THE CONTROL OF FIELD IRRIGATION PRACTICE FROM MEASUREMENTS OF EVAPORATION

By
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INTRODUCTION

In a previous paper (7) estimates of evapotranspiration calculated by eight different meteorological methods were compared with measurements of potential evapotranspiration taken from three drainage lysimeters sited within a field of alfalfa which received daily irrigation. A comparison of the accuracy of the methods tested showed that those based on open water evaporation, either estimated by Penman's method or directly measured with an evaporation pan or tank, were the most efficient. A comparison of the equipment needed, and the time involved in obtaining the estimates, suggested that the U.S.W.B. Class A evaporation pan provided the most practical, accurate and economical method of estimating potential evapotranspiration.

The study referred to also showed that the measured potential evapotranspiration was considerably higher than that from an adjacent field of alfalfa which received less frequent irrigation, in accordance with recommended irrigation practice. Both fields gave the same annual yield of dry matter, which suggests that the achievement of the potential rate of evapotranspiration is not necessary for obtaining maximum yields. Furthermore, in arid regions, where the supply of water is limited and expensive, the optimum irrigation treatment will be determined by the most efficient use of water rather than by the maximum yield. It was therefore decided to study the rate of evapotranspiration under a "most efficient" irrigation treatment, defined as that experimentally determined irrigation practice whose crop yield is not less than 85% of the highest-yielding treatment and which has the lowest water requirement. The usefulness of such a definition depends, of course, on the range of experimental treatments being successfully chosen so that the highest-yielding and "most efficient" treatments can be clearly identified from the shape of the yield response curve. This is believed to have been the case in the experiments considered in this study.

In this paper measurements of evapotranspiration from a number of important irrigated crops, all receiving their experimentally determined "most

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efficient" irrigation treatments, are compared with open water evaporation measured in adjacent Class A evaporation pans.

METHODS AND MEASUREMENTS

The measurements of crop evapotranspiration were obtained from a series of water requirement experiments carried out by members of the Division of Irrigation and Soil Physics, National and University Institute of Agriculture, Rehovot. In Table 1 these experiments are tabulated and brief details given. A full description of the methods of experimentation and analysis used has been published for a number of the earlier experiments (5).

TABLE 1

LIST OF WATER REQUIREMENT EXPERIMENTS FROM WHICH EVAPOTRANSPIRATION DATA WERE OBTAINED

Fig. No.	*Crop*	*Final crop*		*"Most efficient" irrigation treatment*	*Site and soil*	*Season and year*	*Research worker whose data are presented*
		Height, cm	*Root depth, cm*				
1	Cotton	98	210	7 irrigations, at 2-week intervals, wetting to 60 cm depth only	Gilat (N. Negev), Regosolic loess	Apr.–Oct., 1959	H. Bielorai
2	Cotton	108	210	as above	as above	Apr.–Sep., 1960	H. Bielorai
3	Cotton (2 varieties)	125 117	180 180	6 irrigations, at 18-day intervals	Sheluhot (Beit Shean Valley), Serozem	Apr.–Nov., 1959	M. Ophir and E. Shmueli
4	Maize	323	150	5 irrigations, at 2-week intervals	Gilat, as above	May–Sep., 1960	D. Shimshi
5	Peanuts	45	160	5 irrigations, at 3-week intervals	Beit Dagan (Coastal Plain), Alluvial brown Grumusol	May–Oct., 1959	A. Mantel and E. Goldin
6	Sorghum	110	210	2 irrigations, 6 and 10 weeks after sowing	Gilat, as above	May–Aug., 1959	H. Bielorai, A. Reiss and I. Arnon
7	Vine	110	50	12 irrigations, at 11-day intervals	Even Sapir (Judean Hills), Calcareous Rendzina	Apr.–Oct., 1961	S. Gairon, N. Dagani and B. A. Bravdo
8	Agave	150	120	2 irrigations, June and Oct.	Gilat, as above	Nov. 1960– Oct. 1961	M. Achituv

In a standard experiment the crop is sown in soil that has been previously wetted to field capacity, by rain or irrigation, to the final depth of the root zone. When the crop is fully established, the differential irrigation treatments are started. A conventional experimental layout is adopted, with the size of the individual plots dependent partly on crop spacing and topography and partly on the method of irrigation used. Rotating sprinklers on portable aluminum pipes are used with the lower crops, and some form of gated pipes for surface application with taller crops. The plot size ranges from 12 x 12 to 24 x 24 m. Most of the experiments include 5–6 irrigation treatments, replicated 4–5 times. The normal type of treatment is to allow a predetermined number of days to elapse between irrigations, at each of which the full depth of the root zone is rewetted to field capacity. Additional treatments, at which the root zone is only partially rewetted, or in which the yield response to water stress at different growth stages is investigated, are also often included.

In the experiments the evapotranspiration is measured by oven-drying soil samples, taken to the full depth of the root zone (often below 2 meters), and using them to follow the changes in soil moisture content. The samples are taken at the beginning and end of the experiment, and one day before and three to five days after each irrigation. The post-irrigation sampling is made when the sampling zone has drained to field capacity. Treatments receiving infrequent irrigations are also sampled in the intervals between irrigations. For each measurement 4–6 soil cores are removed, from random positions within an experimental plot, with a sampling tube (8), in depth increments of 30 cm. For each treatment 2–3 replicate plots are sampled, so that the mean soil moisture determination for each date and treatment is based on some 70 samples taken from 10 points. An examination of the variance of such data has shown that the mean coefficient of variation of measurements of evapotranspiration based on a series of such measurements is about 10 percent (7).

The actual amount of water applied at each irrigation is determined on the basis of the mean soil moisture content measured on the previous day and of predetermined values of field capacity, bulk density and irrigation efficiency for each site and method of application. When rotating overhead sprinklers are used, the water is applied during the night or early morning to ensure even distribution and reduce spray drift. Whatever the method of application, calibrated water meters are attached to each irrigation line.

The amount of evapotranspiration occurring during the four to six days between the pre- and post-irrigation soil sampling is estimated from the measured values in the first period of measurement after irrigation, when soil moisture is not likely to limit water loss. Such a method of computation ignores the water losses by deep percolation out of the root zone, surface run-off or spray drift during irrigation, and therefore the evapotranspiration values used in this paper are lower than the amount of irrigation water actually applied. To obtain the amount of water needed for irrigation, these values must be divided by the irrigation efficiency factor.

The data on evaporation from a free water surface were obtained from daily measurements of the water level in a standard Class A evaporation pan

(1), taken with a micrometer depth gauge. The water level within the pan was not allowed to fall more than 5 cm below its upper level before refilling, and the pans were frequently cleaned and refilled to reduce the growth of algae. All the evaporation pans were protected against losses from animals and birds by the standard screen of the Israel Meteorological Service, which consists of wire netting of 0.8 cm hexagonal mesh supported by a light metal framework. A comparison of the evaporation from screened pans with that from unprotected instruments has shown a 10.4% reduction of evaporation caused by the screen. This reduction factor was similar throughout the year and at three different stations (hill, coastal plain and Negev)*. The evaporation pans were placed on an open wooden platform, allowing some air circulation beneath the pan (Plate 1).

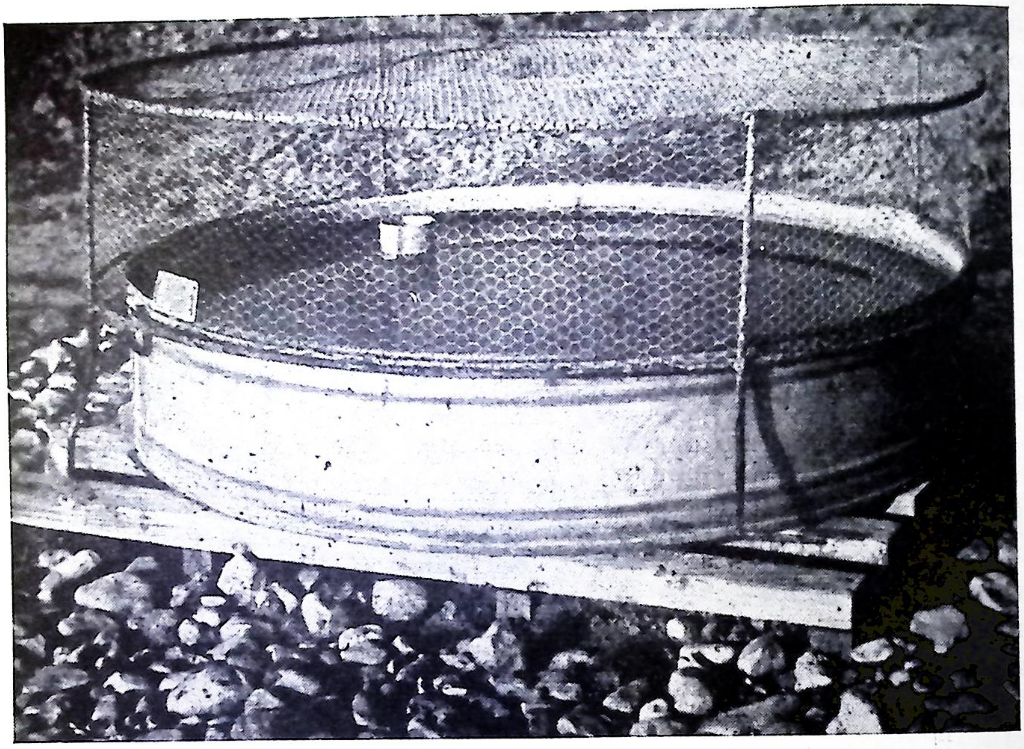

Plate 1 Class A pan, (with standard screen), used for open water evaporation measurement

The evaporation pans were all sited within meteorological enclosures, 40 x 40 m each, on level, bare and unirrigated soil. The sites were chosen for their representative open exposure and were in all cases close to, but unaffected by, the areas of the water requirement experiments. The pans may be considered as giving values of open water evaporation representative of the conditions upwind of the experimental plots.

* Unpublished data of author.

RESULTS

The relationship between the evapotranspiration from the crop and the evaporation from the adjacent Class A pan was compared by plotting the two cumulative totals against each other. The starting point of the cumulative totals was the date of sowing for the annual crops (Figs. 1–6), the date of leaf break (mid-April) for vines (Fig. 7), and the beginning of winter rains for agave (Fig. 8). For the last crop, data had to be omitted for one winter month of heavy rain when deep percolation through the root zone occurred, and also for a three-week period in late summer when an inexplicable increase in soil moisture content was recorded.

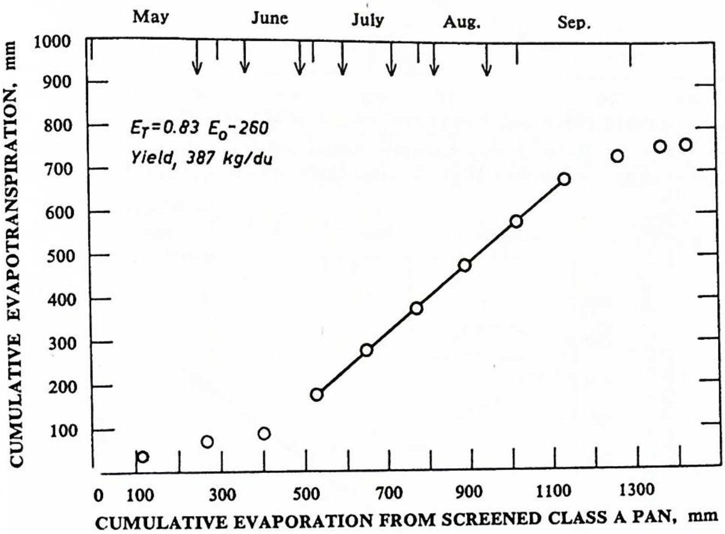

Fig. 1 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Cotton (var. Acala), Gilat, 1959.

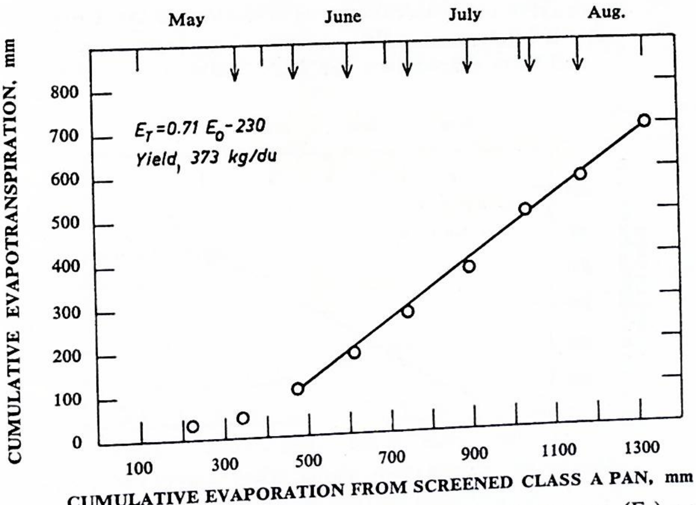

Fig. 2 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Cotton (var. Acala), Gilat, 1960.

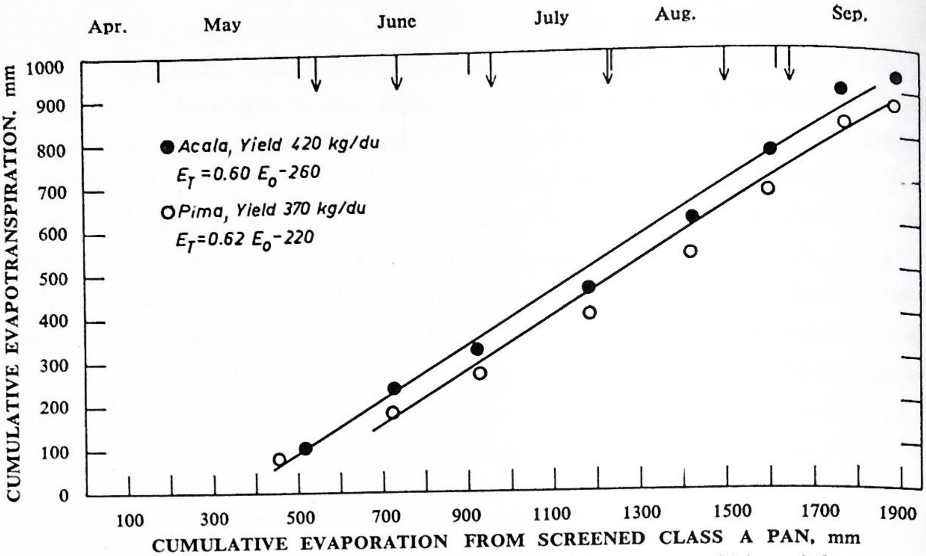

Fig. 3 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Cotton (two varieties), Beit Shean, 1959.

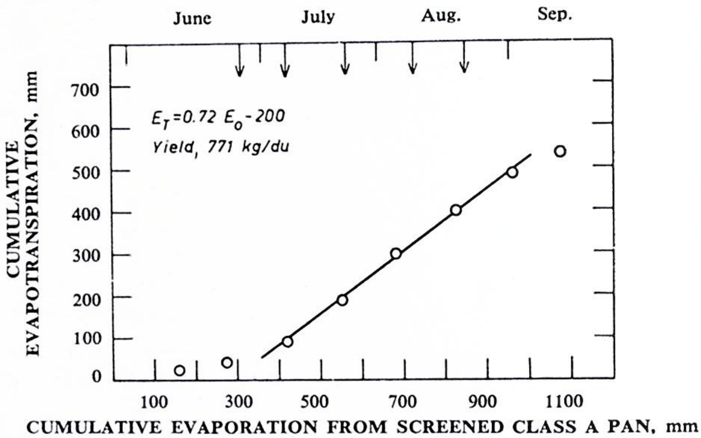

Fig. 4 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Maize, Gilat, 1960.

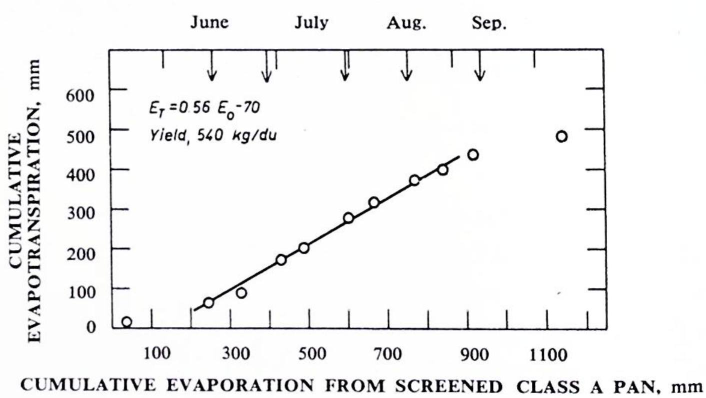

Fig. 5 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Peanuts, Beit Dagan, 1959.

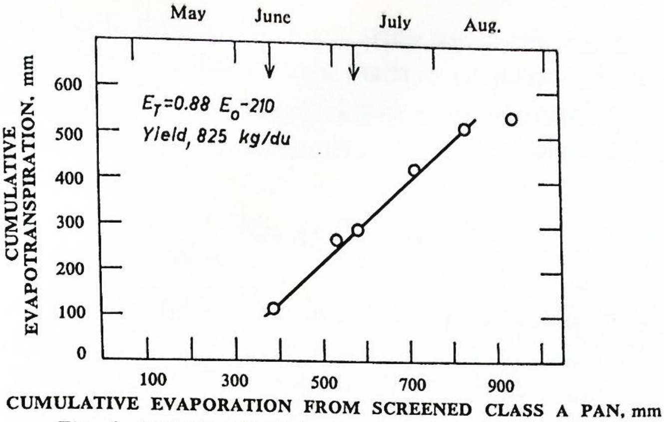

Fig. 6 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Sorghum, Gilat, 1959.

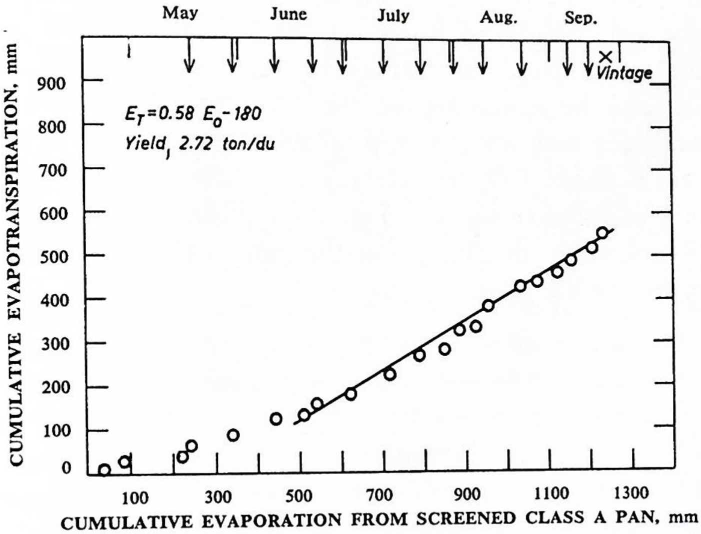

Fig. 7 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Vines, Even Sapir, 1961.

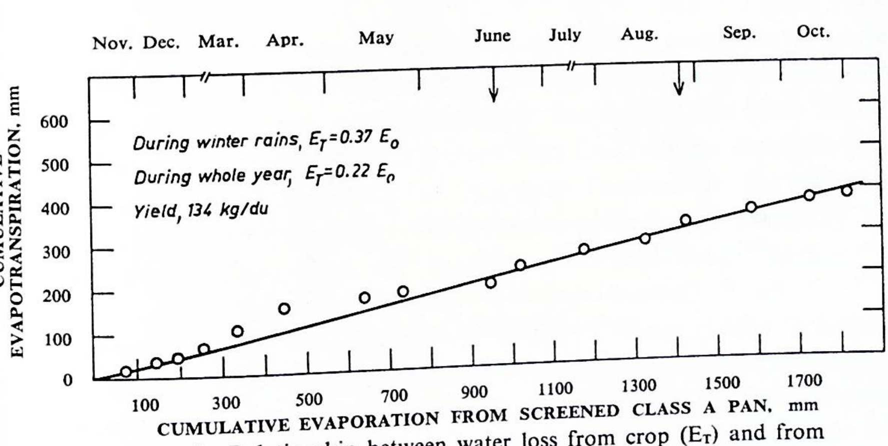

Fig. 8 Relationship between water loss from crop (E_T) and from evaporation pan (E_0). Agave, Gilat, 1960–1961.

The points in the diagrams correspond to individual soil sampling dates. Irrigation dates are shown by vertical arrows below the calendar time scale. The solid lines are straight lines fitted by eye to the middle sections of the sigmoid curves (see below).

DISCUSSION

The method of plotting cumulative totals was adopted as the most useful method from the point of view of estimating evapotranspiration. However, this method may mask part of the variability of the data and, because the individual points are not independent, the usual statistical methods for assessing the variability in the relationship between evapotranspiration and evaporation cannot be used. From the practical point of view, the data whose variability is of importance are cumulative totals for the whole irrigation period, and partial cumulated values over the intervals between successive irrigations. The constancy which can be demanded of the relationship for such periods is limited by the accuracy with which evapotranspiration can itself be determined, which in this case is about 10% (see above). For demonstration purposes, the data plotted on a cumulative basis in Fig. 1 are plotted on a non-cumulative basis in Fig. 9, showing the change in the ratio of evapotranspiration to evaporation during the life of the crop.

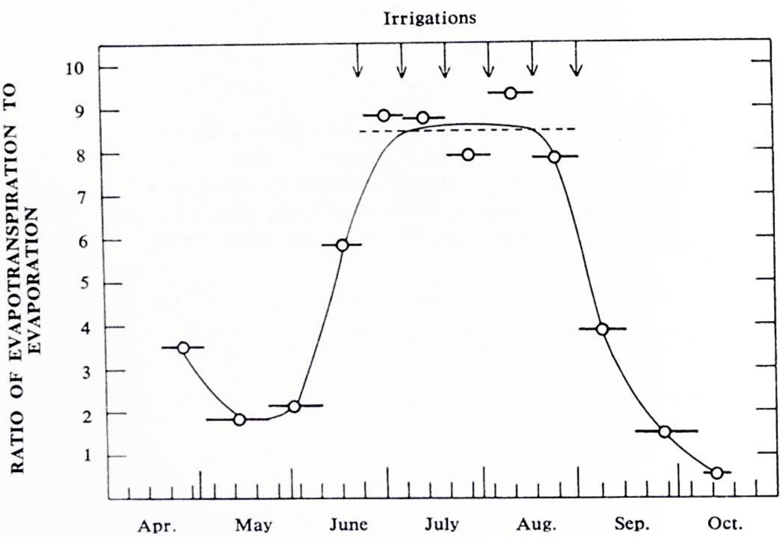

Fig. 9 Changing relationship in relative evapotranspiration during life of crop. Same data as Fig. 1.

It can be seen that during the irrigation period there is no systematic change in the ratio, and that the range of the five ratios corresponding to the five intervals between irrigations is less than 10% of their mean. The mean value of the ratio (0.85) is virtually the same as that derived from the linear part of the cumulative relationship shown in Fig. 1 (0.83). A similar plateau in the ratio of evapotranspiration to evaporation during the main growth period has been reported for the maize crop in America (2).

It is seen from Figs. 1–8 that, in all but one of the experiments (Fig. 8), the cumulative relationship was sigmoid in form. This indicates a low ratio of evapotranspiration to evaporation during the early and late growth stages. For the periods of irrigation application, the relationship between the two measures of water loss can be approximated fairly well by a straight line; the largest deviation from the line is smaller than the standard error of the evapotranspiration measurements, and of the same order of magnitude as the accuracy of water application obtainable in field irrigation practice.

Several reasons may be suggested to explain relatively low evapotranspiration during the early and late growth stages. In annual row crops the greatest water loss during the early stages is by evaporation from the bare soil. In the absence of rain or irrigation, and under rapid drying conditions, such water loss is quickly reduced by the formation of a surface mulch of dry soil (4). During the late growth stages evapotranspiration is reduced by leaf senescence and by increasing soil moisture stress following the cessation of irrigation with crop maturity.

With perennial deciduous crops a similar seasonal fluctuation is to be expected with the development of new foliage in the spring and the onset of the resting stage in the autumn. It can be seen from Fig. 7 that in the case of vines there was a slow increase in relative evapotranspiration from leaf break in mid-April until leaf expansion was complete in early June. From then on, the ratio of evapotranspiration to evaporation remained constant until the vintage at the end of September. There is an indication of a reduction in the relative rate of water loss at vintage time, but the data are insufficient to establish this clearly.

It is only for perennial evergreen crops with a complete or constant-size ground cover that a linear relationship between evapotranspiration and evaporation from a water surface can be expected throughout the year. In the case of agave (Fig. 8) the relationship is indeed seen to be linear throughout the year, with the possible exception of an apparent increase in the relative rate of evapotranspiration during the winter rains, which was probably caused by increased evaporation from the large area of rain-wetted bare soil between the rows.

Before discussing the possible application of these results in field irrigation practice, it is of interest to consider the differences between the slopes of the linear parts of the evapotranspiration-evaporation curves which were obtained for different crops, sites and years. It is evident that there are large differences in relative rate of evapotranspiration between different crops growing on the same site under the same macroclimatic and soil conditions. The ratios of evapotranspiration to Class A evaporation in Gilat range from 88% for sorghum to 22% for agave (Figs. 1, 2, 4, 6 and 8). It thus appears that there are real and substantial differences in the water requirement for near-optimum yields between different crops grown in the same soil and climate.

Differences can also be seen in the relative rate of evapotranspiration from the same crop growing under different conditions of soil and climate and during different years. The results from two successive years, for cotton crops receiving the same irrigation treatment and growing under the same soil conditions, are shown in Figs. 1 and 2. The values of final yield, total seasonal evapotranspiration and total evaporation were similar in both years, but there was a 12% difference between the slopes of the linear parts of the curves. It may be of significance that there was a similar difference in the total amount of open water evaporation during the three months of the irrigation season, the higher relative rate of evapotranspiration in 1959 being associated with a lower amount of open water evaporation, while the total evapotranspiration during that period was about the same as in 1960.

The results for two different varieties of cotton, receiving the same irrigation treatment and grown on the same site during the same time, are shown in Fig. 3. The differences in slope between the two curves are very small.

When the Acala cotton curves for Gilat (Fig. 1) and Beit Shean (Fig. 3) are compared, it is seen that the relative evapotranspiration of cotton grown on the soil of the northern Negev (Gilat) is nearly 15% higher than that of the same crop grown on the heavier soil and under the more intense evaporating conditions of the Beit Shean Valley.

One further point should be considered, which may have some bearing on these differences in relative water loss. It has been shown (7) that in Israel the size of the irrigated area may have a considerable influence on the rate of evapotranspiration. The irrigated area of each of the experiments considered in this paper was approximately the same (about 1 hectare), but the aridity of the area surrounding the irrigation experiment and the Class A pan varied between different sites and seasons, and this may have affected the results obtained. E.g., at Gilat the majority of the surrounding area is unirrigated desert, whereas in the Beit Shean Valley the proportion of land devoted to heavily irrigated crops and fish pond culture is much higher.

The sigmoid curves shown in Figs. 1–8 also differ with respect to the point where the linear part of the curve starts, which indicates the time taken by the various crops to achieve their maximum relative rate of water loss. These values, expressed on a free water evaporation time scale, vary between the crops, but the differences are much smaller than those found in the slopes of the linear parts. In some cases, such as that of vine, this point can be shown to coincide with the time of maximum leaf expansion, but with other crops this point does not correspond to a clearly marked growth stage.

From the practical point of view, the type of relationship illustrated in this paper could be used in the following way. In the first place, records of open water evaporation, together with the appropriate crop constants, irrigation efficiencies and dates of sowing and harvest, could be used to plan the seasonal and yearly water requirements for various districts. On the basis of long-term records of both open water evaporation and rainfall, the year to year variation to be expected in the water requirements of each district can be estimated (6). Measurements of Class A evaporation made in regions of the U.S.A. with an evaporation climate similar to that of Israel, suggest a standard deviation of about 10% for annual evaporation (3).

For actual farm irrigation control, the following method is suggested. On the basis of the results of water requirement experiments of the type briefly described in this paper, the "most efficient" irrigation treatment for each crop and district can be established. With measurements from carefully sited Class A evaporation pans in each locality, it would be possible to calculate the cumulative evapotranspiration (from the previous irrigation or the sowing date) in a simple way, using equations of the type shown in Figs. 1–8. In each case the calculated evapotranspiration will have to be divided by the irrigation efficiency factor appropriate to the method of irrigation application in use.

It must be emphasized that extensive research is needed to establish the values of the constants appropriate for each crop, and their possible dependence on soil type, climate and agronomic practice. Such a research project has already been started for one of the crops considered in this paper. Measurements of evapotranspiration are being made at frequent intervals from plots sited within a number of large commercial cotton fields receiving the recommended "most efficient" irrigation schedule. At the same time, open water evaporation is being measured in Class A pans sited upwind of the irrigated fields.

SUMMARY

A comparison of the measured evapotranspiration from six crops, receiving their experimentally determined "most efficient" irrigation treatment, with the water loss from nearby Class A evaporation pans, showed a sigmoid relationship between the corresponding cumulative values. For the period of irrigation application, the relationship could be approximated by a straight line.

Considerable differences in the slope of this linear relationship were found between different crops growing under the same soil and climate conditions. Smaller differences were found between sites and years for the same crop.

A method of utilizing such relationships for water requirement planning, and for farm irrigation control, is proposed.

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