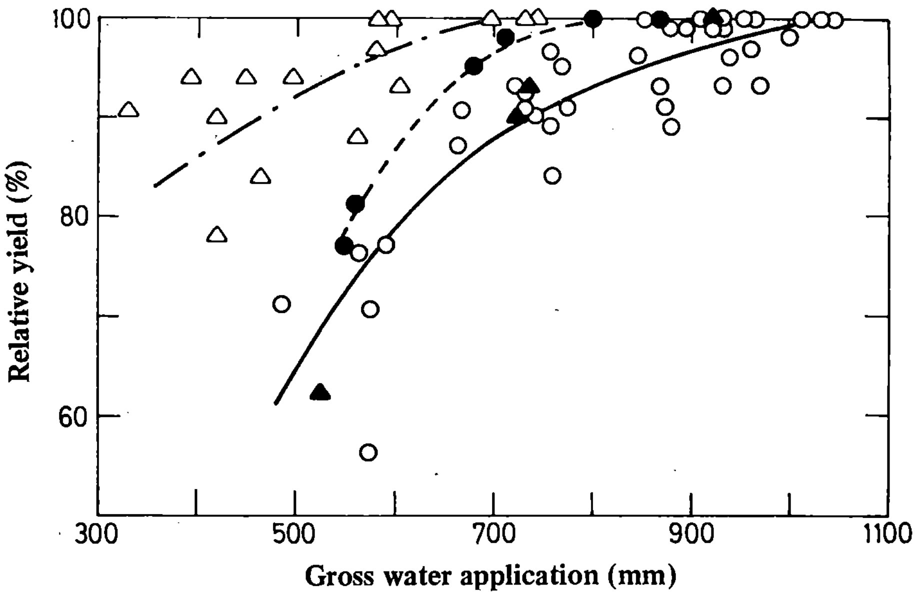

Figure 15c. Relation between relative yield of citrus and gross water application in several regions. Grapefruit on sour orange.

Table 27 Optimum irrigation regimes and yields

Expt. no.	Location	Year	Irrig. freq. (days)	No. of irriga- tions	Gross water app. (mm)	Yield kg/tree	ton/ 1000 m²	relative[1]
Shamouti on sour orange								
1	Central	1964	30[2]	7	711	144	5.2	98
	Coastal	1965	30[2]	7	700	113	4.1	93
	Plain I	1966	30[2]	7	656	124	4.5	97
		1967	21[2]	10	747	165	5.9	100
		1968	30[2]	6	622	120	4.3	92
2	Central	1966	15[3]	11	586	68	3.7	100
	Coastal	1966	21	8	685	68	3.7	100
	Plain II	1966	42[4]	5	473	68	3.7	96
		1967	15[3]	12	634	52	2.8	95
		1967	30	6	584	55	3.0	100
		1967	21[4]	9	702	72	4.0	100
		1968	15[3]	11	559	67	3.7	100
		1968	21	9	722	69	3.3	89
		1968	21[4]	9	715	82	4.5	100

Table 27 (continued)

Expt. no.	Location	Year	Irrig. freq. (days)	No. of irriga-tions	Gross water app. (mm)	Yield kg/tree	ton/ $1000\ m^2$	relative[1]
3	Western Galilee I	1965	24	10	590	86	4.7	96
4	Western	1971	–[5]	5	434	66	2.8	96
	Galilee II	1972	–[5]	5	441	112	4.7	96
5	Central	1964	25	8	615	81	2.9	100
	Coastal Plain III	1965	25	9	690	139	5.0	100
6	Southern	1964	26	8	665	62	2.6	100
	Coastal Plain I	1965	27	8	665	104	4.4	100
7	Southern	1966	24	8	500	83	4.6	100
	Coastal Plain II	1967	24	8	490	116	6.4	99
Shamouti on sweet lime								
8	Central	1967	20[2]	10	492	132	5.5	96
	Coastal	1968	32[2]	7	431	110	4.6	90
	Plain IV	1969	14[2]	11	570	146	6.1	92
		1970	32[2]	8	440	125	5.2	98
		1971	20[2]	9	400	128	5.2	98
		1972	32[2]	7	398	141	5.9	91
9	Central	1964	22	9	675	209	8.6	91
	Coastal Plain V	1965	21	9	675	184	7.7	100
Marsh grapefruit on sour orange								
10	Northern	1967	24	9	722	212	5.9	93
	Negev	1967	18	11	851	226	6.3	100
		1968	24	9	929	262	7.3	100
		1968	18	12	867	248	6.9	93
		1969	21	9	895	248	6.9	99
		1970	24	9	920	262	7.3	99
		1970	30	7	759	254	7.1	97
		1971	24	9	954	322	9.0	100
		1972	24	10	998	281	7.9	100
		1973	24	10	1060	398	11.1	100

Table 27. (continued)

Expt. no.	Location	Year	Irrig. freq. (days)	No. of irriga- tions	Gross water app. (mm)	Yield kg/tree	ton/ 1000 m²	relative[1]
11	Western Jezreel Valley	1964	24	8	680	146	4.7	95
		1965	26	8	710	131	5.2	98
12	Western Galilee III	1965	28	7	700	130	5.4	100
		1966	28	6	450	125	5.2	94
		1967	28	7	395	114	4.8	95
13	Eastern Jezreel Valley	1967	12	14	735	128	6.4	93

[1] Relative yield expressed as a percent of the maximum yield in the same year and experiment.
[2] Depth of wetting – 60 cm. In all other cases – 90 cm.
[3] Alternate row irrigation.
[4] Irrigation water with 130 mg Cl/liter. Other treatments in this experiment were irrigated with water containing 250 mg Cl/liter. The relative yield was calculated separately for each water quality.
[5] In spring, when soil water tension at 90 cm reached 70 cb; in summer, every 42 days.

The data indicate differences in water requirements and yield levels according to the region, length of irrigation season and variety-rootstock combinations. The scattering of points in the figures is due to variations in response between years in each experiment, and also between the regions. However, in spite of this scattering, a reasonable picture is obtained of yield response to irrigation water.

Shamouti on sour orange: The experiments with Shamouti on sour orange encompassed a large region, extending along the Coastal Plain from the north to the south, and included various soil types (see Table 26). In general, the experiments can be divided into two groups. The first one is that in which the optimum seasonal water requirement was in the 600-660 mm range. The average optimum yield was about 5.0 tons/1000 m^2 (Experiments 1, 2, 3, 5 and 6). Water was applied in 7-10 irrigations, at a frequency of 21-30 days. In the second group (Experiments 4 and 7) there was practically no response to water application. The optimum treatment, producing a yield of about 4.7 tons/1000 m^2, was achieved with 8-10 irrigations at a frequency of

24 days. It should be indicated that there were large fluctuations in the absolute yield from year to year, particularly in those groves planted on fine-textured soil (see Table 27).

Shamouti on sweet lime: The optimum yield from this combination, which was tested at two locations (Experiments 8 and 9), was 6.6 tons/1000 m^2. It was obtained with a seasonal water application of 500-550 mm, applied in 8-10 irrigations at a frequency of 20-26 days.

Marsh grapefruit on sour orange: The response of grapefruit to irrigation regimes was more marked than that of the Shamouti orange; in most cases, water applications did have an effect on yield. Water consumption was greater in the warmer regions (Northern Negev and Eastern Jezreel Valley) than in the Northern Coastal Plain. The irrigation requirement for optimum yield (about 5.3 tons/1000 m^2) in the Northern Coastal Plain was 500-560 mm, applied in 6-7 irrigations at 28-day intervals. The seasonal water application in the Western Jezreel Valley for optimum yield (5.0 tons/1000 m^2) was 650-700 mm. In the Eastern Jezreel Valley and the Northern Negev, the seasonal water requirements was somewhat higher – 800-860 mm, applied in 8-12 irrigations at a frequency of 12 days and 18-24 days, respectively. The average optimum yield at these two locations was 7.8 tons/1000 m^2

2. *Effects of irrigation regime on fruit quality*

An example of the fruit quality response of the three variety-rootstock combinations to three irrigation regimes is presented in Table 28. In general, fruit was of high quality, and only in the driest treatments, in which there was a significant reduction in yield, was fruit quality impaired. In such cases, the factors affected were fruit size, peel thickness and percent juice. There were no apparent differences in fruit quality between the treatment defined as optimum and the wetter treatments. Table 28 also indicates the differences among years (in the Northern Negev), suggesting that the effect of irrigation regime is not consistent and depends to a large degree on other factors, such as climate.

3. *Water uptake with depth*

Data on water extraction from the soil profile for the different citrus varieties and soil types are presented in Table 29. Most of the total water consumption was obtained from the 0-90 cm soil layer, which is considered the main root zone. There were differences in extraction

Table 28. Effect of irrigation regime on fruit quality in three of the main experiments

Location and Year	Central Coastal Plain IV (1971)			Central Coastal Plain I (1967)			Northern Negev (1970)			Northern Negev (1972)		
Variety on rootstock	Shamouti on sweet lime			Shamouti on sour orange			Grapefruit on sour orange			Grapefruit on sour orange		
Irrigation regime	DRY	OPT.	WET	DRY	OPT.	WET	DRY	OPT	WET	DRY	OPT.	WET
Water application (mm)	307	400	523	562	749	791	700	850	1000	734	858	1034
Single fruit weight (g)	200	206	209	178	198	197	451	463	454	391*	417	423
Fruit volume (cm^3)	226	232	228	—	—	—	—	—	—	—	—	—
Peel thickness (mm)	7.5*	7.5	6.8	7.5	7.3	7.1	10.4	10.3	9.9	9.9	10.0	9.6
Juice (%)	42.5	42.7	43.9	39.4*	42.3	41.4	40.4*	41.4	42.7	43.7	43.6	42.5
Total soluble solids (%)	12.5*	12.3	11.8	12.8	12.2	12.5	10.4	10.1	10.1	10.1*	9.6	9.5
Citric acid (%)	1.40	1.44	1.40	1.40	1.42	1.44	1.74*	1.65	1.69	1.72	1.78	1.78
Sugars (%)	11.3*	11.2	10.7	11.6	11.1	11.4	10.3	10.9	10.9	—	—	—
TSS/acid ratio	8.6	8.3	8.5	9.2	8.6	8.8	5.96*	6.11	5.98	5.86*	5.43	5.36
Ascorbic acid (Vit.C) (mg/100 cc)	49.8	48.4	47.3	46.4	44.9	45.8	39.7	41.5	39.5	43.8	43.5	42.0

*Significant differences at the 5% probability level.

among the various soil types. In the sandy soils, the 0-90 cm layer contributed about 80% of the total water use, while in the medium-textured and clay soils approximately 90% was from this layer. In light of this information, the irrigation treatments were generally designed to replenish the water deficit from field capacity in the upper 90 cm of soil. This practice reduces water loss resulting from drainage below the root zone if water applications are excessively high. In regions where irrigation water is saline or where salts may accumulate in the root zone due to low rainfall in the winter, it is advisable to measure soil salinity periodically. If leaching is required, this may be done by supplementary irrigation in the winter.

4. *Evapotranspiration (E_t) and Class A pan evaoporation (E_o)*

The daily consumptive water use during the irrigation season in the various regions, as measured in certain experiments, is presented in Fig. 16. Average water use in spring and fall at most locations was low – 2.5-3.5 mm/day – and reached a peak of 4-5 mm/day in June, July

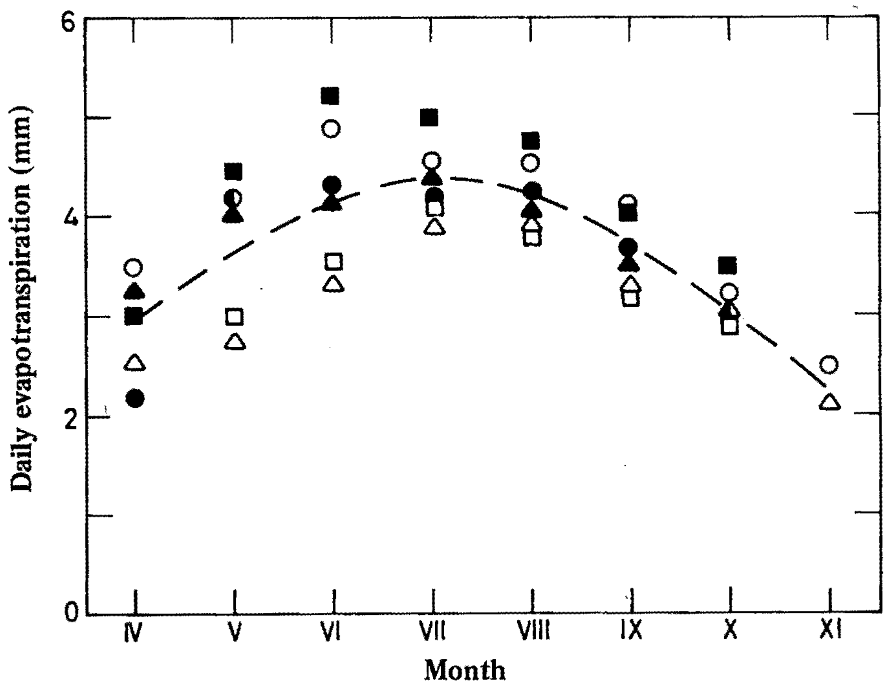

Figure 16. Average daily evapotranspiration (E_t) by citrus groves during the irrigation season.

■ Western Jezreel Valley
□△▲● Central Coastal Plain
○ Northern Negev

Table 29. Water uptake by citrus (expressed as a percent of the total water removed) from the various soil layers.

Location	Soil texture	Variety on rootstock	Tree age (years)	Soil layer (cm) 0-30	30-60	60-90	90-120	120-150	150-180
Northern Negev	Silty clay	Grapefruit on sour orange	12	49	33	16	1	1	–
Western Jezreel Valley	Clay	Grapefruit on sour orange	7	47	27	13	7	6	–
Central Coastal Plain I	Sandy loam	Shamouti on sour orange	35	44	24	13	8	6	5
Western Galilee II	Clay	Shamouti on sour orange	8	47	30	14	3	3	3
Central Coastal Plain IV	Sand	Shamouti on sweet lime	17	32	33	17	13	4	1
Central Coastal Plain V	Sand	Shamouti on sweet lime	12	23	23	24	19	11	–

Table 30. The ratio between evapotranspiration (E_t) and pan evaporation (E_o) for optimum irrigation regimes in three locations

Location	Variety on rootstock	April	May	June	July	August	Sept.	Oct.	Nov.
Central Coastal Plain I	Shamouti on sour orange	0.47	0.52	0.43	0.46	0.53	0.53	0.45	–
Central Coastal Plain IV	Shamouti on sweet lime	–	0.39	0.35	0.42	0.47	0.48	0.48	–
Northern Negev	Grapefruit on sour orange	0.51	0.49	0.51	0.54	0.53	0.56	0.71	0.65

and August. The highest water use was recorded in the Northern Negev and in the Western Jezreel Valley, while the lowest was in the Central Coastal Plain.

The relation between E_t during the irrigation season and the E_o measured with a Class A pan is shown in Table 30. This ratio is not uniform throughout the season; it is fairly constant during June and July, but changes in spring and fall.

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Avocado

The avocado (*Persea americana Mill*) originated in Central America, and consequently adapts to regions with tropical and subtropical climates. Despite the fact that the tree has a tall and extensive canopy, the extent of its root system is limited under most conditions. The crop is sensitive to conditions of poor aeration and low levels of salinity, but resistant to attacks by insects and diseases.

The results summarized below are based on two irrigation experiments conducted over a period of four to six years, from 1968 to 1974, in the Western Galilee and the Northern Coastal Plain.[1] The orchards were five years old when the experiments started, the varieties were Ettinger, Fuerte and Haas, and planting spacing was 6 x 6 meters. The experiments included three to four treatments and four replications. The irrigation frequencies ranged from 7-10 days to 22-28 days.

Results and conclusions

1. *Water requirements and yields*

Avocado is noted for extreme variability in productivity among years; thus many years of experimentation are required in order to obtain significant results.

There was very little difference in yield in the range of water application of 700-1000 mm. There was some yield reduction where the Haas variety was irrigated with 600 mm (Fig. 17). In general it appears that optimum yields of 40-55 kg/tree, depending on variety, may be obtained with 700 mm irrigation water, given at 14-21 day intervals (irrigation at 30% of available water to a depth of 60 cm).

2. *Water uptake with depth*

Water uptake distribution with depth depended on soil type and the

[1] A. Aharoni and D. Kalmar, principal investigators; A. Ben-Yaakov, E. Bresler, M. Brum, A. Lahav and A. Yanai, coinvestigators.

Table 31. Water application, yield and yield components of three avocado varieties in two regions (Mean of four to six years)

Location	Irrigation frequency (days)	Gross water application (mm)	Yield ($kg/1000\ m^2$)			Single fruit weight (g)		
			Fuerte	Haas	Ettinger	Fuerte	Haas	Ettinger
Western Galilee	7	895	42	62	50	322	234	271
	14	757	40	59	47	304	200	262
	21	624	39	54	46	312	205	264
	28	603	38	52	45	293	195	250
Northern Coastal Plain	10	1000	58	99		282	190	
	16	850	56	77		273	178	
	22	761	61	100		259	183	
	10-22	797	61	96		268	169	

consequent root distribution. In Western Galilee, the soil was heavy-textured and roots were shallow; thus 95% of the water was taken up from the 0-60 cm layer (Table 32). In the Northern Coastal Plain, with medium-textured soils, the root system was deeper and water uptake from the top 60 cm was only 80%.

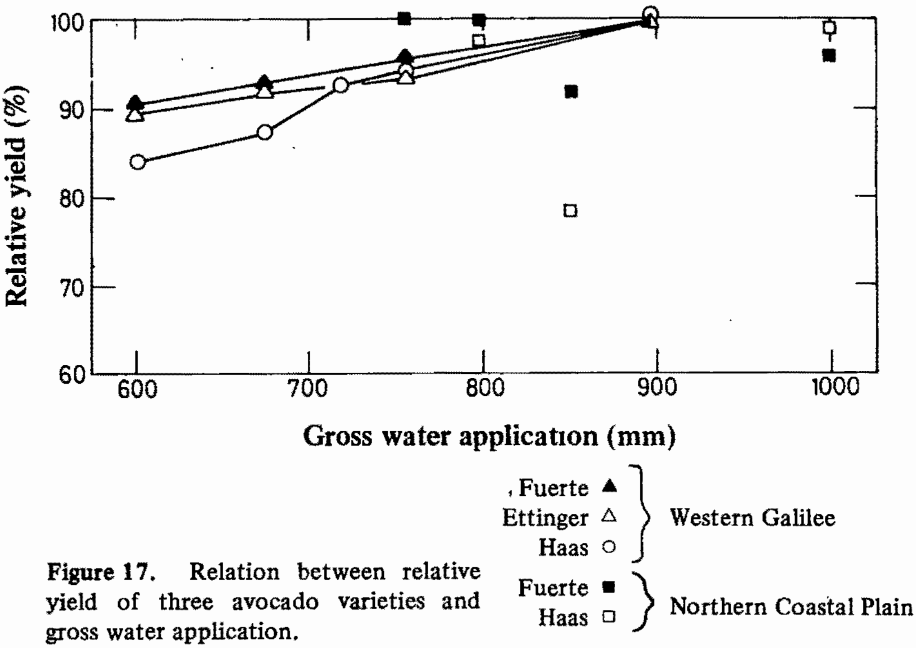

Figure 17. Relation between relative yield of three avocado varieties and gross water application.

Table 32. Water uptake by avocado from the various soil layers (as percent of total uptake) for the optimum treatment

Location	Soil layer (cm)					
	0-30	30-60	60-90	90-120	120-150	150-180
Western Galilee	82	15	2	1		
Northern Coastal Plain	40	40	15	3	1	1

3. *Evopotranspiration (E_t) and Class A pan evaporation (E_o)*

The rate of E_t was relatively constant throughout the irrigation season from June to October (3.0-3.5 mm/day); the ratio E_t/E_o, on the other hand, increased from 0.42 in June to 0.61 in October (Table 33). This demonstrates the possibility of further reducing the water application towards the end of the irrigation season.

Table 33. Daily evapotranspiration (E_t) and E_t/E_o for optimum irrigation of Western Galilee avocado

Month	June	July	Aug.	Sept.	Oct.
E_t (mm/day)	3.3	3.3	3.5	3.1	3.0
E_t/E_o	0.42	0.43	0.49	0.51	0.61

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Apples

The apple (*Malus sylvestris*) is a deciduous tree crop, which develops new growth and foliage in early May. It is adapted to temperate climates, between latitudes 25 and 55°N, with cold winters and moderately warm summers. Israel is at the southern-most limit of the apple-producing region and, because of the relatively mild winters, the tree does not go into dormancy and oil spray is necessary in order to start spring growth. The apple tree has a very extensive root system; depth of root penetration may reach several meters, although it is usually more limited because of its sensitivity to poor soil aeration.

The results summarized below are based on three irrigation experiments conducted over a period of 15 years (1956-1971) at three locations: two in the Upper Galilee and one in the Jerusalem Hills.[1] The soil at all three locations was fine-textured (wilting point about 18%, field capacity 28% by weight). The climatic conditions are described in Table 1.

The experiments in the Upper Galilee (irrigation by sprinkler) consisted of four to six treatments, based on preirrigation moisture content to a depth of 60 cm throughout the irrigation season, and a combination treatment – irrigation infrequently at the beginning and end of the season and frequent irrigation during fruit formation (June-August). The depth of wetting was either 60 cm or 120 cm. The varieties tested were Jonathan and Grand Alexander.

The Jerusalem experiment (irrigation by furrows) consisted of 6 treatments based on preirrigation moisture deficits to a depth of 120 cm. The variety tested was Orleans.

Results and conclusions

1. *Irrigation requirements and yields*

The best irrigation regime in the Upper Galilee proved to be frequent

[1] R. Assaf, B. Bravdo, S. Gairon, H. Ladin and I. Levin, principal investigators.

Table 34. Yield, yield components and irrigation regime of apples for the optimum treatments at three locations

Location	Irrigation regime	No. of irrigations	Gross water application (mm)	Total yield[1] (ton/1000 m^2)	Marketable yield (ton/1000 m^2)	Water use efficiency (kg/1000m^2/ mm)
Upper Galilee I[2]	4 week interval	6	1055	3.07 (88)	1.03	
	combination[3]	8	1110	3.50 (100)	1.30	1.19
Upper Galilee II[2]	irrigation at 40% available water	20	1080	10.95 (100)	7.35	6.80
	combination[4]	12	760	12.42 (113)	11.20	14.70
Jerusalem Hills	irrigation at 25% available water	14	890	2.98 (100)	2.98	3.35

[1] Values in parentheses refer to relative yield. For Upper Galilee II, 100% was taken as the best regular interval treatment.
[2] Upper Galilee I is the northern section and II is the southern section.
[3] Spring and fall – 4-week intervals; summer – 2-week intervals.
[4] Spring and fall – at wilting point; summer – at 40% available water.

irrigation during the main fruit development season (mid-June to mid-August) and infrequent irrigation at the beginning and end of the season. In the latter, the pre-irrigation moisture content was allowed to drop to wilting point to a depth of 60 cm before water was applied. The maximum yield of fruit obtained with this treatment was 12.4 ton/ 1000 m^2, 90% of which was grade 6 or higher, with a gross water application of 760 mm given in 12 irrigations (Table 34).

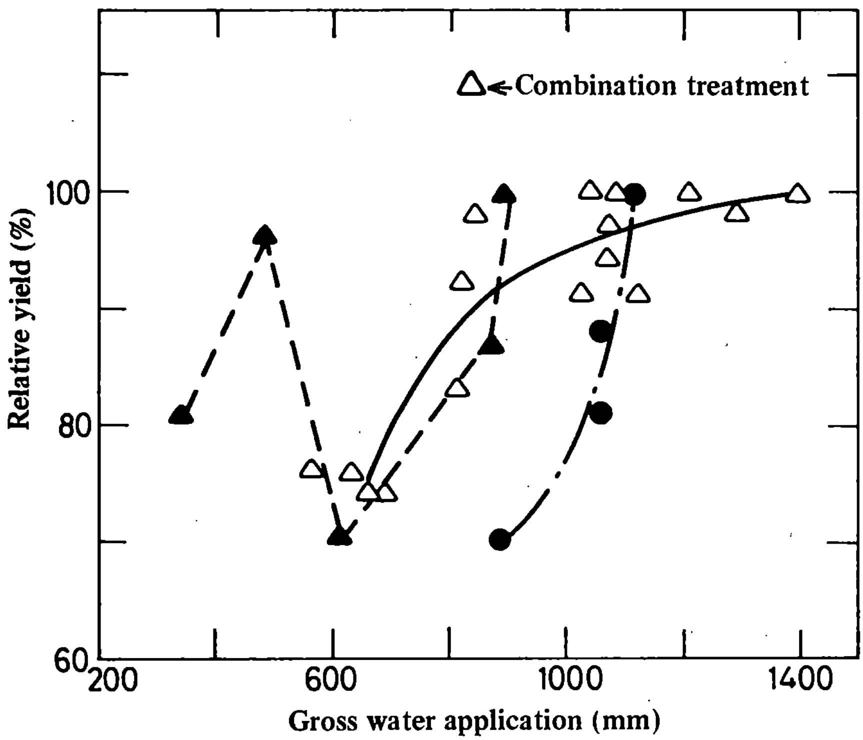

Figure 18. Relation between relative yield of apples and gross water application in two regions.

● Northern Galilee I
△ Northern Galilee II
▲ Jerusalem

The slope of the lines describing relative yield vs. water application rate, given in Figure 18, is similar for the three experiments, though at one location in Upper Galilee the yields were considerably higher than the other two. In the latter case, the yield from the most frequently irrigated treatment was taken as 100%, rather than the maximum yield treatment. It appears that excessive amounts of water were applied in the early Upper Galilee experiment, while the Jerusalem Hills experiment was too short to give conclusive results.

2. *Depth of wetting*

In the optimum combination treatment, 72.5% of the water was taken up from the 0-60 cm layer, while 93% from the 0-120 cm layer (Table 35). Accordingly, the normal required depth of wetting at every irrigation is 60 cm, while the soil is wetted to 120 cm whenever the moisture content in the 60-120 cm depth reaches 60% of available moisture. Usually, this plan will require deep wetting twice during the season.

Table 35. Water uptake by apples from the various soil layers for the optimum and wet treatments (as percent of total) (Upper Galilee II)

Soil layer (cm)	0-30	30-60	60-90	90-120	120-150	150-180
Combination treatment	47.5	25.0	14.5	6.0	4.0	3.0
Wet treatment	53.0	25.0	9.0	5.5	5.0	2.5

3. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

The ratio E_t/E_o for the optimum treatment was 0.8 as a mean for the whole irrigation season. During June-July it rose to over 1.0, dropping at the end of the season to 0.5. The peak evapotranspiration rate was 10 mm/day in early July, and the mean for the season was 8 mm/day (Fig. 19).

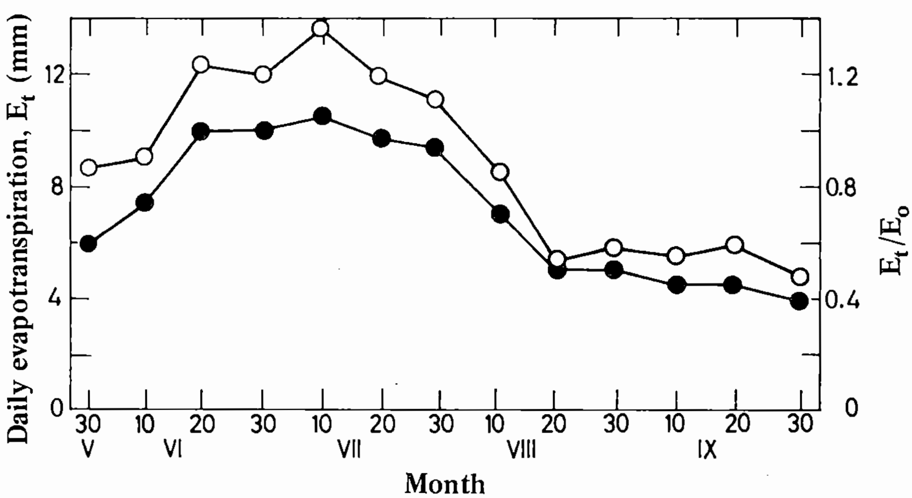

Figure 19. Average daily evapotranspiration (E_t) and E_t/E_o ratio for apples in the Upper Galilee.

4. *Fruit quality*

A linear relationship was found between the final fruit volume and the length of time the tree was under high soil moisture. This relationship may be described by the following equation:

$$y = 58.2 + 0.82\,x; \qquad r = 0.867$$

where

y = final fruit volume as percent of the optimal treatment.

x = number of days the available water content in the soil exceeded 40%.

Although fruit firmness was not affected by the irrigation treatment, sugar content and keeping properties were reduced significantly with increased irrigation frequency.

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Bananas

The banana (*Musa* spp.) is indigenous to tropical regions where its cultivation is generally based on natural rainfall. In Israel, the plant is known to consume large quantities of water, perhaps due to the fact that the main center of production is the Jordan Valley, where irrigation was traditionally provided by flooding, with a low efficiency of water use. With the development of plantations in the Coastal Plain, often on non-level land, the trend was to irrigate by sprinkling, with relatively high efficiency. In consequence, the annual water requirement, excluding winter rainfall, was reduced to about 1200 mm.

The banana plant grows vigorously throughout the summer months, and has a sparse, shallow root system. The plant is not robust, and cannot tolerate stress conditions without being adversely affected. Results of the first experiments conducted in Israel indicated that water should be applied before more than 25% of the available water has been extracted from the root zone; thus, plantations were irrigated weekly or even more frequently. This practice prompted the installation of the first permanent irrigation systems in the Coastal Plain.

In a study conducted in the Coastal Plain,[1] the following conclusions were reached: At the beginning of the irrigation season the evapotranspiration rate was about 4 mm/day, rising to a peak of 6 mm/day in the middle of the season (July, August, September) and then dropping to about 3 mm/day in October (Fig. 20).

Physiological activity varies during the season as a result of foliar growth, flowering and sucker development. However, this seasonal increase in activity is not proportionally related to the rise in Class A pan evaporation. Therefore, the E_t/E_o ratio changes during the irrigation season.

The banana obtains most of its water requirement from the 0-60 cm soil layer, according to the distribution shown in Table 36.

[1] D. Kalmar, principal investigator; J. Ben-Maier and J. Halevy, coinvestigators.

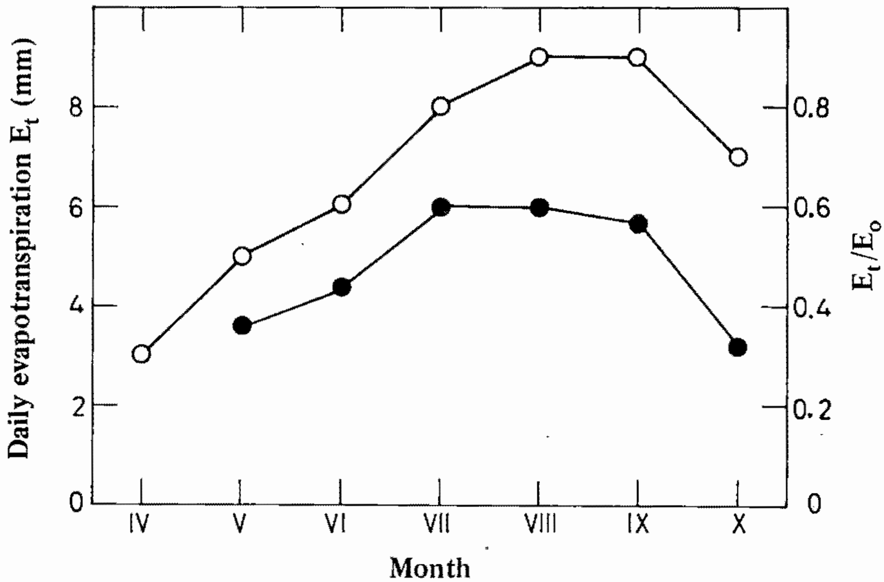


Figure 20. Average daily evapotranspiration (E_t) and E_t/E_o ratio for bananas in the Northern Coastal Plain.

On the basis of the above information, the seasonal water consumption of sprinkler-irrigated bananas is about 1120 mm applied in 30 irrigations. Assuming a yield of 5.7 tons/1000 m^2, one mm of water will produce about 5 kg of banana fruit/1000 m^2.

Table 36. Water uptake by banana plants (expressed as a percent of the total water removed) from the various soil layers

Soil layer (cm)	Water extraction (%)
0-15	30
15-30	30
30-45	23
45-60	17

Publications

1. Kalmar, D., Ben-Maier, J. and Halevy, J. (1970) Sprinkler irrigation of bananas in the Coastal Plain. *Alon Hanoteya* 24:574-585 (Hebrew)
2. Shmueli, E. (1952) Response of banana to reduction of soil moisture. In: "Studies on Banana". Sifriyat Hassadeh, Tel Aviv. (Hebrew)

other crops

Lawngrass

In sharp contrast to agriculture, where plant quality and yield are of major importance, ornamental horticulture is concerned exclusively with the creation of an environment aesthetically suitable for recreation or relaxation. The value of lawngrass depends on its color, density and general appearance rather than its yield. The quality of a lawn depends upon the interaction of many factors, including soil water, nitrogen fertilization and mowing frequency and height. Successful turf culture in arid and semi-arid zones is particularly problematic, since rainfall during the major part of the growing season is either negligible or altogether non-existent, rendering irrigation essential. As water in these regions is often in short supply, there is a problem of how to limit water use and still retain the desirable features of the lawn.

The results presented here were obtained from an experiment conducted during 1961-1962 to study the interaction between irrigation frequency and nitrogen fertilization on the water use, growth and appearance of a kikuyugrass lawn (*Pennisetum clandestinum* Hochst.)[1] This hardy perennial spreads rapidly by thick underground rhizomes, producing an extremely dense, rather coarse turf. It remains green throughout the year.

The soil of the experiment, in the Central Coastal Plain, was a deep sandy loam with a field capacity of 10% and a permanent wilting percent of 4%, both on a dry weight basis. Treatments included 5 irrigation frequencies, each at 3 levels of fertilizer: N_0 – 0, N_1 – 2.1, and N_2 – 4.2 kg N/1000 m^2/month. During the course of the experiment the following factors were measured: plant density, light reflection (by means of a photocell), leaf chlorophyll content (by colorimetry) and visual assessment of lawn quality (by a panel, with scores ranging from 6 – excellent, to 1 – very poor). All measurements were carried out simultaneously. All the plots were mowed weekly, and the clippings collected to determine dry weight yields.

[1] A. Mantell, principal investigator; G. Stanhill, coinvestigator.

Results and conclusions

1. *Irrigation requirements, fertilization and lawn quality*

In terms of its effect on the aesthetic quality of a lawn, a moderate application of nitrogen fertilizer was sufficient to replace a considerable quantity of water. During the period June-October, plots which were irrigated every 25 days (a total net water applicaton of 383 mm in 6 irrigations) and received 10 kg ammonium sulfate/1000 m^2 before each irrigation, were in a condition considered "satisfactory" or better 80% of the time. Grass which received this treatment was of similar quality to that irrigated frequently (weekly) and with a total seasonal application of 830 mm and no nitrogen fertilizer. Furthermore, there was no marked increase in dry matter production (Table 37), so that this treatment provided a considerable saving in water and labor. The addition of nitrogen at frequent intervals during the season improved lawn appearance, without causing excessive growth as long as irrigation was not applied too often.

Table 37. Effect of irrigation frequency and nitrogen level on dry matter yield of kikuyugrass during the period June 1 – October 31

Irrigation frequency (days)	No. of irrigations	Net water application (mm)	Dry matter yield (kg/24 m^2)		
			N_0	N_1	N_2
30	5	329	0.8	1.6	2.2
25	6	383	1.0	2.1	3.7
21	7	478	1.8	2.1	4.3
14	11	600	0.8	3.9	5.2
7	. 20	802	1.9	3.8	5.9

2. *Methods for determining lawn quality*

There was a significant correlation between visual grading and objective measurement of lawn quality. Fig. 21 shows the relation between judging, light reflection and plant density. As density increased and the amount of reflected light decreased (i.e. a greater chlorophyll concentration), a higher score was given to the lawn.

3. *Evapotranspiration (E_t) and Class A pan evaporation (E_0)*

The consumptive use from the 0-120 cm soil layer was less than 3 mm/day during the entire season for the infrequently irrigated plots

(Fig. 22), while for wet treatments (weekly irrigation), consumptive use was somewhat higher and reached a peak of 6.1 mm/day in July.

Between July and September, the consumptive use of lawngrass irrigated every 21 days and fertilized monthly with 20 kg ammonium sulfate/1000 m^2 was 0.62 of the evaporation from a Class A pan.

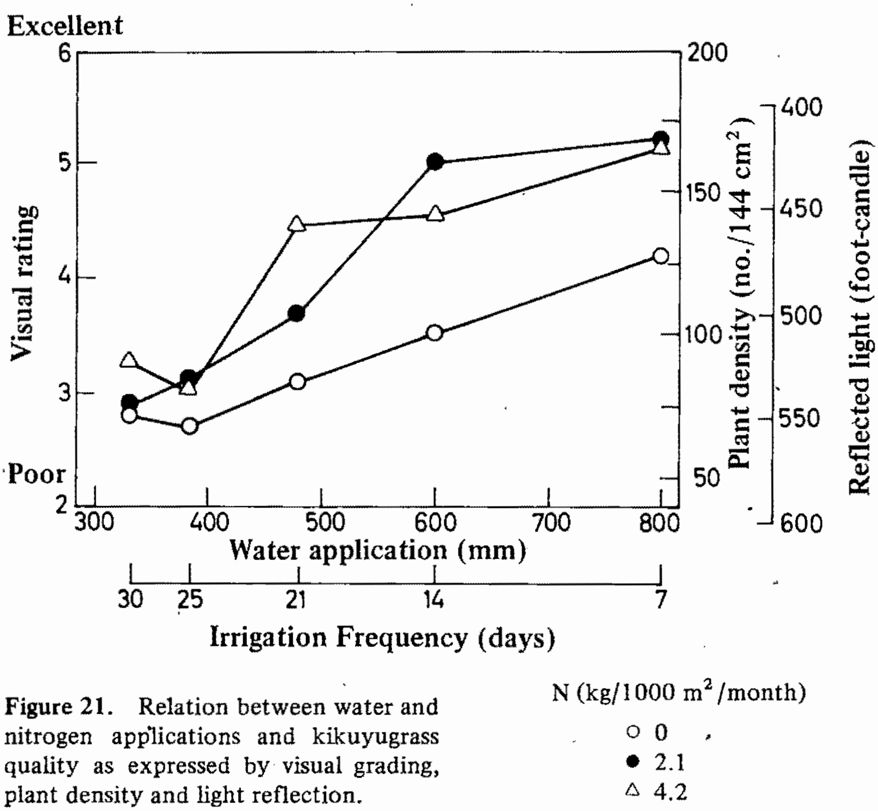


Figure 21. Relation between water and nitrogen applications and kikuyugrass quality as expressed by visual grading, plant density and light reflection.

Table 38. Water uptake by kikuyugrass (expressed as a percent of the total water removed) from the various soil depths

Soil layer (cm)	Irrigation frequency (days)		
	30	21	7
0- 30	26	25	44
30- 60	28	32	27
60- 90	30	24	15
90-120	16	19	14

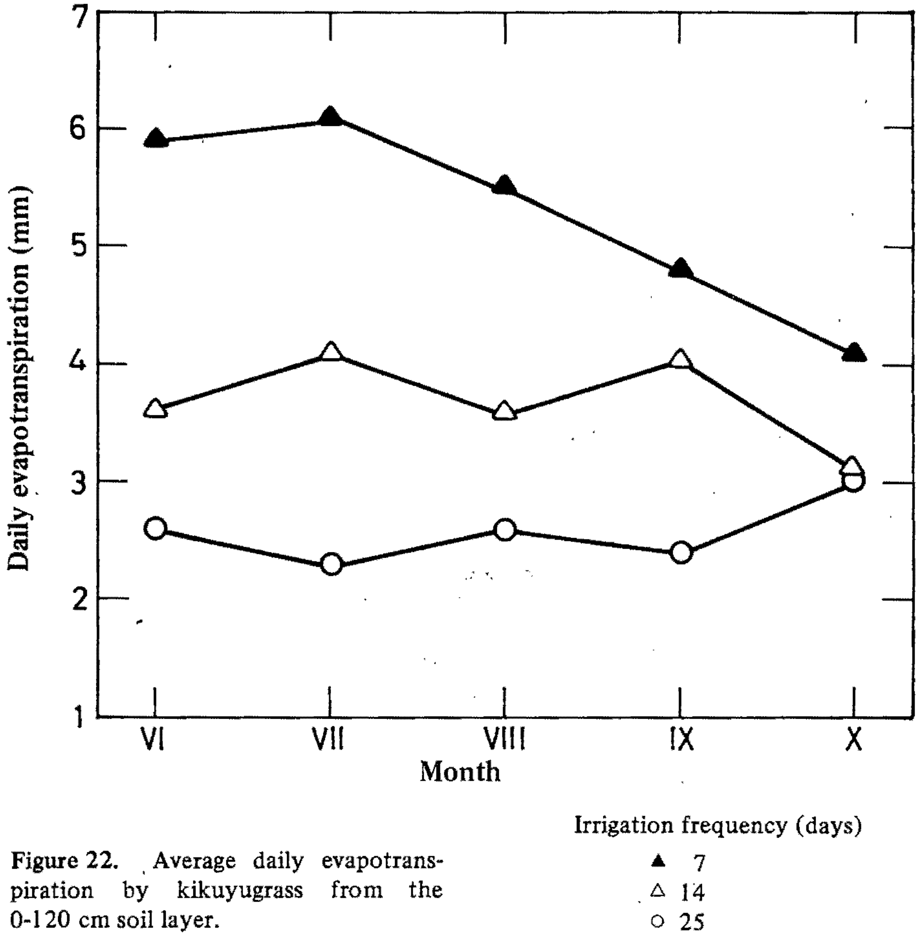


Figure 22. Average daily evapotranspiration by kikuyugrass from the 0-120 cm soil layer.

4. *Water uptake with depth*

About 60% of the total water use was extracted from the 0-60 cm soil layer, and over 80% from the 0-90 cm layer (Table 38).

Publications

1. Mantell, A. and Stanhill, G. (1962) Effect of irrigation frequency and nitrogen fertilization on lawngrass in the Central Coastal Plain. *Natnl. and Univ. Inst. of Agric. Prelim. Rept.* **379** (Hebrew with English summary)

2. Mantell, A. and Stanhill, G. (1963) Effect of irrigation frequency and nitrogen fertilization on lawngrass. *Gan Vanof* **18**:447-449 (Hebrew)

3. Mantell, A. (1966) Effect of irrigation frequency and nitrogen fertilization on growth and water use of a kikuyugrass lawn (*Pennisetum clandestinum* Hochst.). *Agron. J.* **58**:559-561

4. Mantell, A. and Stanhill, G. (1966) Comparison of methods for evaluating the response of lawngrass to irrigation and nitrogen treatments. *Agron. J.* **58**:465-468.

Greenhouse roses

Roses (*Rosa hybrid*) are one of the most extensively grown flower crops today. In many regions, they are grown in greenhouses for marketing during the winter season. The rose production unit is expensive, and the financial and labor input per unit area is extremely high. Consequently, the water requirement factor is only of secondary importance. On the other hand, maintenance of a proper irrigation program is of great importance in order to help guarantee a maximum yield of high quality. Any marked increase in yield and quality is liable to be economically significant for a crop of this type.

Experiments conducted in the Central Coastal Plain from 1969 to 1972 tested the effects of various irrigation regimes and growing media on yield and quality of Baccara roses.[1] The purpose was to reduce, as much as possible, conditions of plant water stress and to examine the effects of such stress on yield. In addition, the following possibilities of reducing plant water stress were investigated: a. Reduced soil water tension through more frequent irrigation; b. Increased air humidity by means of a pad and fan system; c. Direct wetting of the plant foliage by low-intensity sprinkling (using sprinklers with a discharge of about 30 ml/m^2/min). The atmospheric conditions were controlled in different greenhouses, and in each one three irrigation regimes were tested based on preirrigation soil moisture tension.

Results and conclusions

1. *Growing media, water tension and yields*

The maximum flower yield of 150-185 flowers/m^2 was obtained with a growing media consisting of sandy loam soil in which the water tension never exceeded 5 cb. An increase in tension to 10 cb significantly reduced the number of flowers (Fig. 23). Subsequent studies at the same and other locations also indicated a reduction of about 10% in flower yield when the soil water tension rose to 10-20 cb between irrigations. In order to achieve such a response to low soil moisture

[1] Z. Plaut, principal investigator; N. Zieslin, coinvestigator.

tension, it is necessary that the soil be well-drained; in separated growing media, where drainage was prevented and aeration poor, low tension markedly reduced yields compared with those obtained with higher tensions (Fig. 23). Also, with an inert medium, such as volcanic tuff, there was a clear yield response to reduction of the interval between irrigations. Maximum yield was achieved when irrigations were applied at least every 12 hours. Less frequent water applications resulted in a marked yield reduction (Fig. 24). The most outstanding response to irrigation regimes occurred at the end of the winter and in the spring. This finding is of considerable practical importance in light of the efforts to extend the rose marketing season to include the spring months.

Flower quality was not affected by irrigation regimes in the optimum growing medium. However, in the tuff medium there was a marked decrease in flower quality as the intervals between irrigations were increased.

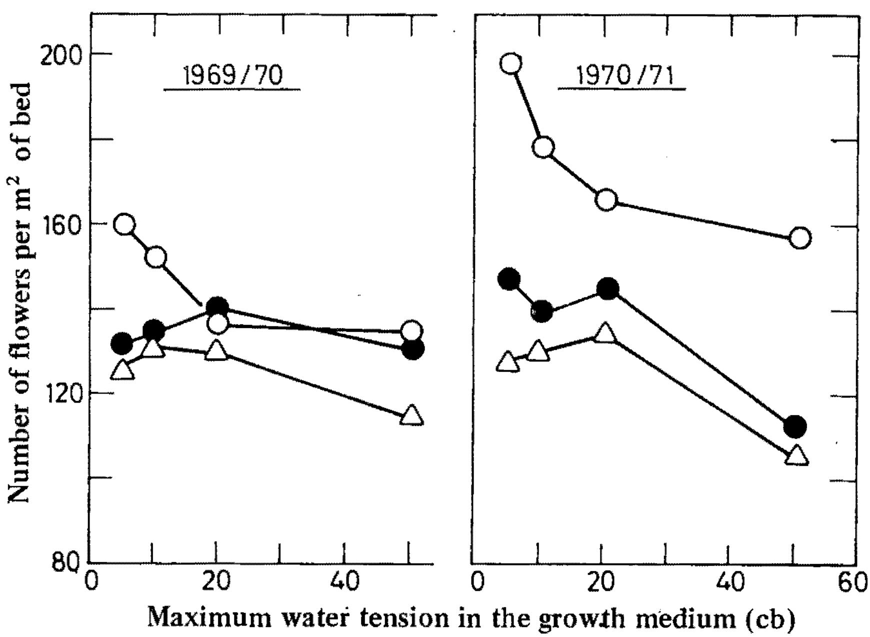


Figure 23. Relation between maximum soil water tension and flower yield of Baccara roses growing in different media 35 cm deep.

○ Sandy loam on local soil
● Separated sandy loam
△ Separated sandy loam + peat (1:1)

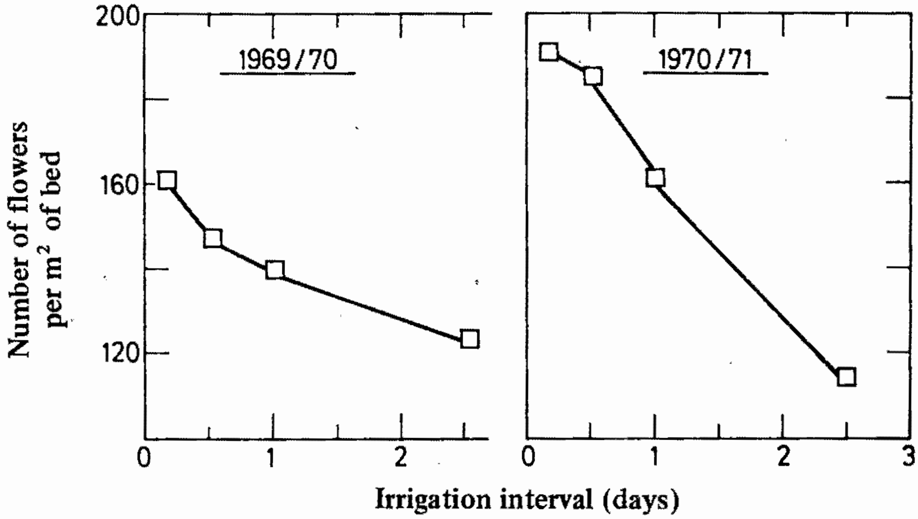


Figure 24. Relation between irrigation frequency and flower yield of Baccara roses growing in separated volcanic tuff 35 cm deep.

Table 39. Effects of irrigation regime and foliage wetting on yield of Baccara roses (no. of flowers/m^2)

Foliage wetting treatment	Total no. of flowers Max. soil water tension (cb)			No. of marketable flowers Max. soil water tension (cb)		
	3-4	5-8	10-15	3-4	5-8	10-15
No wetting	387	391	364	288	293	280
Wetting for 1 minute, every 10 minutes	381	379	352	282	284	263
Wetting for 1 minute, every 5 minutes	354	353	318	253	252	237
Standard error:						
Between irrigation regimes		6.8			5.0	
Between wetting treatments		7.9			6.1	

2. *Air humidity, foliage wetting and yields*

Maintaining a water tension below 5-8 cb in a sandy loam medium separated from the local soil did not affect flower number (Table 39).

On the other hand, a further increase in tension resulted in a marked yield reduction. Wetting the foliage, which increased the plant water potential, distinctly reduced the number of flowers. This decrease was independent of the irrigation regime. The pad and fan system did not produce clear results concerning the effect of climatic conditions on flower yield.

Publications

1. Plaut, Z. and Zieslin, N. (1974) Effect of soil moisture regimes and wetting of plant foliage on Baccara roses. *Agric. Res. Org. Bet Dagan, Prelim. Rept.* 733:63–78 (Hebrew)

2. Plaut, Z. and Zieslin, N. (1974) Productivity of greenhouse roses following changes in soil moisture and soil air regimes. *Scientia Hort.* 2:137-143

3. Plaut, Z., Zieslin, N. and Arnon, I. (1973) The influence of moisture regime on greenhouse rose production in various growth media. *Scientia Hort.* 1:239-250

Poplar

The poplar (*Populus* sp.), a perennial wood crop, is grown commercially over a wide range of ecological conditions throughout the temperate zones of North America, Europe and Asia. It can be grown conveniently in conjunction with agricultural crops, which explains its popularity. It has a very rapid growth rate (1.5-2.5 $m^3/1000\ m^2$/year) and a high yield of wood harvested 20-25 years after planting. The tree is usually propagated vegetatively, although there is also cross-pollination. Consequently, many types and varieties are known.

The poplar requires high light intensity, good physical soil conditions and favorable soil moisture in order to yield commercially. It is therefore usually grown in regions of high rainfall, river flood plains or in the presence of a high water table. In the Mediterranean region it is generally grown in densely planted plantations (50 x 150 cm) with some supplementary irrigation by flooding.

The following results are based on an experiment conducted in the Central Coastal Plain over a period of four years (1960-1963).[1] The soil ranged from sandy loam to loam (field capacity = 13-17%). The trees were planted in 1960 and growth was determined once a year. There were four treatments with four replications. Irrigation was by sprinkler. Two varieties were studied: *P. deltoides* and its hybrid *P. x Euro-americana I-214.*

Results and conclusions

1. *Water application and yields*

The variety I-214 had a more vigorous growth and a better response to moisture than *P. deltoides* (Table 40). The best irrigation regime, for both varieties, was at two-week intervals (irrigation at 2/3 available soil water) with a total yearly water application of 1350 mm in addition to 600 mm rain. More or less water resulted in a decrease in yield and water use efficiency. The growth rate under these conditions during the

[1] E. Rawitz, principal investigator; R. Karshon and K. Mitrani, coinvestigators.

fourth year of growth was 3.0 and 2.4 $m^3/1000\ m^2$/year for I-214 and *P. deltoides*, respectively (Fig. 25).

Table 40. Yield and specific yield of two poplar clones in 1963

Irrigation interval (weeks)	Gross water application (mm)	Wood volume ($m^3/1000\ m^2$)		Specific yield ($m^3/1000$ mm)		Preirrigation soil water content (% by wt.)
		I-214	P.del	I-214	P.del	
1	1530	5.05	3.77	1.77	1.51	10.6
2	1350	4.68	3.71	2.09	1.75	11.0
3	920	3.60	2.79	2.04	1.76	7.5
4	720	2.63	1.28	1.95	1.14	6.6

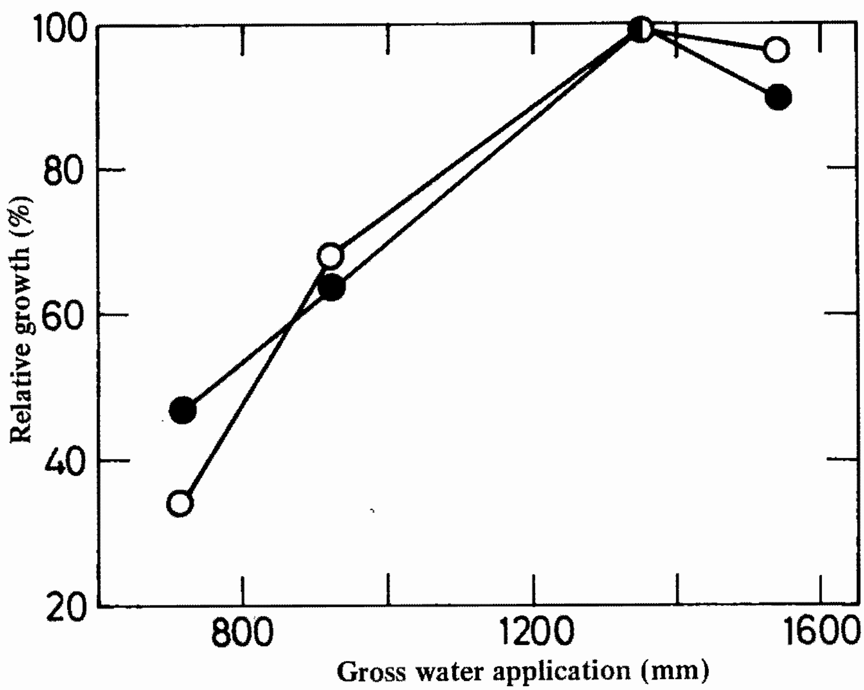


Figure 25. Relative annual increase in wood yield of two poplar varieties in relation to gross water application.

2. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

The E_t/E_o ratio was approximately 1.0 in the optimal irrigation regime, mean for the last year of measurement. Thus, E_t was equal to the potential evaporation (E_o).

3. *Water uptake with depth*

Water uptake was quite uniform with depth, being 32%, 25%, 26% and 17% from consecutive 30 cm increments to a depth of 120 cm. This indicates a very uniform root distribution with soil depth.

Publications

1. Rawitz, E., Karshon, R. and Mitrani, K. (1966) Growth and consumptive use of two poplar clones under different irrigation regimes. *Isr. J. Agric. Res.* **16**:77-78

Sisal

Sisal (*Agave sisilana*) is a perennial xerophyte whose large, hard, succulent leaves are used for their rough fibers, which are distributed in bundles under the epidermis. The plant develops 200-240 leaves in its lifetime; thereafter, a flower is developed, the leaves dry up and senesce and the plant dies. Sisal has a very shallow root system – 83% of its roots are found in the upper 30 cm of soil and 90% in the upper 45 cm.

Sisal is a native of Central America (Mexico). It is grown commercially, without irrigation, chiefly in the tropical or subtropical regions (Hawaii, India, East Africa), and is known to be sensitive to over-irrigation and low temperatures. The rate of leaf production and growth is directly related to the mean monthly temperature, a higher growth is obtained during a month with higher temperatures. Consequently, in Israel, 116 leaves are required to produce 1 kg of fiber, compared with only 47 leaves in East Africa (Kenya) with its high winter temperatures.

The following results were obtained from an irrigation experiment carried out in the Northern Negev on a loessial sierozem soil.[1] The experiment consisted of 16 treatments including winter irrigation only, summer irrigation only, and whole year irrigation. Leaves were harvested once a year, for three years, during July and August; only leaves which formed a 45° angle with the central axis were cut. Irrigation was applied in furrows to wet the soil to 90 cm depth.

Results and conclusions

1. *Yields and water application rates*

Sisal proved to have a very low water requirement. Highest yield may be obtained with 250 mm irrigation water (in addition to 200 mm rain), applied in 2 irrigations, one in June and one in August. (Fig. 26, Table 41). Either more or less water resulted in lower yields. The fiber yield was 0.44 kg per plant per year, or 98 kg/1000 m^2/year (222 plants per 1000 m^2)

[1] M. Achituv, principal investigator; J. Rubin, coinvestigator.

Table 41. Yield and yield components of sisal as affected by irrigation

Number of irrigations and timing	Gross water application[1] (mm)	E_t (mm/year)	Fiber yield (kg/plant/year)	Leaf weight (g)	Fiber weight (g/leaf)	Water use efficiency (g fiber/mm)
0	0	184	0.27	306	11	–
1 (July)	162	215	0.32	394	13	1.60
2 (June, Aug.)	252	374	0.44	443	16	1.45
8 (D, J, M, M, J, J, A, S)	584	379	0.33	408	13	0.48

[1] In addition to 200 mm rain.

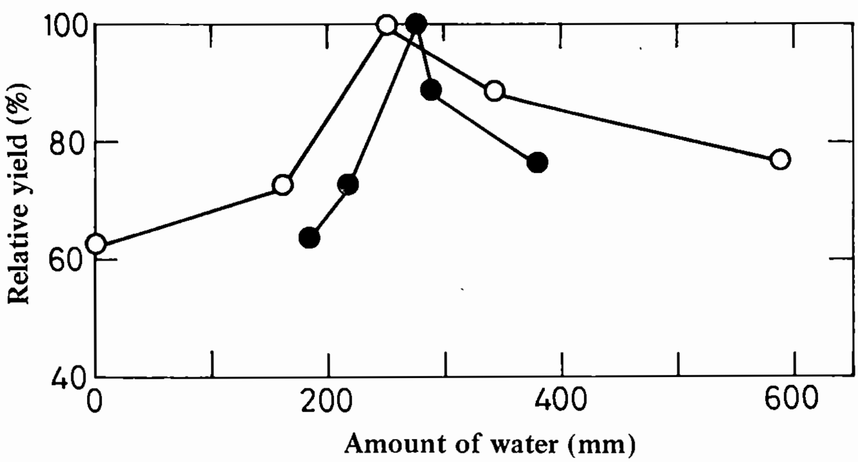


Figure 26. Relation between relative sisal fiber yield and gross water application.

● Gross water application
○ Evapotranspiration

2. *Evapotranspiration (E_t) and Class A pan evaporation (E_o)*

For the optimum irrigation timing the maximum daily E_t was 1.2 mm during the month immediately following an irrigation. The rate of E_t during the rest of the summer was 0.7 mm/day (Fig. 27), while during the winter it dropped to 0.4 mm/day. E_t/E_o was 0.22, the lowest of all agricultural crops (Fig. 28).

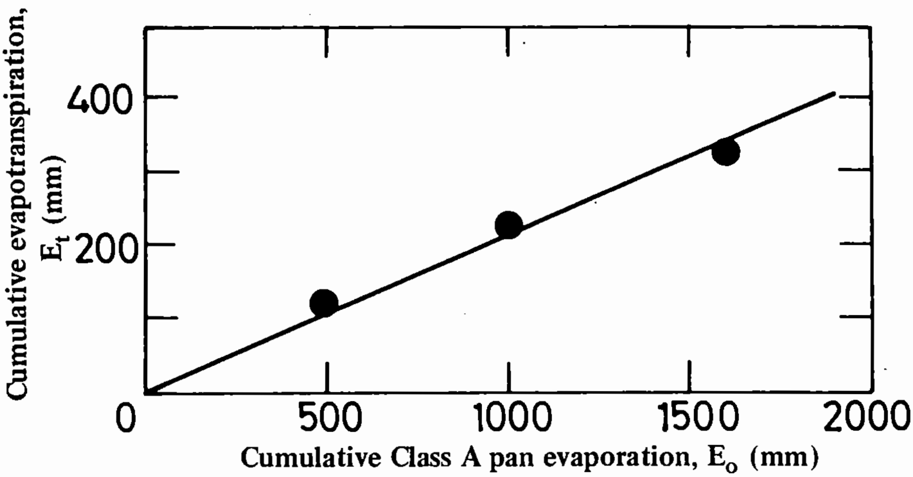


Figure 27. Relation between evapotranspiration (E_t) and Class A pan evaporation (E_o) for sisal.

$$E_t = 0.22\,E_o$$

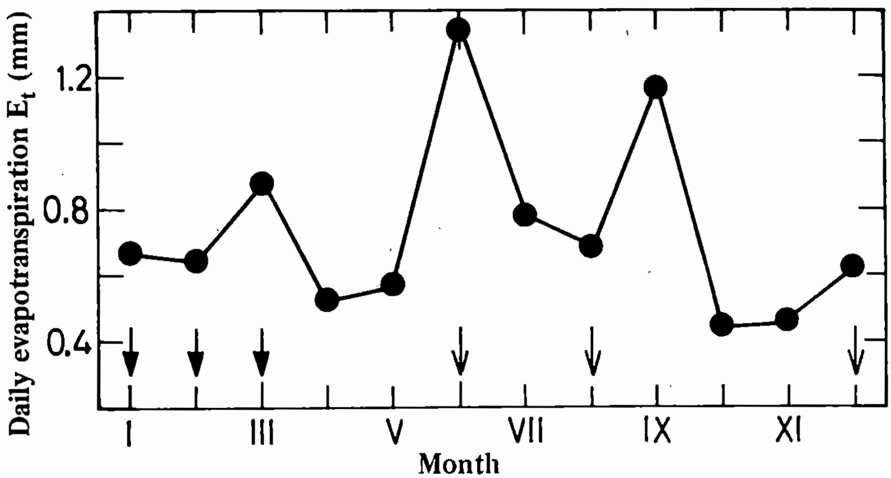


Figure 28. Average daily evapotranspiration (E_t) by sisal.

↓ Rain
↓ Irrigation

3. *Fiber quality*

Irrigation has no effect on yield quality as reflected in fiber strength and micronaire (Table 42).

Table 42. Fiber quality under various irrigation regimes

Number of irrigations	Fiber content (% by weight)	Fiber length (cm)	Fiber thickness (mg/cm)	Fiber strength (kg/mm^2)
0	3.4	66.7	249	7000
1	3.3	62.5	246	7800
2	3.6	64.0	263	8000
8	3.3	62.0	279	7500

Publications

1. Achituv, Miriam and Rubin, J. (1967) The effect of different irrigation treatments on the water requirements, growth and yields of *Agave* plants in the Northern Negev of Israel. *Volcani Inst. Agric. Res. Pamphlet.* **118** (Hebrew, with English summary)

SUMMARY AND CONCLUSIONS

The irrigation requirements of the various crops, together with the irrigation intervals, number of irrigations to be applied seasonally and the expected optimum yields, are summarized in the following table. A few general conclusions may be drawn from the data:

1. For most crops, there is a linear relationship between the relative yield and the amount of water applied in irrigation. This relationship is valid up to a yield of 95% of the maximum yields obtained in the field experiments. At this yield level and water application rate characteristic of each crop, the yield flattens off sharply, indicating a factor other than water limiting further yield increases. Removing such a limiting factor, genetic, cultural or otherwise, might result in a response to higher levels of water application.

2. The regional climate is the predominant factor determining both yield and water requirements. The warmer and drier the climate (the further away from the coast), the lower the yield and the higher the water requirements. Obviously, water use efficiency decreases as the temperature increases and the relative humidity decreases.

3. The yields obtained for summer crops under dryland conditions depend largely on the summer potential evapotranspiration and the amount of winter precipitation.

4. The largest yield increase per unit irrigation water applied was for the grain crops sorghum (1.72 kg/mm) and wheat (1.23 kg/mm) and the least for peanuts (0.65 kg/mm) and cotton (0.24 kg/mm).

The information summarized above was obtained from carefully conducted field experiments in a semi-arid region of winter rains and moderately high summer temperatures. This must be borne in mind when applying the findings to other cultural and climatic conditions. In cases where the net water application is reported, a sufficient amount of water must be added to account for inefficiencies in application and for leaching, where required.

The Class A pan evaporation (E_o) data given for all regions on a monthly basis may be used as a rough guide of applicability. It is likely that regions with similar E_o and rainfall distribution will have similar irrigation requirements and yield response functions. For regions with different climatic conditions, adjustments may be made in the total irrigation requirements on the basis of the differences in E_o.

Summary Table. Irrigation requirements, number of irrigations, irrigation interval and expected yields of field and orchard crops

Crop	Region	Irrigation requirements[1] (mm)	Seasonal irrigations (no.)	Irrigation interval (days)	Expected yield[2] (kg/1000 m^2)
Wheat	Northern Negev & Lakhish	400-450	2		540
	Bet Shean Valley & Jordan Rift	500-550	2		500
Sorghum	Coastal Plain	250-280	2		990
	Northern Negev	380-420	3		780
Corn (grain)	Coastal Plain	330-350	4-6	10-14	850
	Northern Negev & Jezreel Valley	450-480	4-6	10-14	680
Cotton (lint)	Coastal Plain & Upper Galilee	330-360	3	21	176
	Northern Negev & Eastern Jezreel Valley	510-540	4-6	14-21	165
	Bet Shean Valley	780-810	6-7	14-18	170
Sugar beets V[3]	All regions	70-120	0-1	21-30	1080
VI	All regions	120-200	1-2	21-30	1120
VII	All regions	180-250	2-3	21-30	1170
Peanuts	Coastal Plain	530-560	5-6	18-21	510
	Northern Negev	530-560	7-8	12-14	460
Alfalfa (dry matter)	Coastal Plain & Upper Galilee	650-680	1-2 between cuttings		2000
Tomato (Processing)	Coastal Plain	220-240	2-3	12-24	5500
	Northern Negev & Lakhish	410-430	7-8	7	6470

Summary Table (continued)

Crop	Region	Irrigation requirements[1] (mm)	Seasonal irrigations (no.)	Irrigation interval (days)	Expected yield[2] (kg/1000 m²)
Citrus: Shamouti on sour orange	Coastal Plain	600-660	8-10	20-25	4750
Shamouti on sweet lime	Coastal Plain	500-570	8-10	20-25	6300
Grapefruit on sour orange	Northern Coastal Plain	560-600	6-7	20-25	5400
	Western Jezreel Valley	650-700	8-10	20-25	4940
	Northern Negev & Eastern Jezreel Valley	800-860	8-10	20-25	7450
Avocado: Fuerte	Coastal Plain	700-750	10-12	14-21	1370
Haas	Coastal Plain	750-800	10-12	14-21	2250
Apples: Grand Alexander	Upper Galilee	760	12	10-14	11800
Banana	Coastal Plain	1120	30	5-7	5500

[1] Net water application for field crops, gross water application for tomato, alfalfa and orchard crops. Values for wheat include rainfall.
[2] 95% of the maximum yield.
[3] V, VI, VII are May, June, July harvests.

APPENDIX

The experimental results analyzed and reported in this publication were obtained in a relatively small geographical area. The publication of the results in the 1976 edition of this book aroused worldwide interest. Consequently, there was a need to assess the possibility of applying the data obtained to other areas.

Israel, though small in size, is endowed with a diverse climate. For certain crops, irrigation experiments were conducted in a few ecological regions. The data for these crops have been re-examined and published in an article in *Soil Science*, **125** (4), 1978. This article is reproduced below.

Data for cotton, sorghum, and grapefruit in various ecological regions are normalized on the basis of Class **A** pan evaporation. It is shown that climatic variability is taken into account by applying the ratio of net water application to pan evaporation. Thus, the information from Israel can in fact be applied to other regions.

Introduction*

As the need for accelerated food production becomes more acute, irrigation as a means of increasing crop yields acquires a more crucial role in the development of arid as well as humid regions. Irrigation projects in many parts of the world have amply demonstrated the contribution of increased water supply to agricultural productivity. It is difficult to picture the agricultural development, or indeed the general economic development, of Israel without irrigation on a large scale. This is true for other regions as well. Nevertheless, some important irrigation projects have failed to measure up to expectation, in the sense that productivity did not increase sufficiently to justify the investment made. The failure was in no small measure due to the lack of reliable information regarding the water requirements of the crops for optimum production. With the increasing scarcity of water resources, there is a greater need

* Originally published as "Crop Water Requirement in Relation to Climate and Soil" by J. Shalhevet and H. Bielorai in *Soil Science*, **125**(4), 240–247, 1978. Reproduced by permission of The Williams & Wilkins Co.

for better irrigation efficiency and, hence, for more reliable information on consumptive use.

Early in the development of the State of Israel, when it was recognized that the potential water resources would not be sufficient to meet all potential needs, a commitment was made to achieve a high water use efficiency. In 1954 an ambitious research program was initiated to obtain water production functions for all important crops, and to develop a sound irrigation technology. Concurrently, an extension service was developed, and water distribution throughout the country was based on a pressurized grid and sprinkler irrigation. By 1974 about 90 field experiments on 17 crops had been conducted throughout the country; many of them were repeated for a few years. The information obtained was used by water allocation authorities, extension service workers, and farmers in their irrigation activities, and was summarized in the 1976 edition of this book. The summary covered the following crops: wheat, sorghum, corn, cotton, sugarbeet, peanuts, alfalfa, tomatoes, citrus, avocado, apples, bananas, lawngrass, greenhouse roses, poplar, and sisal. For each crop, information was presented for each climatic region separately, and for all soils together, on crop production function (yield vs. water application), optimum irrigation frequencies, water uptake distribution within the root zone, and the daily evaporation rates for the optimum treatment.

The regional results are very useful for designing local irrigation systems and scheduling irrigation. Nevertheless, substantial technological and financial effort, as well as time, are required to accumulate the information for each region. For example, it took a total of about 50 research-worker-years and about $600,000 in 1977 prices to obtain the information on the three crops reported here. The data would be of much greater value and have a much more substantial impact if their usefulness could be extended beyond the restricted region in which they were obtained. This is all the more important because good production function data are lacking at present in most of the irrigated regions of the world, and will not be easily available in the near future.

In the following we shall attempt to analyze the effect of climate and soil on the water requirement of three crops – cotton, sorghum, and grapefruit – for which sufficient data were available from a few regions and soils. The data were obtained from a number of publications (Amir and Bielorai 1966; Amir and Bielorai 1969; Bielorai and Shimshi 1963; Bielorai et al. 1964; Bielorai, Levy, and Shalhevet 1973; Bielorai et al. 1965–74; Bresler et al. 1965a,b; Bresler et al. 1966; Kalmar et al. 1971; Marani and Amirav 1971a,b; Plaut and Shmueli 1966; Plaut, Blum, and Arnon 1969).

Materials and methods

The analysis presented is based on 20 field experiments – 12 with cotton, 4 with sorghum, and 4 with grapefruit – which were conducted during the period 1958–1974. The experiments were located in different climatic regions of Israel; site characteristics are given in Appendix Table 1. Most of the experiments were conducted according to a more or less standard procedure. Each experiment included four to eight treatments with five to six replications. The grapefruit experiments included one main experiment and three auxiliary, smaller experiments (three treatments with three replications). In most of the experiments, the sprinkler irrigation method was used (under-canopy sprinklers in the orchards). Furrow irrigation was used in the early cotton experiments.

Plot dimensions for the annual crops were defined by four sprinklers placed at its corners at a setting of 12 x 12 m. An additional 12-m swath was left on each side as borders, so that total plot size was 24 x 24 m. Consequently, the area required for an experiment was four times the net area of the plot itself. Typically, for a five-treatment, five-replicate experiment, 1.44 ha of land was required, only 0.36 ha of which was used for crop response analysis. The grapefruit plots included 16 trees, the center 4 of which were used for yield analysis.

Soil water content was determined before and after each irrigation, by gravimetric sampling until 1963, and by the neutron moderation method thereafter, at 30-cm intervals to the depth of rooting. Water "constants" (field capacity and wilting percentage), as well as soil bulk density and infiltration capacity, were determined for each experiment's soil. The quantity of water to be applied at each irrigation was determined from the difference between the preirrigation moisture content and field capacity. The total depth of evapotranspiration (E_t) was determined by linearly extrapolating the time vs. soil water content curve to the day of irrigation for each irrigation. No account was taken of slow-deep drainage, which could have taken place between irrigations. In most cases this component should have been small, since irrigation was applied to less than full rooting depth. Nevertheless, especially with the wet treatments, it must be recognized that a drainage component of unknown magnitude (probably less than 5 percent) is included within the (E_t) term. Residual soil moisture content at the end of the season was also determined. In all experiments the soil was at field capacity to rooting depth at the beginning of the season, either as a result of rainfall or of preirrigation.

Appendix Table 1. Location, description, and climatic characteristics of the various experimental sites

Location	Coordinates		Mean daily air temperature, °C			Mean daily relative humidity	Mean annual rainfall,
	Long. °'E	Lat. °'N	April	Aug.	Dec.	Aug., %	mm
Bet She'an Valley	35°30'	32°29'	20.4	30.4	15.4	49	270
Eastern Yizre'el Valley	35°17'	32°36'	18.3	27.6	14.6	59	440
Western Yizre'el Valley	35°12'	32°43'	17.8	26.9	15.0	63	580
Western Galilee	35°06'	35°26'	17.3	26.4	15.4	69	630
Northern Coastal Plain	34°57'	32°27'	17.6	26.0	15.1	67	560
Central Coastal Plain	34°49'	31°56'	17.4	25.6	14.5	67	535
Southern Coastal Plain	34°32'	31°29'	17.6	25.1	13.0	67	360
Northern Negev	34°39'	31°19'	18.6	26.8	14.8	60	240

Evaporation (E_0) was determined from a U.S. Weather Bureau Class A evaporation pan protected by a standard screen of the Israel Meteorological Service located in the vicinity of each of the experiments. The E_t/E_0 ratios in this work were calculated from the total season evapotranspiration, from seeding to harvest, and the cumulative pan evaporation during the corresponding period. For grapefruit the period was from the first to the last irrigation. The E_t/E_0 values should not be confused with the irrigation period ratios used for calculating irrigation needs from Class A pan evaporation (Fuchs and Stanhill 1963).

The seeding date for cotton and sorghum was mid-April in all experiments. The grapefruit trees were over five years old. Yield and yield characteristics were determined at the end of each experimental year.

Results and discussion

In the initial analysis (1976 edition of this book) the linear regression of relative yield (Y) was determined in relation to net water application (D_i) for each of the climatic regions independently. The results are presented in Appendix Table 2. Relative yield (y/y_m) was used to allow the presentation of data from different years on a common basis. The highest yield (y_m) obtained in each year of an experiment was taken as

Appendix Table 2. Parameters for the linear regression equation of relative yield (Y) of cotton lint, sorghum grain, and grapefruit as a function of the amount of irrigation water applied (D_i), ($Y = a + bD_i$)

Crop	Location	Regression coefficient, b, %/cm	Intercept a, %	Correlation coefficient, r	Maximum yield, t/ha
Cotton	Bet She'an Valley	1.03	9.1	0.948	1.79
	Eastern Yizre'el Valley and Northern Negev	1.38	21.4	0.942	1.73
	Coastal Plain	1.50	43.1	0.946	1.85
Sorghum	Northern Negev	2.02	18.0	0.957	8.25
	Coastal Plain	1.69	45.9	0.907	10.44
Grapefruit	Eastern Yizre'el Valley and Northern Negev	0.634	40.8	0.868	78.6
	Western Yizre'el Valley	1.31	6.8	0.995[1]	52.0
	Western Galilee	0.326	76.4	0.543	53.0

[1] Four data points only.

100 percent for that experiment and year; it was usually high in comparison with accepted average yields (see Appendix Table 2). The values of y were the yields of each treatment.

Through the use of the linear regressions given in Appendix Table 2, it is possible to determine the net water requirements for maximum yields for each of the regions. The linearity of the relationship simplifies the calculation of the marginal return of water or the mean water use efficiency (the slope of the line). From the intercept on the yield axis, the yield under dryland farming for each region may be obtained. Accordingly, for cotton, for example, the water requirement for optimum yields (about 95 percent of the maximum) was 35 cm for the cool Coastal Plain, 53 cm for the warm northern Negev, and 80 cm for the hot Bet She'an Valley (Appendix Table 3). The yield without irrigation decreased from 800 kg/ha in the coastal region to 370 and 160 kg/ha in the northern Negev, and the Bet She'an Valley, respectively. The trend in sorghum was similar (Appendix Table 2).

The water distribution in orchards irrigated by under-canopy sprinklers was very nonuniform. This is of little consequence as far as yield response is concerned, as long as each tree receives the required amount of water somewhere in its root zone. For example, the yield of trees irrigated every alternate row was not less than that of those irrigated every row, but the water use efficiency of the former was considerably higher (Heller, Shalhevet, and Goell 1973). On the other hand, the nonuniform distribution makes it difficult to obtain good evapotranspiration and irrigation efficiency data. In some of the experiments reported here, the measured irrigation efficiencies exceeded 100 percent. Therefore, the data on grapefruit are reported in terms of gross rather than net water application.

Various factors, such as experimental technique, varietal differences, cultural practices, and human error, may limit the transferability of experimental information from one location to another. The most important element, however, is the difference in environmental factors, namely, climate and soil. It was thus of interest to normalize the data obtained from the various climatic regions of Israel on the basis of a single climatic variable.

Stanhill (1961) has shown that under Israeli conditions there is a constant relationship between Class A pan evaporation (E_0) and crop evapotranspiration (E_t). The relationship was as accurate as estimates obtained by Penman's method. He concluded that estimates of potential evapotranspiration estimated from Class A pan measurements are

Appendix Table 3. Number of irrigations, irrigation interval, and optimum water requirement for three crops

Crop	Location	No. of irrigations	Irrigation interval, days from seeding						Water requirement, cm
Cotton	Bet She'an Valley	6	63	81	98	118	135	150	78–91
	Eastern Yizre'el Valley and Northern Negev	5	64	80	98	112	130		51–54
	Coastal Plain	3	71	94	110				33–36
Sorghum	Northern Negev	4	38	57	73	87			38–42
	Southern Coastal Plain	3	52	73	91				
	Central Coastal Plain	2	43	82					25–29
Grapefruit	Eastern Yizre'el Valley and Northern Negev	9–12	every 21–24 days						80–86
	Western Yizre'el Valley	8	every 24 days						65–70
	Western Galilee	6–7	every 28 days						56–60

the most practical, accurate, and economical to obtain. Since Class A pan data were available from all experimental locations, the ratios of total seasonal (E_t) to total seasonal E_o, (E_t/E_o) were plotted against relative yield (Y) for the three crops (Appendix Fig. 1).

The best fit linear regression equations for the three crops were:

cotton

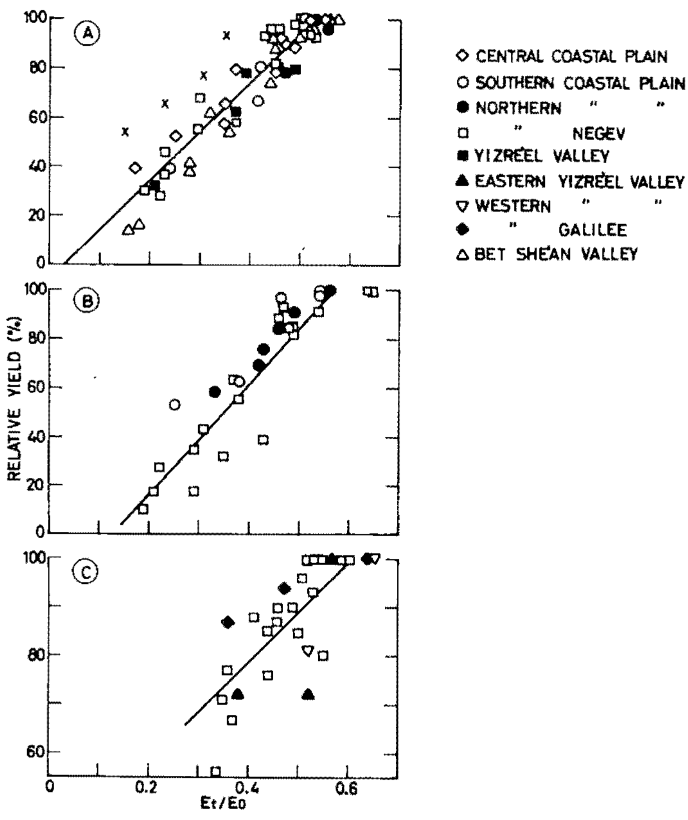
$$Y = -6.0 + 199.2\,(E_t/E_o) \qquad r = 0.944$$

sorghum:

$$Y = -29.3 + 227.2\,(E_t/E_o) \qquad r = 0.937$$

grapefruit:

$$Y = 37.7 + 102.2\,(E_t/E_o) \qquad r = 0.730$$



Appendix Figure 1. The relationship of relative yield expressed in percent (Y), to the ratio of seasonal evapotranspiration to seasonal Class A pan evaporation (E_t/E_o) for (A) cotton, (B) sorghum, and (C) grapefruit.

The regression of yield on the normalized evapotranspiration for the various regions together was as good as the regressions of yield on the net water application for each region independently. The correlation coefficients for the field crops are high, and show that about 90 percent of the variability in yield may be explained by differences in potential evapotranspiration and depth of irrigation water. The remaining 10 percent is most likely due to random variability. For citrus, only 50 percent of the variability may be explained by irrigation and climate. The problems of the variability of moisture measurements in orchards were discussed previously. Another contributing factor to the low regression coefficient for grapefruit is the large citrus yield variability from year to year and from location to location.

The slopes for the two field crops are quite similar – the increase in relative yield is double that of relative transpiration. For citrus there is a unit slope. On the other hand, the intercept values are quite distinct for each crop.

When total dry matter production is plotted against crop transpiration, the line tends to go through the origin (De Wit 1958). On the other hand, when fruit yield is plotted against evapotranspiration, as was done herein, the existence of a positive X-axis intercept may indicate a substantial evaporation component and/or the need for a threshold quantity of water to produce some dry matter, before any marketable yield (seed or fruit) can be produced. The intercept for cotton was very close to zero (0.03), indicating that for this crop most of the evapotranspiration contributed to seed and dry matter production. For sorghum, the intercept was substantial (0.13).

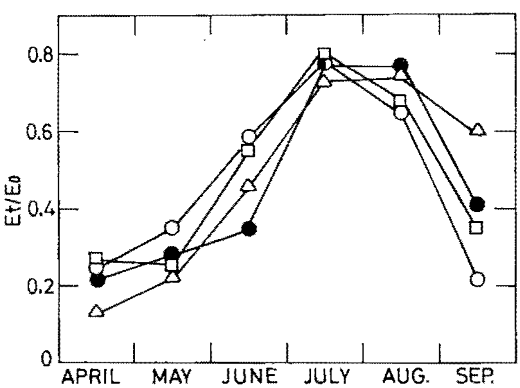
Part of the intercept may be due to evaporation, although normally one would expect less surface evaporation from the faster growing sorghum than for the slower developing cotton (Ritchie and Burnett 1971). Part of the intercept may, however, be attributed to the water requirement for an initial production of dry matter before any grain yield is produced.

With grapefruit, there was a negative X-axis intercept (–0.37), indicating that not all the water used in yield production was taken into account. Indeed, the relationship presented in Appendix Fig. 1C includes only summer irrigation and not winter precipitation, which also contributed to yield production.

The analysis indicates that the results reported for Israel may be used in other regions with similar climatic characteristics (semiarid, with winter rainfall) by accounting for differences in potential evapotranspiration as estimated from Class A pan data. In regions where Class A pan data are not available, other methods of estimating potential evapotranspiration may be used. It should be borne in mind, however, that the results are based on optimum cultural practices as followed in Israel. With sub-optimum fertilization, for example, the relationship of relative yield to evapotranspiration may be different (Shimshi 1967).

For irrigation design and scheduling, it is not sufficient to know the total seasonal consumptive use. Information on weekly evapotranspiration, as well as a reasonable estimate of the optimum irrigation interval, are also necessary. In addition, some crops have a specific sensitivity to water stress at some stage of growth. For example, in Appendix Fig. 1A we have plotted four points (marked with an X) from an irrigation experiment designed to test specific sensitivities (Marani and Amirav 1971a). These points come from relatively dry treatments with one or two early irrigations; there seems to be a somewhat better water use efficiency with these than with the other treatments.

An example of the monthly E_t/E_o ratios for the optimum treatment of cotton in the various regions is given in Appendix Fig. 2. A larger variability than with the seasonal values is apparent, especially toward the season's end where, in the Bet She'an Valley, the season is extended until mid-November for a second flowering period. In addition, the monthly values depend on specific irrigation timing in the optimum treatment, and this might have been different in the different regions. Nevertheless, the reported ratios may provide a rough guide as to the expected monthly distribution, which can be adjusted through local experience and measurements. The peak monthly values range between 0.65 and 0.80, which are higher than the seasonal ratio of 0.53 for maximum



Appendix Figure 2. Monthly relative evapotranspiration (E_t/E_o) of cotton from four regions of Israel.

cotton yield (Appendix Fig. 1A). Fuchs and Stanhill (1963) showed from measurements in many commercial fields in Israel that the mid-season (between June and August) ratio for cotton was 0.69 ± 0.05, and this is the value that should be used to compute irrigation needs. Their results also showed reasonable uniformity of the E_t/E_0 ratio throughout the country.

The optimum irrigation interval depends on two main factors – the evapotranspiration rate and the storage capacity of the soil. Under gravity or portable sprinkler irrigation, it is usually desirable to irrigate as infrequently as possible, as long as crop yield is not adversely affected.

All the experiments on which this analysis is based were designed to determine the smallest frequency for optimum yield. Very high frequencies were never included. The results are reported in Appendix Table 3 and show, for each crop, an increase in the irrigation interval from the inland Bet She'an Valley toward the Coastal Plain. Thus, climate is the overriding factor influencing irrigation interval. Within each region, no differences were found between different soil types.

In Appendix Table 4 we present the field capacity, wilting percentage, and available moisture capacity to a depth of 100 cm of the soils in the various experiments. Despite the fair spread in field capacity values between 25.6 and 47 percent, the differences in available moisture were quite small. This explains the lack of soil effect on irrigation interval. Regrettably, none of the experimental soils was sandy. An average sandy soil would have a water storage capacity of about 11 cm water per 1-m depth, most certainly resulting in a need for more frequent irrigation.

With the recent spread of solid-set irrigation systems (e.g., trickle and center pivot), there is a tendency to reduce the irrigation interval even to the point of daily irrigation. Under such conditions the effect of storage capacity of the soil is of still smaller significance.

Other soil factors of importance in irrigation are the infiltration capacity, hydraulic conductivity, and slope. These factors are important in determining the irrigation efficiency under gravity irrigation. Under sprinkler, and even more so under drip irrigation, the intensity of water application is controlled and is normally lower than the soil infiltration capacity. Runoff is thereby avoided and deep seepage may be avoided by partial root-zone wetting. In most of the experiments reported herein, the soil was wetted at each irrigation to 60–90 cm, when the depth of rooting was 120–180 cm. Consequently, the irrigation efficiencies

Appendix Table 4. Soil moisture characteristics at the various experimental locations

Location	Field capacity	Wilting point	Soil storage capacity (columns 1–2) cm water/100 cm soil	Soil texture
	% by volume			
Bet She'an Valley	38.0	24.1	13.9	Calcareous clay
Eastern Yizre'el Valley	45.0	30.0	15.0	Clay
Western Yizre'el Valley	43.2	27.5	15.7	Clay
Western Galilee	46.8	30.1	16.7	Clay
Northern Coastal Plain	36.4	20.9	15.5	Loam
Central Coastal Plain	33.2	17.0	16.2	Clay
Southern Coastal Plain	32.1	16.8	15.3	Clay loam
Northern Negev	25.6	10.6	15.0	Silt loam

exceeded 85 percent, and depended on irrigation system design factors (spatial distribution), rather than on soil characteristics.

In one instance a strong soil effect was found in relation to citrus response to salinity, but not to irrigation frequency (Shalhevet, Yaron, and Horowitz 1974). The nature of the interaction was such that the finer the texture of the soil, the smaller the salinity effect. Soil also had a strong direct influence on orange yield, where smaller yields were obtained on finer textured soils.

It might be concluded that under normal irrigation conditions in Israel, soil physical characteristics have no influence on either irrigation interval or irrigation efficiency. This does not mean that such effects may not exist elsewhere. Therefore, when the information presented herein is transferred for use under different conditions or with different irrigation methods, all factors should be taken into consideration.

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