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Optimization of Water by Automated Drip Irrigation Control for Apple Trees

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Title

Optimization of Water by Automated Drip Irrigation Control

for Apple Trees.

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ABSTRACT

In a trickler-irrigated apple orchard of cv Golden Delicious and Jonathan, located in the Hula Valley of Israel, automated irrigation actuated by two kinds of SMP sensors, connected to a computer, was studied for six years (1982-87). This report concerns the last three years of the experiments. Electrotensionmeters and heat dissipation sensors were used. Two treatments of SMP thresholds (-10 and -15 kPa) by each type of sensor were included, whose purpose was to limit the water applied as closely as possible to the consumption rate of the trees.

The results showed that the -10 kPa threshold in automated irrigation and neutron probe measurements both used 10% less water than the pan evaporation method, with no adverse effects on yield, fruit size or quality, or vegetative growth. The -15 kPa threshold treatment saved 21% water, with a significant reduction in yield and vegetative growth, but without affecting fruit quality or crop load. In this case the volume of wetted soil and the root volume were restricted, but no effects of water stress in the physiological processes of the plants were found.

The findings of the experiments showed the effect of limiting the root system, pointing to a possibility of growing orchards of smaller trees, planted more densely to maintain the gross yield, resulting in better light penetration for fruit quality and fertility, reduced costs in cultivation and harvesting, while maintaining the desired crop load without reducing fruit size. The experiments also showed the efficacy of automated irrigation.

OBJECTIVES OF RESEARCH PROPOSAL

The aims of this research project are:

- a. To determine the rate of water consumption for optimal apple production;
- b. To test the efficacy of an automatic monitoring and control system intended to supply water at the consumptive rate of apple and other fruit trees;
- c. To explore the possibility of saving water and increasing efficiency in cultivation and harvesting practices in apple trees.

ABBREVIATIONS USED:

Gl. - Golden Delicious

J. - Jonathan

SMP - Soil matric potential

SWC - Soil water content

T₁ - T₆ - Treatments 1 - 6

T.S.S. - Total soluble solids

INTRODUCTION

In previous years (1982-1985) we have successfully operated an automatic irrigation system in an apple orchard, consisting of SMP sensors, linked to a computer (3). Signals from four sensors per treatment were averaged by the computer and used as threshold values to actuate drip irrigation. This method enabled us to control the volume of the irrigated soil and the water availability in the root zone. Water was applied at the rate of consumption of the trees and none percolated to layers below the root zone. When the threshold value was maintained at -10 kPa, there was a saving in water of approximately 10%, compared with irrigation according to Class A pan evaporation control. Tree growth, yields, fruit size and quality were not affected. At a threshold of -15 to -20 kPa, water consumption was reduced by 25%, and root restriction effects became apparent. These effects were expressed by a reduction in vegetative growth and yield, though crop load (yield per trunk area increment unit) and fruit size were not affected. This result opens new possibilities for growing dense orchards with limited vegetative growth per tree, giving improved light penetration, fruit quality, fruit bud differentiation and more convenient cultivation at lower prices. At the conclusion of the experiment (in Ayelet Hashahar), we submitted a new proposal to BARD to initiate a new field experiment. It is intended this time to use the system developed in Ayelet Hashahar in a young, densely planted apple orchard, consisting of semidwarf rootstock (Hashabi clone M.H. 13-4) with spur-type apple cultivars. It was decided in BARD to extend the experiment in Ayelet Hashahar for an extra year, in order to confirm the results, before

intitiating a new experiment. Accordingly, we present in this report the results from Ayelet Hashahar for the years 1985-1987. We have included the results of a number of additional measurements: root mapping, more detailed measurements of water distribution and extra physiological data.

MATERIALS AND METHODS

The experiment was conducted at Ayelet Hashahar in the southern part of the the Hula Valley in Israel. The soil is a brown alluvial vertisol, uniform down to 1.5 m, with an underlying layer of calcareous gravel. The soil texture is 69% clay, 25% silt and 6% sand; pH (in water) is 7.6; bulk density 1.4; field capacity 39% and wilting point 26% (by weight).

The apple cvs, Golden Delicious (G1) and Jonathan (J), on selected Hashabi rootstock (medium vigor), were planted in 1971 at a spacing of 4 x 3 m. Additional pollinators were cvs Orleans and Granny Smith. Fertilizers were applied through the irrigation system at ca. 320 kg N ha⁻¹ and 30 kg P ha⁻¹ (every 3 years), 400 kg K ha⁻¹ and 5 kg ha⁻¹ of Sequestrene H138 annually.

The water retention curve and hydraulic conductivity of the soil, as a function of its volumetric water content (θ) were determined in the laboratory and are presented in Figs. 1 & 2. The available NPK content of the soil was analyzed twice a year at different distances from the emitter, at depths of up to 60 cm. The levels of NPK were within the normal range for good commercial apple orchards, and there was no evidence of nutritional limitations in any of the various irrigation treatments.

The irrigation installation consisted of 8 l/h tricklers placed 1.5 m apart on a single lateral per tree row.

Six treatments were arranged in four random blocks, with 14 trees per replicate. Details of the treatments are given in Table 2.

Two types of automated irrigation were examined:

1. Irrigation actuated by electrotensionmeters to control the SMP levels at the root zone;
2. Irrigation actuated by heat dissipation sensors (Phene type - Phene et al., 1971) to control SMP levels in the root zone.

Both systems were connected to a computerized control unit (PCU 10, Motorola, Israel). Irrigation in each treatment was controlled by four sensors, one per replicate. The electrotensionmeters were constructed of regular tensionmeters (AMI Ltd., Israel and Irrometer Co., U.S.A.) equipped with electronic vacuum transducers (Motorola Co., U.S.A.) connected to the computer. The electrotensionmeters produced continuous signals in accordance with the pressure inside the tensionmeters. The heat dissipation sensors (Agwatronics Co., U.S.A.) measure the SMP by recording the heat dissipation in a porous ceramic body which is in equilibrium with the SMP of the soil and is monitored by the computer.

In addition, regular tensionmeters were placed at similar distances and depths from the tricklers in order to compare the automatic SMP readings of the electrotensionmeters and heat dissipation sensors. Close agreement was found between these manual recordings on the regular tensionmeters and the computer-recorded readings of the electrotensionmeters (data not shown).

For each treatment, the data obtained from the 4 sensors were averaged by the computer. The sensors were positioned at a distance

of 30 cm and a depth of 35 cm from each trickler: this position was selected after preliminary trials. Irrigation was operated in pulses of 10 min on and off, to minimize overshooting the SMP level following the off signal. The electronic circuit of the system is shown in Fig. 3.

The non-automatic irrigation treatments were also operated by the computer. In these treatments, irrigation was performed daily by programming the computer to supply amounts of water on the basis of Class A pan evaporation (Fig. 4) with different coefficients, and on measurements of soil water content (SWC) by a neutron probe. These neutron probe measurements (Ronly Electronics, Israel) were made twice weekly. The access tubes were located at horizontal distances of 20, 35, 70 and 105 cm from the tricklers. The readings were taken at 30 cm increments down to a depth of 90 cm. The quantity of water in the plots irrigated according to this method was calculated to maintain a constant average SWC close to field capacity, at a distance of 35 cm from the trickler and in a profile of 0-60 cm deep.

The circumference of each tree-trunk was measured with a tape at a fixed point of 20 cm above the ground, each winter. The rate of fruit growth was monitored weekly by a plastic measuring tape on 8 carefully selected fruit, growing on equal-sized spurs, evenly distributed around the tree (128 fruit per treatment). Fruit that dropped during the season (ca. 10%) was discarded.

At the end of the 1987 season two 2 m long trenches were dug, perpendicular to the tree row, and one 6 m long trench was dug parallel to the row, 20 cm from the trees. The trenches, one to each variety and each treatment, were 2 m deep. The walls of the trenches

were flushed with water, and visible roots were counted in each square (20 x 20 cm) formed by attaching a net to the trench wall. The sizes of the roots were measured in the following ranges: 1>, 1-3, 3-5, 5-10 and 10< mm.

RESULTS

Water quantities

The amounts of water applied in the Class A Pan Evaporation treatment, with commonly used coefficients (T_s) averaged 838 mm, the highest quantity throughout the 3 experimental years (Table 1). T_1 and T_2 (irrigated at a threshold of -10kPa) consumed 10% less water than T_s . T_3 (neutron probe measurements) consumed amounts similar to T_1 and T_2 . T_4 and T_6 (automatic irrigation at a threshold of -15kPa) consumed 77% and 81% respectively of the quantity used in T_s .

Soil water content

Results of SWC measured throughout the 1987 season are given here as representative of all three experimental years (Figs. 5-8). In T_1 , T_2 and T_3 , at 35 cm distance from the trickler, the SWC was almost constant throughout the season in all three layers: 0 - 30, 30 - 60 and 60 - 90 cm. The SWC increased with depth. At a distance of 70 cm from the trickler the SWC was lower in all treatments, and the difference between the layers increased. In treatments T_4 , T_5 and T_6 the SWC at 35 cm was constant throughout the season, increasing with depth. The SWC of T_5 was

similar to these, whereas treatments T_4 and T_6 had a lower SWC at all three depths. At 70 cm distance, the water content of T_4 , T_5 and T_6 declined at all three depths, throughout the season. This decline was slightly sharper in T_4 and T_6 than in T_5 .

T_3 was irrigated according to frequent neutron probe measurements. The level of SWC was maintained as close as possible to field capacity by adjusting the daily water application. Consequently, the SWC line was almost straight during the entire season.

Representative results of daily measurements of SWC, carried out on August 19, 1987 (Figs. 9, 10) show that the SWC of T_1 was higher than that of T_3 and T_4 at all depths, at the 35 cm distance. The differences between the treatments were sharper at depths of 30 and 90 cm than at 60 cm. The SWC of T_4 declined with depth. At a distance of 70 cm from the trickler the SWC decreased at all depths in all three treatments. The greatest decrease was recorded at the 0 - 30 cm layer. The soil water content of T_4 decreased more than that of the rest of the treatments.

At the distance of 105 cm from the trickler the SWC of T_1 and T_3 was lower than at the 70 cm distance in the 0 - 30 cm layer, but the same at the 30 - 60 and 60 - 90 cm layers. T_4 remained at wilting point in the upper layer at both distances, but slightly above wilting point in the lower two layers, albeit considerably lower than T_1 and T_3 .

Control of SMP by the automated irrigation

The daily fluctuations of SMP in the -10kPa and -15kPa threshold treatments are presented in Figs. 11-13 as a

representative example of the effect of the SMP on the opening and closing of the irrigation system during the 24-hr period. It is seen that over- and undershooting were relatively low.

Root distribution

The number of roots along the tree row, decreased slightly in T_1 , T_4 and T_5 , as a function of the distance from the emitters, in the 0 - 20 cm layer (Figs. 14, 15). At deeper layers no such decrease was noted. Most of the roots were concentrated on the 0 - 40 cm layer, while only very small concentrations of roots were recorded below 60 cm.

The average density of roots for the 0 - 120 cm profile was highest in T_1 and lowest in T_5 . The differences were mainly due to the distribution in the 0 - 20 cm layer. The density of roots observed normal to the lateral varied less among the treatments at all distances and depths. Figs. 16, 17). In T_5 the number of roots was slightly higher than in other treatments. The differences increased at distances of 120 - 200 cm, with T_5 having the highest and T_1 the lowest root density. The longer distances relate to roots outside the drip irrigation zone.

Yields and their components

The yields in cv Golden Delicious (Gl.) were higher in 1985 and 1987 than in 1986, due to alternate bearing (Table 2). In cv Jonathan (J) the yields were higher in 1985 and lower in 1986 and 1987. In both cultivars the yields of T_4 and T_6 were lower than in the other treatments, especially in the "on" years. The average number of fruit per ha in Gl. for the years 1985-87 was lower in

T₄ and T₆ than in the other treatments (Table 3), though the decrease in T₆ was not statistically significant. In J. the average number of fruit for the three years was significantly lower in both T₄ and T₆ than in the rest of the treatments. There was no significant variation in fruit size in either cultivar in any of the treatments (Table 3).

Growth rate of fruit

The growth rate of fruit in both cultivars, throughout the three years of experiment, was linear and no disturbances due to water stress were apparent (Figs. 18-20).

It is important to note that, despite the lower quantities of water applied in T₄ and T₆, the growth of the fruit was not affected and no significant differences were observed under these treatments, in comparison with the others. It should also be noted that these figures do not represent the absolute size of the fruit and should be used only for analyzing the rate of growth of the fruit - for the detection of water stress effects.

Fruit quality

Fruit quality, as expressed in terms of %T.S.S., acid content and firmness was satisfactory and was not greatly affected by the irrigation treatments in either cultivar throughout 1985-87. Small differences, sometimes significant, expressed in occasional increase in T.S.S., acid content and firmness, were recorded in T₄ and T₆ compared with the other treatments (Tables 4, 5). Such differences were small and do not represent any meaningful differences in quality.

Physiological measurements

Leaf temperatures were higher in T₄ and T₆ (-15 kPa threshold) on shoots without fruit than in the rest of the treatments (Table 6). In T₅ leaves on fruit-bearing shoots had lower temperatures than elsewhere among the treatments. The stomatal resistance of T₄ and T₆ was higher, and the transpiration rate lower, than in other treatments, both as regards fruit-bearing shoots and non-bearing shoots. In all treatments leaf temperatures and stomatal resistance were lower, and transpiration higher, on fruit-bearing shoots than on others. In measurements conducted on August 31, 1987, no significant differences were found in leaf temperatures, photosynthetic rates, stomatal conductance and intercellular CO₂ among the treatments T₁, T₄, T₅ and T₆ (Table 7).

Leaf mineral content

Since no significant differences in leaf mineral content were apparent between any of the different treatments, the average for all treatments for each year 1983-87, in both cultivars, is presented in Figs. 21 and 22. In both cultivars N and K decreased continuously through the seasons in all years, while Ca and Mg increased. P decreased in both cultivars, with the exception of the single case of Gl. in 1985. Variability was apparent between one year and another in P, K and Mg, but N and Ca contents were less variable. No relationship was apparent between mineral content and yield or growth parameters. The level of minerals was maintained at a normal level throughout the period, and no Ca-deficient values were noted, due to the fertilization program.

Fruit mineral content

All mineral concentrations declined continuously, in both cultivars, over the period (Figs. 23, 24). This decline is a result of dilution, due to the increase in fruit weight and volume. It is interesting to note that in 1987 the mineral concentrations in both cultivars were relatively high, despite the big differences in crop load and total yield (Tables 2, 3). The N:Ca ratio was low, and consequently a very good keeping quality was obtained, after 5 months in cold storage.

Gains in trunk cross-section and crop load

The gain of the cross-sectional area of the trunk was high in 1985 and much lower in subsequent years, in both cultivars and in all treatments (Table 8). Accumulated gain for the three years of experiment was lower in T₄ and T₆ than in the other treatments.

The crop load was higher in Gl. than in J. (Table 8). In T₁ and T₄ the average crop load was the same, due to a similar reduction in yields and growth.

DISCUSSION

The last three years of experiment (1985-87) generally confirm the results of the previous years (1982-84) (3). Automated irrigation controlled by SMP sensors resulted in a reduction of 10% in the water consumption, when -10 kPa was maintained at a distance of 30 cm and a depth of 35 cm from the trickler, compared with irrigation according to a Class A evaporation pan (Table 1). Irrigation according to measurements by neutron probes resulted in a similar saving in water consumption. This is to be expected, since both sensor and probe methods maintained a constant SMP in the root zone. Water availability was always constant, even when water consumption varied according to the needs of the tree at various stages of growth, vegetative and reproductive development and crop load and their interaction with climate. When SMP was maintained at -15 kPa, at the same distance and depth to the trickler, water consumption dropped by about 20%, compared with pan evaporation (T_5). This irrigation regime resulted in a smaller volume of wetted soil (Figs. 9, 10, 16, 17) and root growth was restricted to a smaller volume of soil.

In spite of the reduction in the quantities of water applied in T_4 and T_6 , no symptoms of water stress were detected. Fruit size was not reduced and the rate of fruit growth was linear: two parameters that have been found to be very sensitive to water stress (1, 2, 4, 5, 6, 7). Nor were the rate of photosynthesis or the intercellular CO_2 concentration significantly affected by the reduction in the volume of irrigated soil in T_4 and T_6 (Table 7) two more known and sensitive indicators of water stress

(7, 13, 14).

Additional evidence for the absence of water stress in T_4 and T_6 is given by the lack of differences in fruit quality, as expressed by TSS, acid content and firmness. The effects of water stress on ripening and on fruit quality have been noted by many researchers (2, 6, 8, 9, 10).

The higher leaf temperatures and stomatal resistance found in T_4 and T_6 , when compared with T_1 and T_2 (Table 7), may be attributed to the reduction in vegetative growth and increased exposure to sunshine. Higher stomatal resistance may also be due to the alteration of growth regulators produced by the roots under conditions of root restriction (11, 12).

Figs. 9, 10, 16, 17 show clearly that the volume of irrigated soil in T_4 and T_6 was smaller than in the rest of the treatments. The soil water content at distances of 70 and 105 cm from the dripper was lower at all depths. It seems, therefore, that the control of SMP by automated irrigation provides a means to control the size of the active root volume, resulting in smaller trees in which the crop load, as expressed by the ratio of yield to increment in the cross-sectional trunk area, is not affected. These results point to the possibility of growing denser orchards, with an increased number of trees per area unit, thereby compensating for the reduction in net yield per tree, while improving fruit quality by improved light penetration and the increase of efficiency in various practices of cultivation, such as pruning, spraying, etc. Finally, harvesting efficiency would be increased.

DESCRIPTION OF CO-OPERATION

Dr. Phene visited Israel twice, in 1982 and 1983, to calibrate the sensors and instruct on system design.

The Israeli partners visited Dr. Phene in Fresno, CA, for training and to learn the operation of the system; Dr. Assaf in 1984 and 1985, Dr. Levin in 1985 and Dr. Bravdo in 1985 and 1987.

EVALUATION OF THE RESEARCH ACHIEVEMENTS

1. An automated irrigation system consisting of SMP sensors and a computer were successfully operated in a high-yielding apple orchard for six years. To the best of our knowledge, no information has been published on similar studies in fruit trees.

2. Measurements showed that water percolation down to soil layers below the root zone was minimized. The system thus provides a means to approach the target of irrigating at the rate of consumption at two levels of SMP.

3. The response of the trees to treatments at two levels of SMP satisfied expectations in the following aspects:

- a) significantly less water was used at the lower SMP level;
- b) The treatment at the lower SMP level resulted in a reduced volume of wetted soil and consequently a reduced root volume;
- c) Vegetative growth and yield were lower in this treatment, but fruit size remained constant.

4. The fruit load, expressed as yield per unit of trunk area increment was equal in all treatments at the end of the second three-year experimental period. These results show that restricting the root system by controlled irrigation under field conditions reduced vegetative growth without reducing productivity (i.e. the ratio of reproductive to vegetative growth increased). It is expected that this technique of irrigation will allow more trees to be planted per hectare. This would reduce agrotechnical operating costs, and improve light penetration into the canopy, and consequently improve fruit quality and possibly even bud fertility. Such a technique might be able to replace the use of dwarfed root-stocks.

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TABLE 1

Treatment Details and Total Water Applied (mm)

Treatments	Application mode & SMP* thresholds	Total water amounts (mm)			
		1985	1986	1987	Average
T ₁	Electr.** -10kPa	722	766	782	763
T ₂	HDS*** -10kPa	742	765	779	762
T ₃	Neutron probe	692	779	797	756
T ₄	Electr.** -15kPa	617	660	656	644
T ₅	Pan evaporation	786	883	844	838
T ₆	HDS*** -15kPa	653	698	673	675

* Soil matric potential

** Electrotensionmeters

***Heat dissipation sensors

TABLE 2

Apple Yield (t/ha) in Two Cultivars

CV.	Treatment	1985	1986	1987	Average
Golden Delicious	1	90	80	104a	90a
	2	84	79	110a	91a
	3	87	74	103a	88a
	4	67	61	87b	72b
	5	93	73	113a	93a
	6	82	75	91a	83a
Jonathan	1	67	35	33a	45a
	2	74	35	33a	47a
	3	64	33	41a	46a
	4	43	30	25b	33b
	5	64	44	34a	47a
	6	53	37	30ab	40ab

Significant differences by letter separation; $p = 0.05$.

TABLE 3

Number of Apples (10^{-3} /ha) and Weighted Average of Size (ϕ cm)

Treat -ment	1985		1986		1987		Average	
	No.	Size	No.	Size	No.	Size	No.	Size
1	6.95a	6.64	6.58a	6.47	9.28a	6.20	7.60a	6.46
2	6.35a	6.71	6.24a	6.60	9.39a	6.33	7.33a	6.55
cv3	6.80a	6.63	6.33a	6.38	8.80a	6.33	7.31a	6.45
Gl4	5.25b	6.61	5.68b	6.16	7.59b	6.28	6.17b	6.36
5	7.16a	6.67	6.26a	6.39	10.05a	6.22	7.82a	6.43
6	6.35a	6.64	7.00a	6.16	8.18ab	6.21	7.18a	6.34
1	5.85a	6.48	3.37a	6.18	2.94a	6.43	4.05a	6.36
2	6.50a	6.48	3.39a	6.22	2.93a	6.38	4.27a	6.36
cv3	6.08a	6.27	3.19a	6.18	3.70a	6.38	4.32a	6.28
J4	3.90b	6.38	2.87b	6.19	2.32b	6.34	3.03b	6.30
5	5.40a	6.57	4.26a	6.20	3.07a	6.38	4.24a	6.38
6	4.64ab	6.47	3.76a	6.21	2.66ab	6.43	3.69b	6.37

Significant differences by letter separation; $p = 0.05$.

TABLE 4

Fruit Quality in cv Golden Delicious

Para- meters	Treat- ment	1985	1986	1987	Average
% T.S.S.	1	12.96	15.00	12.96	13.64
	2	12.83	14.89	12.71	13.48
	3	12.91	15.06	12.35	13.44
	4	13.07	15.59	13.00	13.89
	5.	12.41	14.95	12.46	13.27
	6	13.69	16.07	12.63	14.13
	Average	12.98	15.16	12.69	13.64
	S.E.	0.155	0.175	0.097	0.118
Firmness lb/in ²	1	17.50	19.30	19.00	18.27
	2	17.35	18.30	19.45	18.37
	3	17.50	19.00	19.10	18.50
	4	17.20	19.80	19.25	18.75
	5	17.10	19.40	20.00	18.83
	6	17.35	19.80	18.70	18.62
	Average	17.33	19.10	19.25	18.56
	S.E.	0.060	0.256	0.165	0.081
% Acid*	1	0.46	0.32	0.60	0.46
	2	0.46	0.35	0.63	0.48
	3	0.47	0.37	0.64	0.49
	4	0.49	0.37	0.65	0.50
	5.	0.47	0.39	0.57	0.48
	6.	0.44	0.36	0.60	0.47
	Average	0.47	0.36	0.62	0.48
	S.E.	0.006	0.009	0.011	0.005

* Calculated as malic acid.

TABLE 5

Fruit Quality in cv Jonathan

Para- meters	Treat -ment	1985	1986	1987	Average
% T.S.S.	1	14.10	14.80	13.96	14.29
	2	13.75	14.30	13.70	13.92
	3	13.88	15.12	14.03	13.34
	4	13.87	14.43	14.05	14.12
	5	13.40	13.87	14.38	13.88
	6	14.13	15.02	13.98	14.38
	Average	13.86	14.59	14.02	14.16
	S.E.	0.099	0.178	0.081	0.081
Firmness lb/in ²	1	15.5	18.7	19.00	17.73
	2	16.0	19.8	17.45	18.42
	3	16.5	19.4	19.10	18.33
	4	16.9	18.4	19.25	18.18
	5	16.9	17.8	20.00	18.23
	6	16.4	19.0	18.70	18.03
	Average	16.37	18.9	18.90	18.15
	S.E.	0.202	0.266	0.166	0.092
% Acid*	1	0.61	0.64	0.60	0.62
	2	0.63	0.71	0.63	0.66
	3	0.59	0.67	0.64	0.63
	4	0.59	0.70	0.45	0.65
	5	0.67	0.69	0.57	0.64
	6	0.65	0.75	0.60	0.67
	Average	0.62	0.69	0.62	0.65
	S.E.	0.012	0.014	0.011	0.007

* Calculated as malic acid.

TABLE 6

Tree Response to Three Extreme Treatments
 (cv. Golden Delicious. Measurements 10:00 - 12:00)

Without Treatment	Transpiration (mg/dcm ² /hr)		Stomata resistance (sec/cm)		Leaf temperature (°C)	
	With fruit	Without fruit	With fruit	Without fruit	Without fruit	With fruit
-10 kPa	5928a	5493a	1.37a	1.50a	33.5a	33.6a
Pan evap. coefficients	5149a	4837a	1.38a	1.68a	30.3b	32.0a
-15 kPa	4440b	3818b	2.27b	2.74b	35.4a	37.0b

Significant differences by letter separation; p = 0.05.

TABLE 7

Effect of Different Irrigation Treatments on Photosynthesis
and Some Related Parameters in Apple Trees

Treatment	Leaf temp.	Cell temp.	CO ₂	PM	CM	Int. CO ₂
1	39.9	38.9	306	17.2	370	203
4	39.9	39.3	284	16.0	483	190
5	40.2	39.5	292	17.6	609	214
6	40.0	38.5	302	11.8	307	215
Average	39.9	39.1	296	15.6	447	205

PM = Photosynthesis - $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$

CM = Leaf conductance - $\mu\text{mol H}_2\text{O m}^{-2} \text{ s}^{-1}$

CO₂, Int. CO₂ - ppm.

TABLE 8

Gain in Trunk Cross-section Area (cm²)
and Crop Load (kg/cm²gain)

Treat -ment	1985		1986		1987		85-87	
	Gain	Crop load	Gain	Crop load	Gain	Crop load	Total gain	Av. load
1	15.9	6.8	6.7	14.3	3.8	32.9	26.4a	18.0
2	13.8	7.3	7.5	12.7	6.1	21.6	27.4a	13.9
cv. 3	15.6	6.7	8.4	10.7	8.5	14.6	32.5a	10.7
Gl. 4	7.9	8.3	4.4	16.6	3.6	29.2	17.7b	18.0
5	11.9	9.3	7.1	12.4	3.7	36.8	22.7ab	19.5
6	12.0	8.3	6.1	14.8	3.5	31.7	21.6ab	18.3
1	14.6	5.5	4.8	8.8	7.8	5.1	27.2a	6.5
2	11.9	6.7	4.6	9.2	9.5	4.2	26.0a	6.7
cv. 3	9.3	8.3	8.5	4.6	8.6	5.7	26.4a	6.2
J. 4	12.8	4.0	4.1	8.7	7.2	4.3	24.1ab	5.7
5	16.0	4.8	3.7	14.3	8.2	5.0	27.9a	8.0
6	10.4	6.1	3.7	11.9	7.9	4.6	22.0b	7.5

Significant differences by letter separation; p = 0.05.

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Fig. 1. Soil Water Retention Curve

Fig. 2. Hydraulic Conductivity vs. Soil Water Content.

Fig. 3. Sensor operation chart

Fig. 4. Class 'A' pan evaporation

Fig. 5. Seasonal soil water content (Neutron probe counts) of T_1 and T_2 in 1987, in 3 soil layers and 2 distances from emitter.

Fig. 6. Seasonal soil water content (Neutron probe count) of T₁ in 1987 in 3 soil layers and 2 distances from emitter.

Fig. 7. Seasonal soil water content (Neutron probe count) of T₄ and T₆ in 1987 in 3 soil layers and 2 distances from emitter.

Fig. 8. Seasonal soil water content (Neutron probe count) of T_1 in 1987 in 3 soil layers and 2 distances from emitter.

Fig. 9. Diurnal soil water content (Neutron probe count) in 3 soil layers and 3 distances from emitter.

Fig. 10. Diurnal soil water content (Neutron probe count) in 3 soil layers and 3 distances from emitter.

Fig.11. Diurnal SMP in T1. 22 - 29 of July.

Fig.12. Diurnal SMP in T4. 22 - 28 of July.

Fig.13. Diurnal SMP in T2 and T6. 22 - 23 of July.

Fig.14. Root distribution along the tree row in different soil layers of the 0-120 cm profile, in 3 treatments.

Fig.15. Root distribution along the tree row in the 0-120 cm soil profile

Fig.16. Root distribution normal to the tree row in different soil layers of the 0-100 cm profile in 3 treatments

Fig.17. Root distribution normal to the tree row in the 0-100 cm soil profile

Fig. 18. Seasonal fruit growth of cvs. Golden Delicious and Jonathan in 1956.

Fig. 19. Seasonal fruit growth of cvs. Golden Delicious and Jonathan in 1986.

Fig. 20. Seasonal fruit growth in cvs. Golden Delicious and Jonathan in 1987.

Fig. 21. Leaf mineral content (% dry matter) in cv. Golden Delicious.

Fig.22. Leaf mineral content (% dry matter) in cv. Jonathan.

Fig. 23. Mineral content of whole apples (% dry matter) in cv Golden Delicious.

Fig. 24. Mineral content of whole apples (% dry matter) in cv. Jonathan.