Comparison of Optimal and Deficient Irrigation of Avocado by Phytomonitoring

Leo Winer[1]
Extension Service, Ministry of Agriculture and Rural Development
41 Ahuza St.
43000 Raanana Israel
leowin@shaham.moag.gov.il

Abstract. Two irrigation regimes, the one optimal (100%) and the other deficient (70% of optimal), were compared in a 'Hass' avocado (*Persea americana* Mill.) orchard at Kibbutz Ma'agan Michael during the 2001 and 2002 seasons. Changes in trunk and fruit diameter, in the volumetric moisture of the soil, and in vapor pressure deficiency in the atmosphere were phytomonitored, using electronic sensors to transmit data to a remote computer. Micronic fluctuations in growth rate and shrinkage in the trunk and in the fruit showed similar trends, and were sometimes affected by the amount of irrigation. The trunk appeared to be more sensitive to medium changes than the fruit, as growth or shrinkage or both were usually seen first in the trunk and only later in the fruit. Deficient irrigation resulted in an increase in the daily shrinkage of the trunk and slower growth of the fruit. In both seasons**,** fewer large fruits were obtained from trees grown under deficient than under optimal irrigation. Daily shrinkage of the trunk is the best indicator of irrigation efficacy, and monitoring of such shrinkage is currently the only reliable way to follow up water consumption in avocado.

Introduction

Plant parameters offer the most direct way of obtaining information about the water status of plants. Monitoring of fluctuations in water status allow us to gain a better understanding of the effects of environment on the growth and water requirements of plants. For many years the water status of plants was determined by measuring the water potential of plant tissue (usually the leaves) in pressure chambers (Scholander et al. 1965). This is a destructive measurement and is unsatisfactory because it is non-continuous and therefore does not adequately reflect the plant water status, which varies considerably during the course of the day. A more suitable approach is one in which the water status is monitored continuously.

Over the last three decades a new approach was developed for the continuous monitoring of plant water status, based on the determination of micronic changes in the trunk and fruit diameter and leaf thickness (Burquez 1987, Huck and Klepper 1977, Huguet 1985, Schroeder and Wieland 1956, Sionist and Henderson 1973, Syvertsen and Levy 1982). These changes in the diameters of plant organs were found to

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correlate with fluctuations in the plant water status. Periodic changes were observed on a daily basis in the different plant organs, i.e., expansion and growth at night and organ shrinkage during the day. The amount of expansion or shrinkage of the organ depends on the climatic conditions, the type of soil, and the availability of water in the soil. A great advance was made in the 1980s, with the use of fluctuations in the trunk diameter to indicate the water status of the tree. Li and his colleagues showed that the trunk was the first plant organ to react to water stress, and it did so by a reduction in growth (Li et al., 1989). Maximal daily shrinkage of the trunk was found to be the best indicator of the water status in peach trees (Huguet 1985; Garnier and Berger 1986).

In the 1990s, Isaac Adato introduced the idea of using the maximal daily shrinkage of the trunk as a measure of the water status of avocado trees in practical farming. This approach was based on examining the effects of empirical changes in the amount of irrigation on the maximal daily trunk shrinkage. An increase in irrigation would be considered effective if it diminished the maximal daily shrinkage of the trunk. By the same reasoning, less irrigation water could be applied if the smaller amount did not lead to an increase in the maximal daily shrinkage of the trunk. In terms of this approach avocado is considered a 'non-stress crop', and must be irrigated with an amount causing the lowest possible trunk shrinkage for maximal yield and fruit growth.

In the present study we investigated the possibility of using the maximal diurnal trunk shrinkage as a parameter for determining water status in avocado trees.

Materials and Methods

Avocado trees of the cultivar 'Hass' on seedling Degania 117 rootstock, growing in a commercial plantation of Kibbutz Ma'agan Michael on the Mediterranean coast of Israel, were studied during the 2000–01 and 2001–02 seasons, when the plantation was 5 and 6 years old. Spacing was 6 m between rows and 4 m between trees in a row. Water was applied through two lines of drip irrigation along the row placed on either side of the tree, 1 meter apart, with drippers spaced at 0.5-m intervals in each line. Irrigation frequency varied during the season, and ranged from one pulse of irrigation every 2 days in the spring and autumn to three pulses of irrigation a day during the hot summer. The "optimal" irrigation was based on the standard pan evaporation coefficients which varied during the season from 0.35 to 0.85, with corrections for the daily maximal trunk shrinkage. Fertilization through the irrigation water was adjusted where necessary to maintain a constant concentration.

Two irrigation regimes were applied: the "optimal" irrigation (determined as described above), and "deficient" irrigation with about 30% less water than the optimal. For the optimal irrigation regime five replicates, each about 0.15 to 0.2 hectares, were established. For the deficient irrigation there were only three replicate of 0.2 to 0.25 hectares each. Data were collected by a Local Phytomonitoring Station (LPS; Phytech Technologies, Yad Mordechai, Israel), comprising data loggers, a computer program for data display, and a cellular forecasting system to transfer the data to a remote computer. Meteorological sensors were used to measure temperature and relative humidity. The volumetric humidity of the soil was measured by a Theta probe (Delta-T) from Phytech. Changes in trunk diameter were measured by electronic dendrometers

(Phytalk; Phytech), using a Linear Variable Differential Transformer (LVDT). These dendrometers are sensitive enough to measure tissue fluctuations in micrometers. The dendrometer was set up with a screw inserted into the xylem in the center of the trunk, while its cylinder was in contact with the circumference of the trunk and moved with it (Fig. 1). Each dendrometer was connected to an electronic data logger and a forecaster, which transmitted the data through a cellular network to the remote computer. A computer program supplied by Phytech calculated the daily shrinkage and expansion of the trunk. Fluctuations in fruit size were measured by sensors FI-3EA from Phytech based on LVDT. For each treatment we used two electronic trunk dendrometers and two fruit sensors.

The maximal diurnal trunk shrinkage and the rate of fruit growth were calculated according to the continuously monitored changes in the trunk diameter and fruit size. Each season the yield of every replicate was harvested separately, and the distribution of fruit size was determined according to commercial standards.

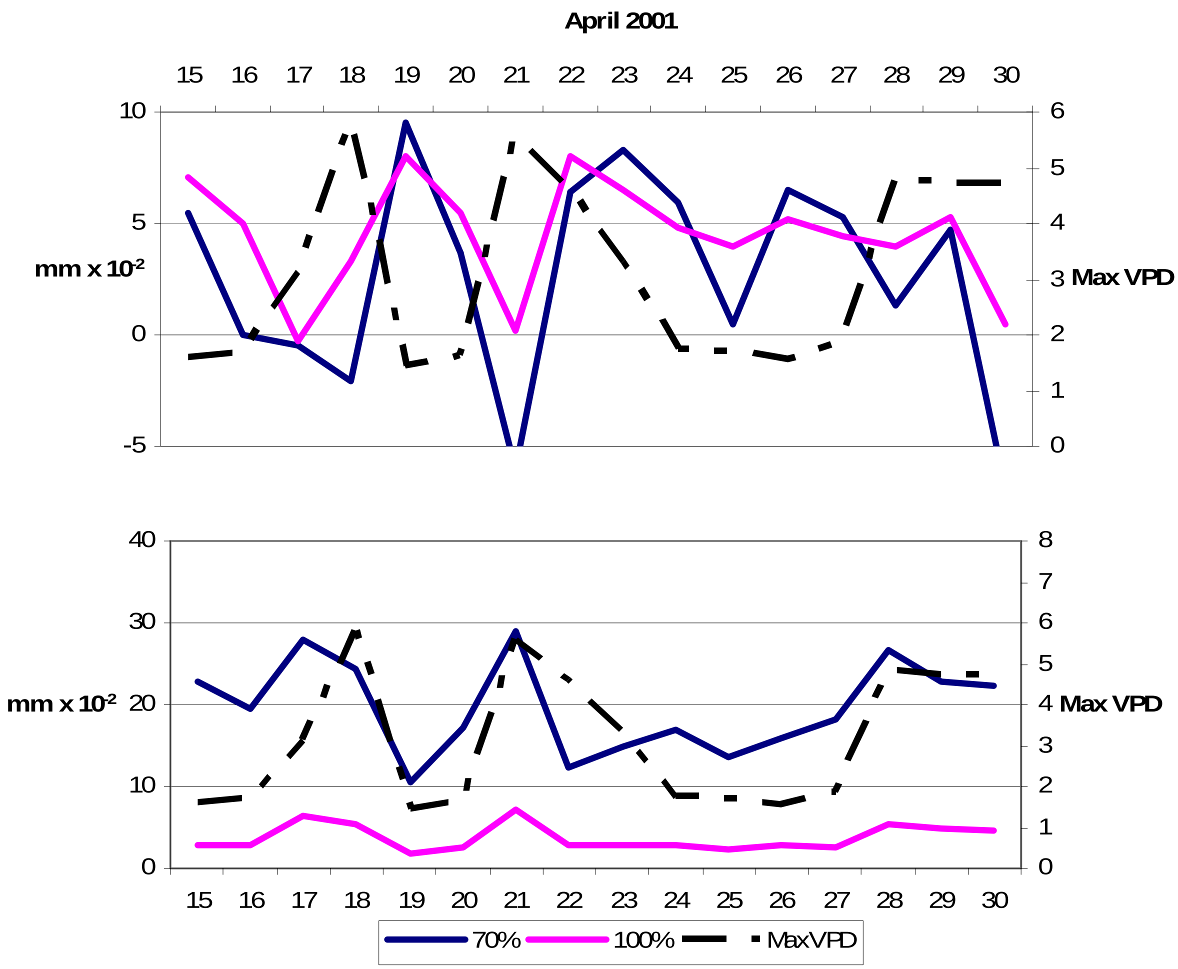
Fig. 1. Electronic trunk dendrometer device on an avocado tree.

Results and Discussion

Background data. Rainfall during the winter of 2000/01, prior to the start of the study, was only 397 mm, compared to 823 mm in the winter of 2001/02. Similar amounts of irrigation were applied between April and November in the two seasons of the study, i.e., 8400 m^3 per hectare under the optimal irrigation regime and 5900 m^3 per hectare under the deficient irrigation regime.

Daily growth and shrinkage of the trunk in the spring. The second half of Apr. 2001 was taken to be representative of the spring period. The last significant spring rains (85 mm) were in February, an additional 9 mm fell in March, and at the beginning of April the trees were receiving irrigation water according to the optimal (100%) or deficient (70%) irrigation regimes established for this study.

Spring in Israel is characterized by periods of *hamsin*, when hot dry east winds cause a significant drop in the atmospheric vapor pressure (VPD). Between 15 and 30 Apr. 2001 there were three periods of *hamsin*. The first occurred on 18 Apr. and lasted for 1 day only. The others each lasted for 3 days (21–23 Apr. and 28–30 Apr.; Fig. 2). The maximal VPD (MaxVPD) during each *hamsin* was higher than 5 kPa (Fig. 2). In trees irrigated according to the optimal regime, during each *hamsin* there was a sharp decrease in the daily trunk growth until growth stopped altogether. In trees with deficient irrigation the decrease in the daily trunk growth was much more pronounced than the increase, and instead of trunk growth there was negative growth (shrinkage) of 0.02–0.07 mm per day (Fig. 2a). Trunk growth (mean ± SE) under optimal and under deficient irrigation during that period is recorded in Table 1.



A.

B.

Fig. 2. Fluctuations in maximal vapor pressure deficit in Spring 2001 (15–30 Apr.) and their effects (a) on daily trunk growth and (b) on shrinkage under deficient and under optimal irrigation.

The daily fluctuations in shrinkage of the trunk were found to correlate with the changes in MaxVPD (Figs. 2b and 3). An increase in MaxVPD was usually accompanied by an increase in the daily trunk shrinkage. The maximal daily trunk shrinkage was strongly affected by the irrigation (Fig. 2b). This influence could be discerned under normal climatic conditions, but was much more pronounced on days of *hamsin* (Fig. 2b), when trunk shrinkage under optimal irrigation was significantly less than under deficient irrigation (Fig. 2b). The differing effects of the two irrigation regimes can also be seen in the mean daily shrinkage in the period 15–30 Apr. 2001 (Table 1).

Table 1. Trunk growth and trunk shrinkage (mean ± SE) under deficient and under optimal irrigation during the periods 15–30 Apr. 2001 and 15–30 Apr. 2002.

Diurnal rate of change ($\times 10^{-2}$ mm)	15–30 April 2001		15–30 April 2002	
	Deficient (70%)	Optimal (100%)	Deficient (70%)	Optimal (100%)
Trunk growth	2.64 ± 1.29	4.47 ± 0.68	4.19 ±0.69	6.41 ± 0.92
Trunk shrinkage	9.71 ± 1.51	3.74 ± 0.44	13.51 ± 1.75	3.93 ± 0.26

The coefficient of correlation between MaxVPD and daily trunk shrinkage was higher in the case of optimal irrigation (R^2 = 0.61) than deficient irrigation (R^2 = 0.51) (Fig. 3). This finding suggests that the shrinkage response of a tree to a decrease in the MaxVPD is limited by the amount of irrigation it receives.

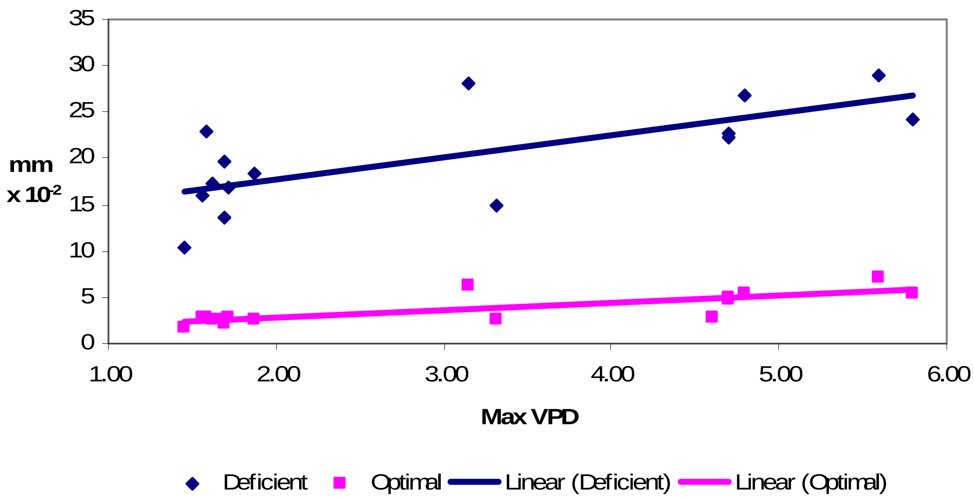
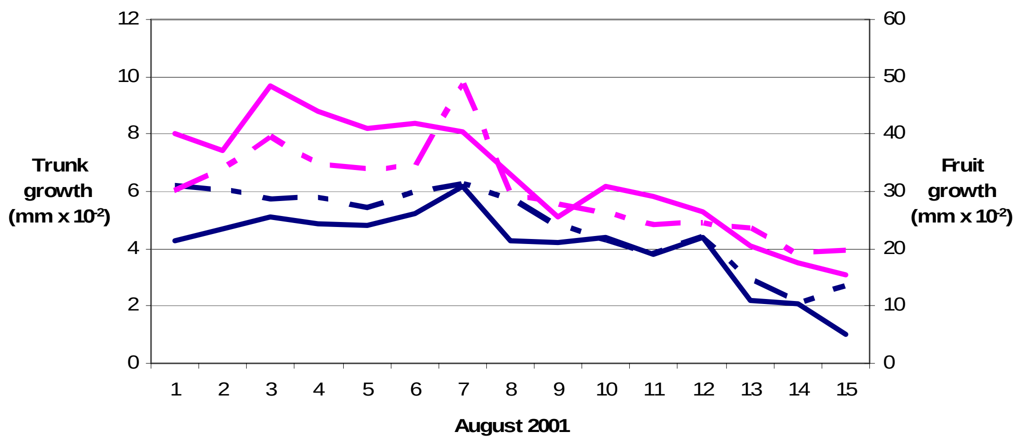
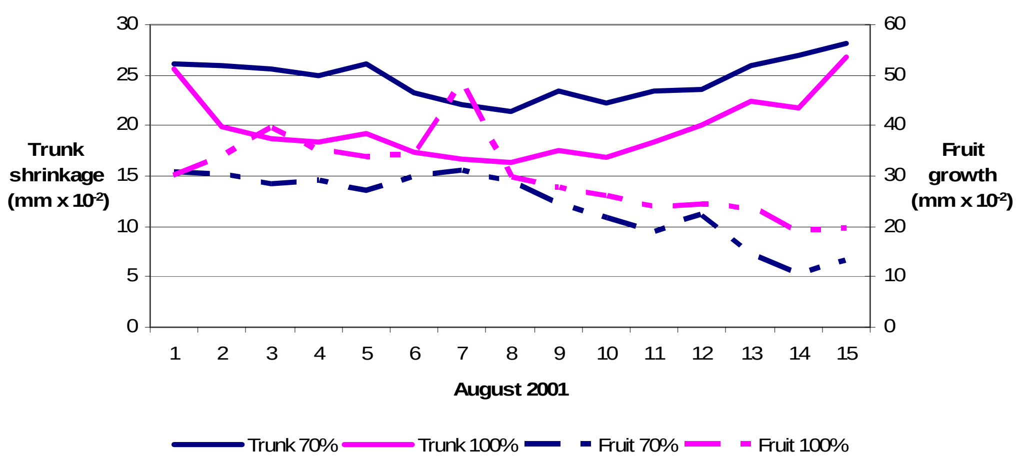


Fig. 3. Correlation between maximal vapor pressure deficit and daily trunk shrinkage in Spring 2001 (15–30 Apr.) under optimal and deficient irrigation. Regression lines between the two parameters are shown.

Daily growth and shrinkage of the trunk and fruit in the summer. The first half of Aug. 2001 was taken as representative of the summer period. Growth of the trunk and the fruit generally showed a positive correlation during the summer (Fig. 4a). Usually (but not always) the fluctuations in the growth rate in the trunk and in the fruit occurred at the same time. Under optimal irrigation in summer, there were two occasions when the decrease in the trunk growth rate occurred before the decrease in the fruit growth. The first was on 6 Aug., when there was a decrease in the growth rate of the trunk, but the decrease in the fruit growth was seen only on the following day (Fig. 4a). The second occasion, seen on 12 Aug., was similar (Fig. 4a). The trunk thus appears to be more sensitive than the fruit in its response to medium changes. Under deficient irrigation the correlation between the rate of growth of the trunk and the fruit was less clear. There were even some cases in which the correlation was negative: between 1 and 3 Aug. there was a small increase in the growth rate of the trunk with no accompanying change in the fruit growth rate, and this was followed by a decrease in the growth rate of the fruit (Fig. 4a). A similar negative correlation between the growth of the trunk and fruit was seen on 14 and 15 Aug. (Fig. 4a). In general, a negative correlation between the trunk and fruit growth rates was temporary, and the general tendency for the two organs was with similar trends, though their timing did not always coincide (Fig. 4a).



A.



B.

Fig. 4. Growth parameters in Summer 2001 (1–15 Aug.) under optimal and under deficient irrigation. (a) Fluctuations in the daily growth of trunk and fruit. (b) Fluctuations in daily shrinkage of the trunk and in daily growth of the fruit

Daily shrinkage of the trunk was negatively correlated with fruit growth (Fig. 4b). Thus**,** deficient irrigation that caused an increase in the maximal trunk shrinkage also diminished the fruit growth rate, and optimal irrigation that diminished the maximal trunk shrinkage increased the fruit growth rate (Fig. 4b).

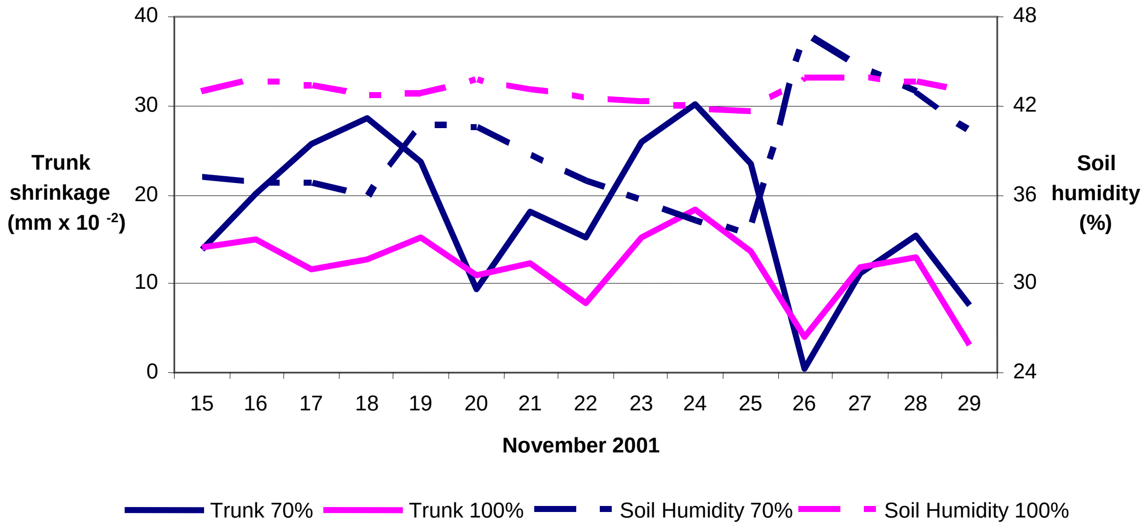


Fig. 5. Daily shrinkage of the trunk and changes in volumetric humidity of the soil under deficient irrigation and under optimal irrigation during Autumn 2001. Data are from 15 to 29 Nov., taken as a representative period for the autumn. The total amount of rainfall during this period was 6 mm.

Daily growth of the fruit and shrinkage of the trunk during and after rain or irrigation in autumn. The second half of Nov. 2001 was taken as representative of the autumn period. During that month the rainfall was negligible (about 6 mm), and the rise in volumetric humidity of the soil therefore resulted from irrigation and not from rain (Fig. 5).

Under optimal irrigation the soil was almost at field capacity and oscillations in its volumetric humidity were small, ranging from 41.8% to 44% (Figs. 5 and 6). Under deficient irrigation the oscillations were larger and changed from 33.8% to 478% in 6 days (Figs. 5 and 6). This situation is typical of autumn, when many growers postpone irrigation because they expect that the rain will continue. Under deficient irrigation there was a steep increase in the daily maximal trunk shrinkage of 0.1 to 0.2 millimeters (Fig. 5). Under optimal irrigation the increase in trunk shrinkage over the same period was much more gradual (Fig. 5).

The rate of fruit growth changed significantly between irrigations, especially under deficient irrigation (Fig. 6). Under optimal irrigation fruit growth oscillated between 0 and 0.15 millimeters per day (Fig. 6). Under deficient irrigation**,** there were days when the fruit did not grow, but instead shrank by 0.28 mm between 17 and 18 Nov. and by 0.15 mm between 22 and 24 Nov. (Fig. 6).

My experience with dendrometers has shown that immediately after a significant rainfall (around 30 mm) there is a significant decrease in shrinkage of the trunk, but that in some cases after 2 or 3 days the daily trunk shrinkage starts to increase, a situation that demands irrigation to prevent damage to the fruit. Rainfall of up to 10 mm sometimes does not reach the radicular system and thus might not be effective, as evidenced by its failure to influence the daily trunk shrinkage.

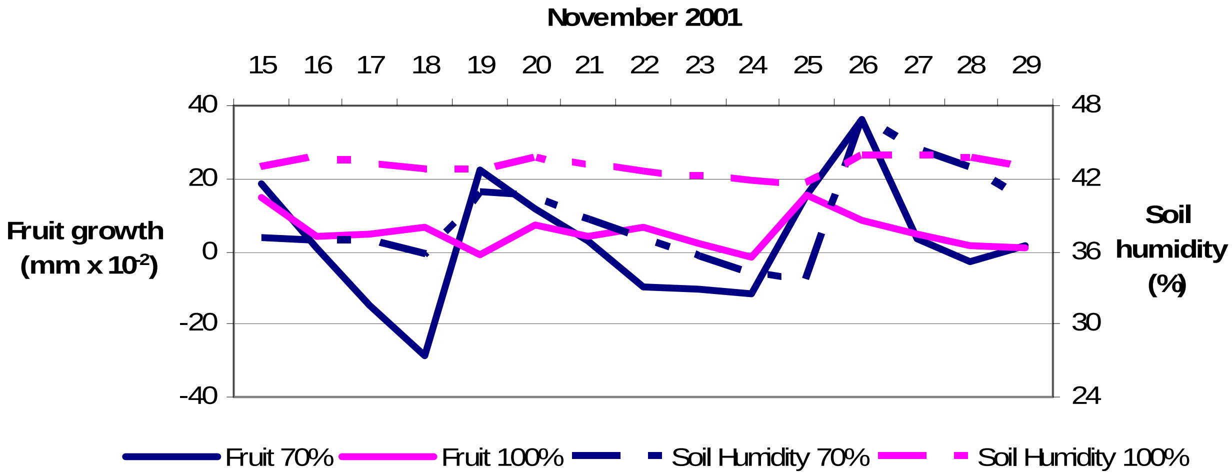


Fig 6. Fluctuations in fruit growth and in the volumetric humidity of the soil under deficient irrigation and under optimal irrigation during Autumn, 2001. Data are from 15 to 29 Nov., taken as a representative period for the autumn. The total amount of rainfall during this period was 6 mm.

*Yield and fruit size***.** The yield in the 2001 season was particularly high for a 5-year-old **'**Hass' plantation, reaching 26,650 kg/ha under the optimal irrigation regime (Fig. 7). Deficient irrigation slightly affected the total yield, which reached 25,480 kg/ha (Fig. 7). The mean yield in 2002 was about 10,000 kg/ha for both treatments (Fig. 8). The distribution of fruit size, however, differed significantly under the two irrigation regimes; deficient irrigation significantly diminished the number of large fruits and number of fruits fit for export (Figs. 7 and 8). These yield results should be regarded as a trend only, especially as the study was conducted for only two seasons, and in view of the marked differences in annual yields obtained during those two seasons.

Conclusions

Climatic and soil parameters do not yield sufficient information for accurate determination of water use by the tree. In avocado orchards, the commonly used methods based on pan evaporation coefficients do not take into account the efficacy of irrigation, the yield levels, or the physiological condition of the tree. Irrigation based on plant parameters is better able to meet the needs of the plant and improve orchard results. Daily trunk shrinkage is a sensitive measure of the water status of the tree, and can be used to indirectly determine its water use. In the relatively short period (two seasons) of this comparative study of the outcome of optimal (100%) and deficient (70%) irrigation of avocado, there was no irrigation-related yield difference in each season, but fruit size was significantly diminished and daily trunk shrinkage significantly increased by deficient irrigation.

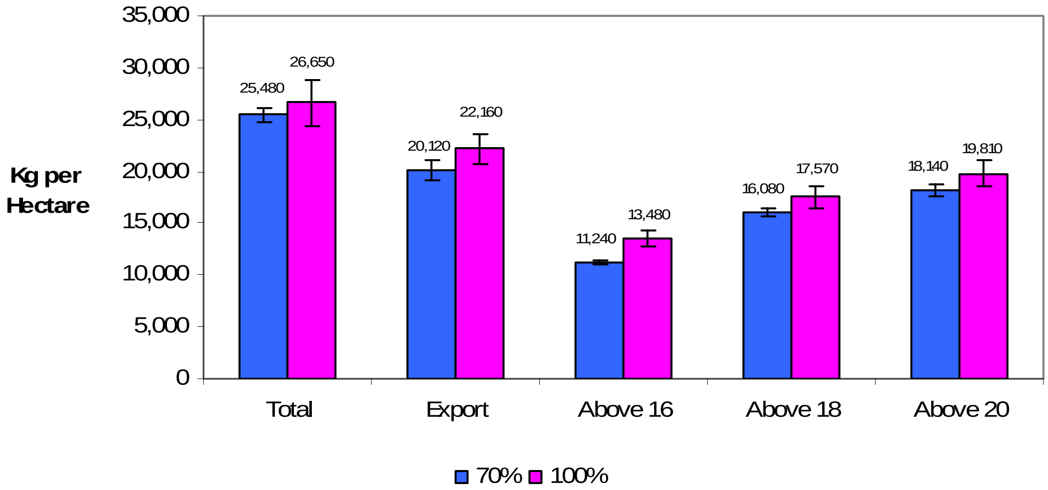


Fig. 7. The influence of irrigation treatment during the first year of the study (2001) on total yield, export yield and the yield of fruit by size (means ± SE). Size 16 fruit ranges between 222 to 250 g per fruit. Size 18 fruit ranges between 200 to 222 g per fruit. Size 20 fruit ranges between 180 to 200 g per fruit.

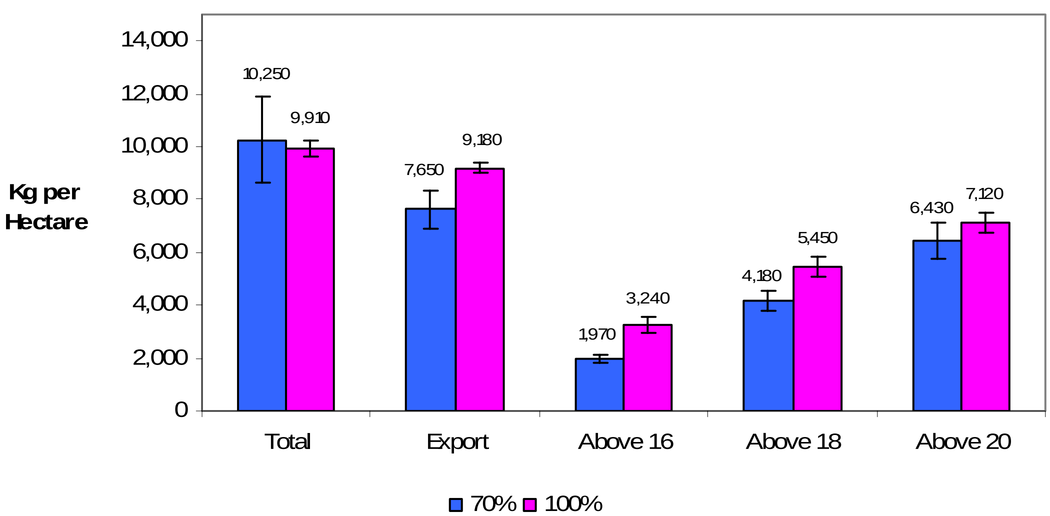


Fig. 8. The influence of irrigation treatment during the second year of the study (2002) on total yield, export yield and the yield of fruit by size (means ± SE). Size 16 fruit ranges between 222 to 250 g per fruit. Size 18 fruit ranges between 200 to 222 g per fruit. Size 20 fruit ranges between 180 to 200 g per fruit.

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