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Water Requirements of Avocado in Israel. II*
Influence on Yield, Fruit Growth and Oil Content §

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Abstract

The effect of four different irrigation intervals, 7, 14, 21 and 28 days, on the avocado tree was tested during the years 1968-1974 in the northern coastal plain of Israel. The respective average annual water applications were 8890, 7450, 6680 and 5940 m^3/ha. The cultivars Ettinger, Fuerte and Hass were tested in five replications in randomized blocks.

After 6 years no significant reduction in yield was observed with Ettinger or Fuerte trees irrigated once in 21 or 28 days. With the Hass cultivar the 28-day interval gave lower yields than with the three other intervals tested.

Shortening of irrigation intervals increased the growth rate and size of individual fruits, which may be of economic importance for cv. Hass, where overproduction leads to small fruits unsuitable for export. Shortening of irrigation intervals tended to increase the oil percentage of the fruit, which may advance the harvest date. In view of the equal yields obtained and the predominance of cv. Hass in avocado plantations, it was concluded that the 21-day interval was the optimum irrigation frequency under the experimental conditions.

Introduction

An irrigation experiment on the avocado tree was conducted during 6 years in the northern coastal plain of Israel. The objectives were *(a)* to find soil or plant physiological indicators for ascertaining the water status and *(b)* to determine the best irrigation schedule for achieving highest yields of export quality fruit.

Soil moisture tests showed that most of the water consumed came from the upper 60 cm. When irrigation intervals were increased, the contribution of the uppermost soil layer to the overall water consumption lessened. It was likewise found that decreased irrigation intervals and increased water application rates resulted in increased accumulation of salts and increased growth rate of the tree (Kalmar and Lahav 1977).

Methods

Four irrigation treatments were given, with intervals of 7, 14, 21 and 28 days between irrigations and respective average annual water applications of 8890, 7450, 6680 and 5940 m^3/ha. The detailed layout of the experiment was given previously.

Evaluation of Yields and Fruit Size

The fruits of each tree were counted and weighed.

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Fruit Growth

Experimentation was aimed at establishing parameters for the determination of irrigation timing for avocado plantations. Growth of avocado fruits in 1969-1970 was determined by measuring the distance between two metal discs glued to opposite sides of a fruit. The measuring gauge used was sensitive to changes of 10 μm. Subsequently the data were recorded by means of fruitographs (Fig. 1) which recorded all stages of the daily and seasonal growth and shrinkage of fruits (Lahav and Kalmar 1972; Lahav *et al.* 1975).

Measurements were carried out in the Hass cultivar only (distinguished by small fruits). Fruits of trees irrigated at 7-day intervals were measured and compared with those irrigated at 28-day intervals. During the 6 years of experimentation, the growth pattern of many fruits was studied. The data presented here can be regarded as typical, as the findings recorded were observed repeatedly in other trees, fruits and seasons.

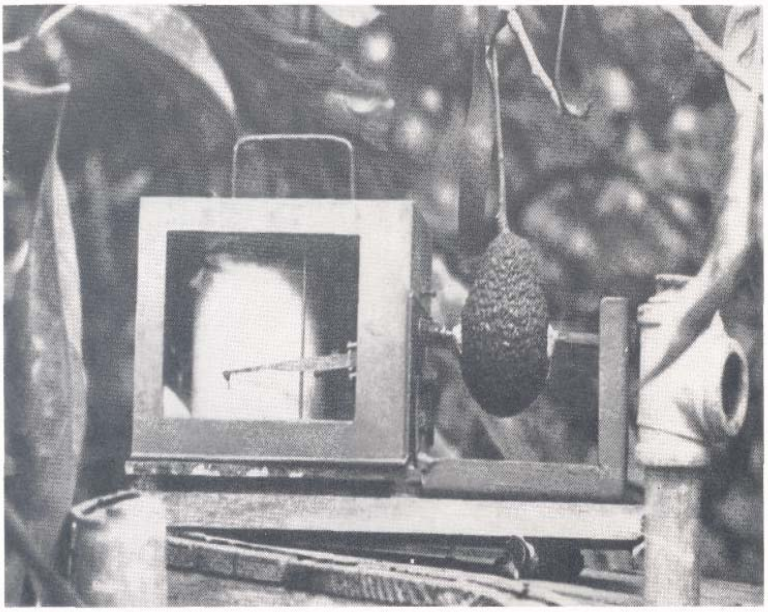


Fig. 1. Measuring growth of avocado fruit diameter by means of a fruitograph.

Significant differences were observed in the growth of fruits between trees in an 'on year' and those in an 'off year'. As problems of fruit size arise principally in years of abundant yields, the results reported here are only for trees of high productivity.

Oil Content

In view of the importance of the oil percentage on harvest date, representative uniform-sized fruits of the Fuerte and Ettinger cultivars were analysed for oil content. Samples comprised five fruits of several sizes from each of the 20 plots, taken at harvest time. Analyses were made by the Halowax method, in which the refractive index is measured (Gazit and Spodheim 1969).

For all parameters regression analyses on the amount of water applied were made, and the deviation from linearity calculated.

Results

Yields and grading

Yields by weight and number of fruits are given in Tables 1 and 2 respectively. The Ettinger and Fuerte cultivars gave satisfactory yields. Yields decreased with increase in irrigation intervals, but only in one case (Ettinger in 1973-74) were significant differences found between treatments. The drop in yield was in most cases expressed only in the weight of the crop and not in the number of fruits, which remained nearly constant over all treatments.

Table 1. Effect of irrigation interval on the average yield of avocado

Each figure is the mean for five plots

Cultivar	Year	Yield (kg/tree) Irrigation interval (days): 7	14	21	28	SE of means	Signif. of linear component	Deviation from linearity
Ettinger	1968–69	10·2	17·6	20·7	18·8	3·5	0·05	NS
	1969–70	19·5	24·4	18·3	16·4	3·8	NS	NS
	1970–71	73·6	73·0	66·5	63·1	5·0	NS	NS
	1971–72	49·8	45·0	45·0	54·0	3·2	NS	NS
	1972–73	53·0	42·9	49·9	47·9	3·4	NS	NS
	1973–74	92·5	79·4	76·7	72·4	4·9	0·01	NS
Av., 1970–71 to 1973–74		67·2	60·1	59·5	59·3	2·6	NS	NS
Av., 6 years		49·8	47·0	46·2	45·4	1·5	NS	NS
Fuerte	1968–69	7·3	4·7	11·3	6·0	2·7	NS	NS
	1969–70	41·9	32·2	30·1	28·6	4·4	NS	NS
	1970–71	52·9	56·9	47·8	46·9	4·9	NS	NS
	1971–72	45·2	37·4	40·4	43·4	2·9	NS	NS
	1972–73	52·7	66·1	61·2	50·4	4·4	NS	NS
	1973–74	50·9	43·6	46·5	50·6	3·2	NS	NS
Av., 1969–70 to 1973–74		48·7	47·2	45·2	44·0	1·6	NS	NS
Av., 6 years		41·8	40·1	39·5	37·6	1·6	NS	NS
Hass	1968–69	41·7	57·2	64·6	58·0	2·7	NS	NS
	1969–70	86·3	77·3	41·1	33·7	4·2	0·01	NS
	1970–71	32·5	64·1	95·0	97·0	5·2	0·01	NS
	1971–72	104·3	63·3	44·1	47·0	5·3	0·01	NS
	1972–73	18·1	39·5	72·4	40·2	4·4	0·05	NS
	1973–74	93·8	56·6	13·5	40·3	4·9	0·01	NS
Av., 1969–70 to 1973–74		67·0	60·2	53·2	51·6	2·2	0·05	NS
Av., 6 years		62·8	59·7	55·1	52·7	1·8	0·05	NS

The Hass cultivar gave the highest overall yield during the 6 years of the experiment. The treatments had a significant effect on the yield and on the number of fruits, starting in the second year of the experiment.

At the conclusion of the experiment, differences in yields between trees irrigated at 7-day and 28-day intervals were found to be about 10 kg/tree, which was significant.

Effect of Irrigation Regime on Alternate Bearing

In the second year of the experiment, irrigation treatments applied at 21-day and 28-day intervals resulted in a 50% reduction of yields of cv. Hass from those irrigated at 7-day and 14-day intervals. These yield differences resulted in alternate bearing.

Table 2. Effect of irrigation interval on the number of avocado fruits per tree (1968-69 to 1973-74 average)

Each figure is the mean for five plots

Cultivar	No. of fruits per tree Irrigation interval (days): 7	14	21	28	SE of means	Signif. of linear component	Deviation from linearity
Ettinger	100	106	99	104	6	NS	NS
Fuerte	125	116	124	118	5	NS	NS
Hass	276	286	255	254	10	0·05	NS

In Fig. 2, yields for cv. Hass are expressed as percentages of 'on year' trees (more than 50 kg/tree) during each of the six years, and in the year following (1974-75). Alternate bearing of trees irrigated at 7- and 14-day intervals was the opposite of that of trees irrigated at 21- and 28-day intervals. The 7-day interval trees tended more to alternate bearing than did trees irrigated at the other intervals.

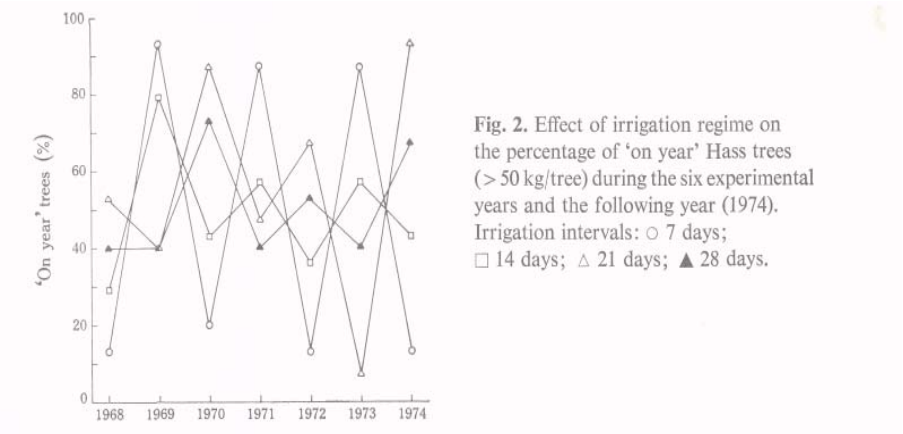


Fig. 2. Effect of irrigation regime on the percentage of 'on year' Hass trees (> 50 kg/tree) during the six experimental years and the following year (1974). Irrigation intervals: ○ 7 days; □ 14 days; △ 21 days; ▲ 28 days.

Fruit Size

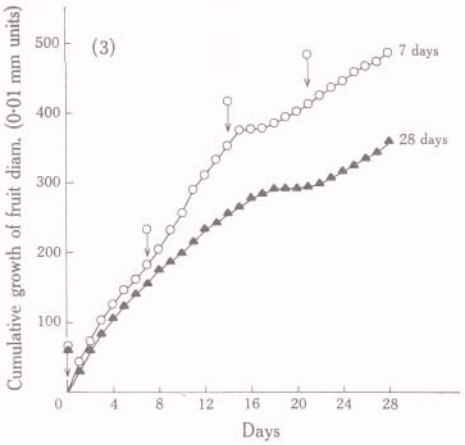
In most cases, the largest-sized fruits occurred under the 7-day interval treatment and the smallest under the 28-day treatment (Table 3). Fruits of cvv. Ettinger and Hass were more affected than cv. Fuerte fruits. Whereas the average fruit size difference between trees irrigated at 7-day and 28-day intervals in cv. Fuerte was 9 g (about 3% of fruit weight), similar treatments with Hass trees produced an average difference of 18 g (9%), and with cv. Ettinger of 35 g (11%).

Contrary to expectations, fruits of Ettinger trees irrigated at 21-day intervals were about the same, and those of Hass relatively larger, than those irrigated at 14-day intervals. With cv. Hass this observation was recorded in five out of the six years of experimentation. In some cases (Fuerte in 1972-73, 1973-74), the fruit size was affected more by the yield than by the irrigation interval.

Table 3. Effect of irrigation interval on mean avocado fruit weight

Each figure is the mean for five plots

Cultivar	Year	Mean fruit weight (g) Irrigation interval (days): 7	14	21	28	SE of means	Signif. of linear component	Deviation from linearity
Ettinger	1968–69	377·9	323·8	317·2	324·7	9·6	0·01	NS
	1969–70	303·3	311·2	321·0	287·8	5·0	0·01	NS
	1970–71	271·3	261·7	264·2	249·8	5·0	0·01	NS
	1971–72	293·6	285·6	269·8	245·5	6·1	0·01	NS
	1972–73	364·6	341·5	344·7	315·3	5·9	0·01	NS
	1973–74	341·4	326·9	330·7	321·7	5·1	0·05	NS
	Average	325·4	308·4	307·9	290·8	4·3	0·01	NS
Fuerte	1968–69	331·8	335·7	332·3	333·0	8·2	NS	NS
	1969–70	329·7	327·9	315·8	328·0	6·0	NS	NS
	1970–71	321·9	304·5	313·7	293·0	5·8	0·01	NS
	1971–72	289·0	298·1	265·3	267·2	6·1	0·01	NS
	1972–73	314·5	293·3	294·4	310·4	5·0	0·05	NS
	1973–74	276·5	292·5	282·2	278·3	4·7	0·05	NS
	Average	310·6	308·7	300·6	301·6	3·0	0·05	NS
Hass	1968–69	221·8	207·4	197·0	191·9	8·0	0·05	NS
	1969–70	207·8	205·3	210·6	206·5	5·2	NS	NS
	1970–71	234·1	200·2	204·9	195·3	4·9	0·01	NS
	1971–72	195·7	186·8	198·0	181·2	3·9	0·01	NS
	1972–73	238·1	236·5	267·1	248·1	4·3	0·01	NS
	1973–74	168·4	155·0	162·6	136·1	3·0	0·01	NS
	Average	210·9	198·5	206·7	193·2	2·5	0·01	NS



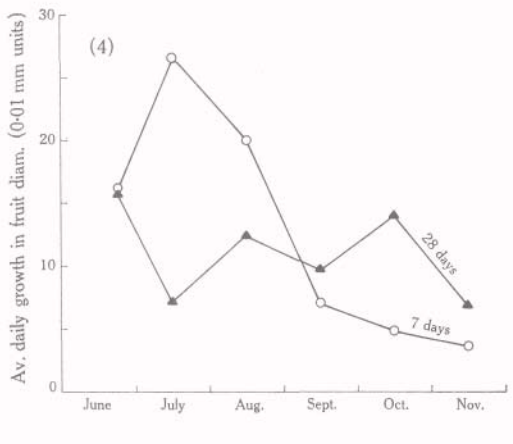


Fig. 3. Comparison of the effects of 7-day and 28-day irrigation intervals on the typical cumulative growth curve of the diameter of cv. Hass fruit (Aug., Sept. 1972). Arrows represent irrigations.

Fig. 4. Effect of irrigation interval on growth of Hass fruit (daily average, 1972). ○ 7 days; ▲ 28 days.

Fruit growth

Fig. 3 illustrates fruit growth in August-September 1972. A considerable growth difference was registered between the two extremes of irrigation intervals (7 and 28 days). After 28 days, the difference in the fruit circumference was 1.3 mm. Fig. 4 represents fruit growth of cv. Hass throughout the summer of 1972. In June, growth was uniform, as a result of water being available in the soil following winter precipitation. The greatest growth differences were recorded in July-August, the period of most vigorous fruit growth, whereas in September growth was again uniform. In autumn a growth advantage was registered with fruit irrigated at the 28-day interval.

Oil content

Oil content is largely affected by yields and by the size of fruit. It is difficult, therefore, to evaluate the effect of irrigation interval on the percentage of oil in the fruit. Oil content was determined in the years 1968-1970, when yields of cvv. Ettinger and Fuerte were relatively uniform. Results point to a tendency towards a decrease in oil percentage with an increase in irrigation interval (Table 4).

Table 4. Effect of irrigation interval on avocado fruit oil content

Each figure is the mean for five plots

Cultivar	Date of sampling	Average fruit weight (g)	Oil content (%) Irrigation interval (days): 7	14	21	28	SE of means	Signif. of linear component	Deviation from linearity
Fuerte	8.xi.68	445	14·6	16·9	15·3	15·2	1·02	NS	NS
	25.xi.69	352	13·8	12·7	12·6	13·3	0·34	0·05	NS
	15.xi.70	261	14·8	15·2	15·5	13·5	0·43	0·05	NS
	15.xi.70	364	16·3	15·8	15·3	14·5	0·56	0·05	NS
Ettinger	10.x.70	298	10·7	10·3	9·4	9·9	0·23	0·01	NS
		277	10·4	10·0	10·1	9·3	0·17	0·01	NS
		234	9·0	9·5	8·9	9·2	0·22	NS	NS
	Average	270	10·0	9·9	9·5	9·5	0·11	0·01	NS

Discussion

The relationship between growth of canopy and fruit-bearing capacity is known in a wide range of fruit trees (Zahner 1968), including avocado trees (Richards *et al.* 1962). Heavy crops suppress vegetative growth. The influence of alternate bearing of avocado trees on tree growth, especially of the Hass cultivar, has been well documented (Lahav and Kalmar 1972; Lahav *et al.* 1975).

The effect of irrigation regime on the rate of avocado tree growth has a cumulative character. Irrigation treatments influencing growth may, in the course of years, affect the productivity potential of the tree.

A close correlation was established between the tree volume and yield, especially with the Fuerte cultivar (Fig. 5), which was in fact less prone to alternate bearing than the Ettinger and Hass cultivars. With all three cultivars an average decrease in yields was registered (13%), with a lengthening of irrigation interval from 7 to 28 days, compared with a more substantial decrease (26%) in the tree volume

(Kalmar and Lahav 1977). Consequently a large tree, obtained with closely timed interval irrigations, bore correspondingly more fruits. However, as previously pointed out, the differences in yields were not significant. Possibly the influence of the irrigation regime was relatively small, because the weight of the crop depends on the number of fruits rather than on their size (Tables 1, 2). The differential irrigation treatments started with the termination of fruit set, and therefore they had only a slight effect on the number of fruits.

Because of the alternate bearing habit of the avocado tree, the effect of irrigation interval on yield could be determined only from data obtained by pairing of years. Although a constant drop in yields was registered for the Ettinger and Fuerte cultivars with an increase in irrigation interval, no significant difference concerning fruit number or weight was established. The average yield decrease for the 6-year period, for trees irrigated once a month as against those irrigated once a week, amounted to 4 kg/tree only (Table 1). This decrease is accounted for by the influence of irrigation regime on fruit size (Table 3).

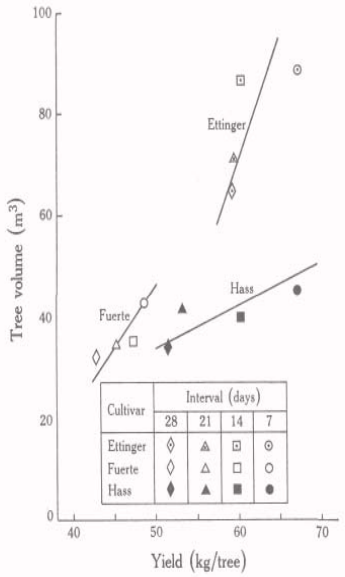


Fig. 5. Relationship between tree canopy volume at end of experiment and the average yield (1969–1974).

Regression equations:

Ettinger: $Y = -54{\cdot}39 + 2{\cdot}15x$; $r = 0{\cdot}674$
Fuerte: $Y = -52{\cdot}92 + 1{\cdot}94x$; $r = 0{\cdot}889$*
Hass: $Y = 12{\cdot}62 + 0{\cdot}48x$; $r = 0{\cdot}754$.

With the Hass cultivar an average decrease of 10 kg/tree was registered for trees irrigated at 28-day *v.* 7-day intervals. The decrease in yield of 17% only is surprising in light of the well-known sensitivity of the Hass cultivar to water supply (Homski 1969), and considering extremes of irrigation intervals of 21 and 28 days. The decrease in yields for cv. Hass was expressed in fruit number and size. An analysis of 5-year yields (without 1968-69) of this cultivar gives comparative figures of three 'on years' with the 7-day interval against only two 'on years' with the 21-day interval. Alternate bearing continued also in the year following the termination of the experiment (1974-75), although the entire plantation was irrigated that summer at a 21-day frequency. The yields for the 6-year period (1969-70 to 1974-75) showed no differences between 7-day and 21-day irrigation intervals (Table 5). Only at the 28-day interval was a significant decrease in productivity found.

A decrease in the seasonal water regime increased significantly the efficacy of its utilization for fruit production in all three cultivars. The highest capacity of water utilization for fruit production was found in the Hass cultivar. An addition of 1000 m^3 water/ha (above 5000 m^3) resulted in yield increases of 380 kg/ha for Ettinger, 320 kg/ha for Fuerte, and 820 kg/ha for Hass. The relatively low utilization capacity of Fuerte—a very important cultivar in both Israel and California—should be noted, especially as regards the two basic parameters, canopy and fruit production. This may explain the tendency to plant Hass rather than Fuerte trees (Rock 1971-72).

A distinct influence of irrigation interval was expressed in the increase of individual fruit size with increased frequency of irrigation. The influence was greatest with the Ettinger cultivar: fruit picked from trees irrigated every 7 days was 35 g larger than that of trees irrigated every 28 days (6-year average). With Fuerte the difference was 9 g, and with Hass it was 18 g. The smaller effect on the fruit size of the Fuerte and Hass cultivars may be explained by the fact that they were picked well after the start of the rainy season, which was not the case with the Ettinger cultivar. The Fuerte and Hass cultivars demonstrated considerable fruit growth with 'dry' treatments in autumn after rainfall, especially with the high temperatures still prevailing then. The increased fruit growth in autumn of trees irrigated at 28-day intervals can be explained by retarded growth during the summer. The same could be observed with trunk growth (Kalmar and Lahav 1977). Autumn irrigation was often followed by an average daily growth of 0-4 mm or more in fruit diameter.

Table 5. Effect of irrigation interval on the yield of Hass avocado trees in the last 5 years of experimentation (1969-70 to 1973-74) and in 1974-75

Each figure is the mean for five plots

Period	Yield (kg/tree) Irrigation interval (days): 7	14	21	28	SE of means	Signif. of linear component	Deviation from linearity
5 years, 1969–70 to 1973–74	67·0	60·2	53·2	51·6	2·2	0·05	NS
1974–75	11·8	41·8	95·8	62·4	4·3	0·01	NS
6 years, 1969–70 to 1974–75	57·8	57·1	60·3	53·4	1·8	0·05	NS

It can be concluded that, to achieve optimal fruit size with the maximum saving in water, irrigation should be frequent in the summer but withheld in the spring (after fruit set), when it would be wasted, as water reserves in the soil are still plentiful after the winter rains. Also in autumn, with the termination of the vigorous growing stages of the fruit, the effect of irrigation treatments is relatively small.

A decrease in irrigation intervals brought about a slight increase in the oil percentage (Table 4). Since the oil percentage in the fruit constitutes an important indicator for determination of harvest date, it should be possible to advance somewhat the harvesting date for the Ettinger and Fuerte cultivars by frequent irrigations to increase the oil percentage and fruit size.

In view of the similar yields obtained at all intervals, and the predominance of the Hass cultivar, it can be inferred that for avocado plantations, on heavy soil and under sprinkler irrigation, the preferable regime is approximately 6680 m^3/ha (plus

6000 m^3 of winter rains), given at 21-day intervals. Under this treatment, water was more effectively utilized than with the other irrigation treatments tested. More frequent irrigation is preferable only when the objective is to advance the harvest date of Ettinger fruit, or to increase the size of Hass fruit in an 'on year.'

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