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**Otimization of Water and Fertilizer Application by
Automated Low Volume Irrigation for Citrus**

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Abstract

Two fertirrigation field experiments, one in Israel and one in Florida were conducted. Shamouti orange on Palestinian sweet lime rootstock inarched by sour orange was used in Israel, at the regional orchard of Emek Hefer. The experiment in Florida was conducted on Valencia oranges at Lake Alfred.

In Israel, 11 fertirrigation treatments were applied in which the interaction between the watered root zone volume and level of NPK fertilizer was studied. Variation in the volume and distribution of the wet root zone was induced by irrigating with microsprinklers at weekly vs. daily intervals and by 2, 4 or 8 drippers per tree with 8, 4 or 2 l/h emission rate per emitter, respectively. Electrotensiometers and class A evaporation pan were used for determining the amount of irrigation water. In Florida 3 methods of irrigation — drip spray and undertree sprinklers, 3 levels of nitrogen fertilization and two levels of irrigation controlled by electro soil moisture tensiometers using tensions of 10 and 30 kpa for initiating the two irrigation treatments were studied. In Israel, a significant increase in yield, number of fruits and leaf NPK content with the increase in the fertilizer dose was recorded. No significant influence of the volume of the irrigated soil and of the intervals between microsprinklers irrigation treatments were noted. A tendency for higher yield in the combination of 4 drippers per tree with high fertilization dose was observed during 4 successive years. In Florida no significant differences in yields were obtained between the irrigation treatments or the N application rates although a tendency for an increase with increasing irrigation water was obtained.

Abstract

Two fertirrigation field experiments, one in Israel and one in Florida were conducted. Shamouti orange on Palestinian sweet lime rootstock inarched by sour orange was used in Israel, at the regional orchard of Emek Hefer. The experiment in Florida was conducted on Valencia oranges at Lake Alfred.

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Objectives of the original research proposal

The objectives of the original proposal were as follows:

- a. Determine the consumption rate of water use for optimal production of citrus yields.
- b. Develop and test an automatic monitoring and control system for applying water and fertilizers at the rate of consumption for different levels of water and mineral concentrations in the soil.
- c. Determine the concentration of nitrogen in the soil solution conducive to production of optimal yields and fruit quality.
- d. Increase the efficiency of water and fertilizer use by preventing leaching to soil layers below the root zone. This will also prevent pollution of the underground water.

The use of electrotensimeters for controlling the irrigation no doubt supplies water at the rate of consumption. This device operates continuously and is capable of changing the rate of consumption by keeping the SMP at various levels. The trees adjust to the water regime dictated by the electrotensimeters by changing their vegetative growth and leaf area. In Israel, the amount of irrigation water applied to all treatments did not vary. However, soil moisture readings indicated almost no percolation of water and the yields were very high reaching 94 t/ha. This may indicate that the amounts of water applied in combination with the fertilization was not far away from the optimum. Nevertheless, the system developed within this project enables us to study the effect of controlled root environment in terms of SMP, mineral concentration and composition and the volume of the irrigated soil. This also opens new possibilities of studying the effect of changing these factors at various stages of growth and development, such as flowering, ripening time, etc. In conclusion, there were achievements in all the objectives although complete optimization probably has not yet been reached. Further studies

in Israel are needed to attempt a further increase in yield and quality. Experiments based on the methodologies developed in Israel need to be carried out in Florida in order to obtain responses to fertilizer doses and amounts of water application.

Materials and Methods

An irrigation and fertilization experiment was established in the Emek Hefer citrus orchard located in the central coastal region of Israel. A 25-year-old Shamouti orange orchard, planted at $6 \times 4\text{m}$ distances, originally Shamouti $\times$ sweet Palestinian lime rootstock inarched by sour orange rootstock 7 years after planting, was used for this experiment. This is a typical orchard for the central coastal area of Israel. The soil characteristics are given in Tables 1 and 2. The orchard was irrigated by overhead sprinklers until the commencement of the present experiment in 1983. In order to conduct the experiment a new irrigation system was installed in May 1983. The experimental design consisted of 11 treatments arranged in 5 randomized blocks, 4 trees per replicate arranged in a quadrangle and surrounded by one guard row, i.e. each replicate consisting of 16 trees out of which the 4 inner trees served for measurement and analysis.

Eight drip and 3 microsprinkler irrigation treatments were applied (Table 3). Treatment 1 served as control representing the best irrigation regime as obtained in a former experiment conducted in Nordia, about 10 km distance from the present experimental site.

Treatments 1, 2 and 3 were designed to compare daily *vs.* weekly irrigation at the same level of fertigation and daily irrigation at two levels of fertilization.

Treatments 4, 5, 6 and 8, 9, 10 were designed to compare 4 *vs.* 8 drippers per tree (one *vs.* two laterals) at 3 levels of fertilization and at the same rate of water emission (32 l/t/h). Treatments 7 and 11 were designed to compare an extreme restricted volume of irrigated soil (2 drippers per tree) *vs.* extended volume of irrigated soil (8 dripper per tree) at the same rate of water emission (16 l/h/tree). All dripper were pressure regulated button type 'Netafim Ltd.' Israel. All microsprinklers were 70 l/h 'Ein Tal'

Ltd. Israel.

Treatment 1 was irrigated at a 1 week interval whereas treatment 2 and 3 were irrigated daily. All the rest of the treatments were irrigated daily. From 1983 to 1988 irrigation was controlled by a Motorola 2000 irrigation computer. All drip treatments received 6 pulses of 1 to 2 hours 'on' and 0.5 to 1 hour 'off' according to the daily amount of irrigation determined by class A pan evaporation using a coefficient of 0.6. The annual amount of precipitation in this area is 500 mm limited to the period between October and May.

A 7:3:7 fertilizer — product of Fertilizers and Chemicals Ltd. (Haifa, Israel) was applied through the irrigation water from April to September each year. This fertilizer contains 7.5% N (4.5% N-NO₃ and 3% N-NH₄ by weight) 3.2% P₂O₅ (by weight) 6.5% K₂O (by weight) and 3% Koratin (a standard mixture of microelements). The fertilizers were injected by means of venturi pumps and the three levels of fertilizer concentration 30, 60, 100 ppm N presented in Table 3 and all other tables where the level of fertilization is presented refer in fact also to P and K at the proportion of 7.5:3.2:6.5 of N:P₂O₅:K₂O.

In 1989 a new computerized system consisting of electrotensiometers (Ami Ltd. Israel) SMP sensors (heat pulse, phene type) and a Meik 2000 (PCU-10) computer (Motorola Inc.) for the irrigation control. The sensors were placed in block 5 of treatments 5 and 9 which served as leading plots for the irrigation of treatments 4, 5, 6 and 8, 9 10 respectively.

Three sensors of each type were installed at a 30 cm depth and distance from the drippers in 3 out of the four trees in the plots. The irrigation was activated whenever the SMP dropped below a predetermined threshold value, programmed into the computer.

The computer screened all the sensors every 20 minutes, averaged the SMP values and activated the irrigation according to the average

threshold value. A constant amount of irrigation water was applied every morning between 5 and 9 am (about 3 mm in the middle of the season) regardless of the sensors readings. Only then was the irrigation activated by the SMP sensors. This procedure was aimed at reducing the fluctuations due to over and undershootings. Only the electrotensiometers were used for controlling the irrigation whereas the SMP pulse heat sensors were used just for monitoring. The operating flow chart is presented in Fig. 1A.

The crop of each tree was weighed each year at harvest time. Size distribution of the fruit and average fruit size were measured on samples of 20 kg per tree. Fruit quality was assayed on a sample of 12 fruits per tree. The quality measurement consisted of TSS by refractometry, total acidity by titration and peel thickness by a calliper.

Leaf water potential was measured by a scholander type pressure bomb and photosynthesis and related parameters by a Licor 6000 portable system. Trunk diameters were measured once a year at a constant point on the trunk marked by color. In trees with more than one trunk the values were added. Leaf mineral analysis was conducted once a year using standard water extraction methods. The advantage of this method is demonstrated in Tables 20, 21.

Cultural practices

In 1983, the orchard was severely pruned. The height of the trees were limited by topping to 3.5 m and a 2 m distance between canopies of adjacent rows was maintained by hedging. This procedure was executed every other year.

Results and Discussion

The amounts of water and fertilizers applied are presented in Tables 5 and 6. Due to the severe pruning in 1983 the yields were low and meaningless in the harvest of January 1984 and January 1985. In the spring of 1985 the bloom was severely damaged by frost and consequently low and variable yields were obtained at the harvest of January 1986. Table 6 presents the yields harvested in that year. Although the yields were relatively low, initial effects of irrigation and fertilization were apparent. The lowest yield was obtained in treatment 4 — i.e. 2 laterals 8 drippers per tree and 30 ppm N in the irrigation water. The highest yields were obtained in treatment 3 — daily microsprinkler, 100 ppm in the irrigation water. There was a tendency towards higher yields in the daily microsprinkler and one lateral of drip irrigation and of increasing yields with the increase in fertilizer concentrations of the irrigation water. Nevertheless, no conclusions should be drawn due to the low yields obtained this year.

The yields harvested in January 1987 were very high and the effects of the irrigation and fertilization treatments were more obvious and significant than in the January 1986 harvest (Table 7). The highest yields were obtained in treatment 10, and the lowest in treatment 4, similar to the previous years results (Table 6). No differences were observed between the microsprinkler treatments and their yields were high as well. Table 7 also shows that the main effects were due to the fertilization rather than the irrigation methods. Increasing the nutrient concentrations in the irrigation water resulted in an increase in yields and this effect tended to be greater in the one lateral treatment 8, 9, 10 than in the two lateral treatments 4, 5, 6. Treatments 7 and 11 did not differ significantly in their yields although treatment 7 was slightly lower.

The average fruit weight was the highest in treatment 7 and the

lowest in treatment 10. It seems that in these two extreme treatments the average single fruit weight was inversely related to the crop yields but nevertheless, the average single fruit weight was increased with the increase in the level of fertilization (Table 8). Similarly, the number of fruits per tree was positively related to the crop yield in the two extreme treatments 7 and 10 but the average fruit size for each drip fertilization level was increased with the increase in the concentration of the fertilizer in the irrigation water (Table 8). Within the treatments subjected to high fertilization level there was a perfect inverse rank correlation between yields and average single fruit weight and a positive correlation ($r = 0.9$) with the number of fruit per ha. The correlation coefficients of these parameters in the medium fertilization level (60 ppm) were lower. It seems therefore that the major effects on the yields were due to the level of fertilization rather than to the method of irrigation. The increase in yields was due mainly to the increased number of fruit since within each level of fertilization the number of fruit increased while the average single fruit weight decreased with the increase in yields.

The volume of irrigated soil did not seem to be a limiting factor. A tendency for increasing yields and number of fruit and decreasing fruit size was apparent in treatment 10 which had 4 drippers per tree and a high fertilization level (100 ppm N in the irrigation water).

In 1988 the yield of treatment 10 was the highest but did not differ significantly from the other drip treatments which were fertigated by the high fertilizer concentration (Table 10). The lowest yield was obtained in treatment 4. Although the yields were slightly lower in 1988 due to the 'off' year the ranking of the yields of most treatments was similar to 1987 and so were the conclusions. Again the major effects were due to the fertilizer concentration rather than to the method of irrigation. The average fruit weight was the highest in treatments 2 and 9 and the lowest

in treatment 11 (Table 11). Overall the average fruit weight of the highly fertigated treatments was slightly decreased and the number of fruit increased with the increase in the fertilization level (Table 12). Within the highly fertilized (100 ppm) drip irrigation treatments there was a perfect positive rank correlation ($r = 1.0$) between the number of fruits and the yields but no correlation existed this year between the crop levels and the average fruit weight. It seems therefore that the yield of this year (January 1988 harvest) were more strongly related to the number of fruits than to the average fruit weight as compared with the previous year's results.

In 1989 the yields were slightly higher than in 1988 (Table 13). Unfortunately the crop was harvested right after a severe frost and the frozen fruits lost about 10–15% weight. Nevertheless, the ranking of the yields were very similar to that of the former three years. The highest yields were obtained in treatment 10 for the fourth year in a row. The lowest yields were obtained in treatment 4. Again major effect on yields was the concentration of the nutrients in the irrigation water rather than the method of irrigation (Table 13). The increase in yields due to the fertilization was more significant than in previous years. The volume of the irrigated soil was not a limiting factor. There was no difference in crop yield between treatments 7 and 11, namely 2 vs. 8 dripper per tree. On the other hand, the low irrigated soil volume treatment 10 ranked as number 1 in yields during four successive years. It seems therefore that a combination of root restriction and high fertilizer concentration has some advantages. However, since the difference in yields between treatment 10 (4 dripper per tree) and treatment 6 (8 drippers per tree) was not significant for each specific year this hypothesis requires further proof. It is important to note however that root restriction by drip irrigation does not reduce yields. Due to many technical advantages of drip irrigation over other irrigation methods it seems that the relatively scarce use of drip irrigation

as compared to other irrigation methods in the coastal area of Israel as well as in many other citrus growing countries is inconsistent with the results of this experiment.

The average single fruit weight was not affected in 1989 by either the crop level or the fertilizer concentration (Table 14). The number of fruit per ha was the highest in treatment 10 and lowest in treatment 4. The concentration of the fertilizers in the irrigation water has significantly affected the number of fruits in all treatments (Table 15). In the high fertilizer concentration treatments a high rank correlation was found between the crop yield and the number of fruit ($r = 0.825$). It seems therefore that in this year the crop yield was determined only by the number of fruits whereas the single fruit weight was not affected at all.

It may be concluded that during the four experimental years a few facts and processes were apparent — (a) the concentration of the fertilizers in the irrigation water has significantly increased the yields in all years and the level of significance was consistently increased from year to year. (b) Treatment 10 with 4 drippers per tree always had the highest yields. This may indicate the advantage of root restriction when combined with high concentrations of fertilizers in the irrigation water. (c) Extreme root restriction of 2 drippers per tree did not affect the yields, fruit size or number of fruits. (d) At the beginning of the four experimental years fruit size was negatively related to the yields within the high fertilization level treatments. During the experimental period the fruit size effect on the yields consistently diminished until the last year, 1989, where no difference in the single fruit weight was apparent. (e) The effect of the concentration of the fertilizers in the irrigation water was mainly on the number of fruits. The significance of this effect has increased during the experimental period. It seems that there was a cumulative effect of the fertilization on the trees, resulting in an improved capability of the trees to

maintain a high number of fruits without interfering with fruit size. Unfortunately, in this experiment we did not have any reliable measure for crop load since it was difficult to estimate the growth component. We did not have means to measure leaf area index and the inarching of the trees (see methods) did not allow us to obtain a reliable measure of trunk cross sectional area increment (data not shown due to high variability).

Leaf mineral analysis

In the first experimental year 1983 there was no effect of irrigation and fertilization treatment on leaves (N-NO₃ (Table 16), P (Table 17) and K (Table 18)) content. In 1987, the leaf mineral analysis was made using two methods — ashed and water soluble. The water soluble fraction resulted in more significant differences between the levels of fertilizers in the irrigation water regarding N-NO₃, P and K (Table 19). A comparison between microjects and drip irrigation using 8 and 4 dripper per tree showed no significant differences among the ashed leaves in N, P, K, Mg (Table 20). In water soluble fraction, there was a slightly higher P content in the 4 dripper per tree treatments (Table 21).

The leaf mineral analysis in 1988 shows a highly significant effect on the N-NO₃ due to the fertilization treatment. The average N-NO₃ content for all treatments regardless of the irrigation methods was increased with the increase in the fertilizer concentrations in the irrigation water and this occurred without exception in all irrigation treatments where fertilizer concentrations were varied (Table 22). The phosphorous content (water soluble fraction) was significantly affected by the level of fertilization when the figures were averaged regardless of the method of irrigation (Table 23). Within each method of irrigation, the increase due to higher fertilizer dose was significant only in the daily microjects irrigation treatments No. 2 and 3. In the drip irrigation treatments only a tendency for this increase was apparent. No significant differences were apparent in

the K content of the leaves (Table 24). Magnesium content was increased by the NPK fertilization dose in the one lateral treatment 8,9,10 as well in the overall average of the three fertilization levels regardless of the irrigation method (Table 25).

The levels of N-NO_3 in leaf samples taken in October 1989, similar to the results of 1988 responded well to the fertilization dose applied and the average content increased significantly regardless of the irrigation method (Table 26). Nevertheless there were also slight differences due to the irrigation. All the treatments which received 100 ppm N in the irrigation water had a N-NO_3 content which exceeded 100 ppm. Phosphorous content in the irrigation treatments did not vary significantly between treatments receiving 60 and 100 ppm N in the irrigation water similar to the results obtained in 1988. No significant differences in P leaf content were apparent within each fertilization level regardless of the irrigation method or the volume of irrigated soil (Table 27). Unlike the results of 1988 the leaf K content in the samples of 1989 were significantly affected by the fertilization dose. The absolute levels of K in the highly fertilized treatments were higher than in 1988 and exceeded 1.0% (Table 28). The Mg leaf content in the 1989 samples was not significantly affected by neither fertilization or the irrigation levels (Table 29).

Fruit quality

The TSS content of the fruit was not considerably affected by the irrigation and fertilization treatments. The results of the 1989 harvest are presented as a representative example (Table 30). No significant differences between the levels of fertilization were apparent, however, the average TSS of treatment 4, 5, 6 (8 drippers per tree) were significantly lower than the rest of the treatments although this difference was not considerable and was not apparent in the other experimental years (not shown). The acid content in the 1989 harvest also was not significantly affected by the

fertilization dose (Table 31) and neither was the sugar/acid ratio (Table 32). Percentage juice and peel thickness were not affected by the irrigation and fertilization treatments (Tables 33, 34). It can therefore be concluded that the irrigation and fertilization treatments did not affect any of the common quality parameters of the fruit.

Physiological measurements

Leaf water potential measurements conducted between 9 am to 1 pm several times throughout the experimental years did not vary significantly among the irrigation and fertilization treatments. The values of the water potential varied in the range of 1.6–1.7 Mpa. A representative sample is shown in Table 35. Photosynthesis and related parameters as measured by a portable Licor 6000 system varied significantly among the various treatments. No significant differences between 4 and 8 drippers per tree were apparent, however, the net photosynthesis and stomatal conductance were significantly affected by the level of fertilization in both irrigation methods. From Table 36 it is apparent that treatments 5 and 8 which received the lowest fertilization rate also had the lowest net photosynthesis and stomatal conductance. The similarity in the intercellular concentration indicates that the reduction in net photosynthesis was due to reduction in both stomatal and non stomatal conductance.

The reduced stomatal conductance in treatments 4 and 8 were associated with a slight increase in leaf temperature. It is apparent however that the fertilization dose rather than the volume of the irrigated soil was responsible for the reduction in the net photosynthesis rate.

Soil moisture measurements

A representative example of soil moisture measurements made during the summer of 1986 is presented herein. The soil moisture profile in treatment 1 which was irrigated by microsprinklers was uniform along the season and no differences were apparent between 30–60 and 90–120 cm depth (Fig. 1). At the 13th Julian day after a heavy rain the readings were taken at soil water saturation, whereas all other readings were taken 3 days after irrigation of the weekly microsprinkler irrigation treatment 1. In the daily irrigation treatments 2, 3 (Figs. 2, 3) there was a big difference between the 30–60 and 90–120 cm layers, and upper 30–60 cm treatment was wetter throughout the entire season. In both treatments there was a constant drying of the lower layer indicating no water percolation to layers below the main root zone. The upper layer 30–60 cm fluctuated probably due to the variation in the differences in timing between irrigation and measurements. In the daily microsprinkler irrigation treatments the upper layer served as the main source for the water consumption of the trees whereas the lower layer had a negative balance during the season due to the shallow irrigation applied in comparison to treatment 1 in which the whole profile down to 120 cm served as a reservoir of soil water for the trees (Figs. 1, 2, 3). In all drip irrigation treatments most of the water uptake was from the upper 60 cm layers. Among treatments 4, 5, 6 which were irrigated by the two laterals, there was a constant decline in the soil water content of both layers particularly in treatment 6 which received the highest fertilization dose (Figs. 4, 5, 6). It may well be that this treatment extracted relatively more water due to increased growth and leaf area. Unfortunately we have no quantitative data to confirm this since leaf area as well as trunk cross sectional area increment was difficult to measure (see methods). However the drop in soil water content at the lower layer indicates that no water percolation to deeper layers had

occurred. Among treatments 8, 9, 10 (Figs. 8, 9, 10) only in treatment 9 the soil moisture content of the lower layer declined whereas in treatments 8 and 10 the soil water content was almost stable throughout the season in both layers. The fluctuations in the water content of the 90–120 cm layer may indicate some water percolation. In treatment 7 that was irrigated by 8 drippers of 2 l/h soil moisture content of both layers consistently decreased throughout the season. This again indicates that no water percolation occurred at all in this treatment (Fig. 8). In treatment 11 there was a constant increase in the soil water content of the upper layer 30–60 cm whereas the lower layer 90–120 cm had an almost constant soil moisture content except on two dates towards the end of the season. Here again the fluctuations in the lower layer may indicate some water percolation. It is interesting to note that in all the drip treatments the lower layer was always wetter than the upper one probably due to the shape of the wetting bulb (onion shape) and the distribution of the roots that are a function of the interaction between water and mineral distribution and aeration. In the daily microsprinkler treatments the upper layer was always wetter.

Irrigation according to the rate of consumption by a computerized irrigation system

The computerized irrigation system did not work satisfactorily due to technical problems and financial difficulties. Only towards the end of 1989 did the system function satisfactorily. The irrigation was controlled in treatments 5 and 9 by 3 electrotensiometers. Treatments 4 and 6 and 8, 10 were irrigated according to treatments 5 and 9 respectively.

The heat pulse sensors (phene type – Aquatronic 11)) served only for monitoring the soil moisture content but not for irrigation control. Unfortunately no satisfactory results were obtained with these sensors. We cannot say at this stage whether the reason was technical only. From

August 25 to October 11 all treatments were set to irrigate at a threshold value of 12 Kpa. Over this entire period treatments 4, 5, 6 consumed about 35% more water than treatments 8, 9, 10 (data not shown). However, these values were affected by a few failures in the system. When readings of short intervals are compared it seems that the consumption of all treatments were similar regardless of whether they were irrigated by 4 to 8 drippers per tree. This question as well as the exact determination of the water consumption by the trees and their comparison with the common pan evaporation coefficients are now under investigation.

Conclusions

This experiment clearly demonstrated the following facts:

- a) A well established orchard of the age of 25 years or more can be converted from overhead sprinkler into drip or microsprinklers successfully. The root system is very flexible and can rapidly adjust to low-volume irrigation.
- b) The number of drippers per tree varying from 2 to 8 also affected the volume of the irrigated soil per tree. However no significant effect on the growth, yields or fruit quality, was apparent.
- c) No significant differences in yields were apparent between drip and microsprinklers within each year but one treatment with 4 drippers per tree and 100 ppm N, 40ppm P_2O_5 and 40ppm K_2O in the irrigation water had the highest yields and highest fruit number during 4 successive years.
- d) The major factor affecting the yields in this experiment was the level of fertilization. During 4 successive years yields as well as number of fruit were increased with the increase in the level of fertilization. The range of fertilizer dose was not wide enough for identifying the leveling off point in terms of fertilizer dose.

- e) The increase in yields was due mainly to the increase in the number of fruits per tree. Fruit size was initially decreased in the highly loaded treatments. During the years the trees probably accumulated enough leaf area in order to adjust for the high cropping and no differences in fruit size were apparent in the 4th experimental year.
- f) Very little, if any, percolation occurred in the various treatments. The significance of this fact is not only in water saving but also in eliminating ground water pollution by fertilizers.
- g) This experiment demonstrated that profitability of the Israeli citrus industry can be greatly increased and cost of production diminishes by controlling the soil and the canopy environment by automatization and mechanization.

Table 1. Mechanical composition of the soil (Emek Hefer 1983)

Depth (cm)	Sand %	Silt %	Clay %	Chalk
0-30	84.3	2.0	13.7	0
30-60	88.3	3.0	8.7	0
60-90	83.8	2.5	13.7	0
90-120	88.3	2.0	9.7	0
0-30	88.3	2.0	9.7	0
30-60	88.3	2.0	9.7	0
60-90	86.8	2.0	11.2	0
90-120	83.8	2.0	14.2	0
120-165	88.3	1.5	10.2	0

Table 2. Chemical composition of the soil in two representative plots
(Emek Hefer, 1983)

Soil depth (cm)	Conduct- ivity ds/m	Na meq/l	K meq/l	Ca-Mg meq/l	N-NO ₃ ppm	P ppm	Cl meq/l	pH	Satura- tion %
0-30	1.7	3.2	0.73	12.20	34.0	25.0	2.68	6.3	40.0
30-60	0.62	2.2	0.18	4.00	21.0	17.5	1.20	6.8	37.5
60-90	0.66	2.9	0.10	3.20	21.0	17.5	0.80	6.6	37.5
90-120	0.64	2.9	0.12	3.15	20.0	12.5	0.80	6.8	37.5
120-165	0.50	2.4	0.11	2.46	17.0	7.5	0.92	6.8	37.5
0-30	0-30	2.9	0.63	11.40	54.0	25.0	1.64	6.8	50.0
30-60	30-60	2.2	0.16	4.24	20.0	25.0	0.80	7.3	37.5
60-90	60-90	2.9	0.11	3.50	20.0	25.0	0.96	7.2	37.5
90-120	90-120	2.9	0.09	3.42	15.0	32.5	0.60	6.9	37.5
120-165	120-165	2.4	0.09	3.50	10.0	10.0	0.56	7.1	37.5

Table 3. Experimental Plan (Emek Hefer)

N concentration ppm	irrigation frequency	rate per tree 1/tree/h	rate per emitter (l/h)	emitters per tree	Treatment No.
60	weekly	70 l/h	70 l/h	1*M	1
60	daily	70	70	1 M	2
100	daily	70	70	1 M	3
30	daily	32	4	8*D	4
60	daily	32	4	8 D	5
100	daily	32	4	8 D	6
100	daily	16	2	8 D	7
30	daily	32	8	4 D	8
60	daily	32	8	4 D	9
100	daily	32	8	4 D	10
100	daily	16	8	2 D	11

*D - drip

*M - microsprinklers

Table 4. Amount of fertilizers applied to the experimental orchard, Emek Hefer (kg pure N per ha)

Treatment	1983	1984	1985	1986	1987	1988	1989
1	190	280	240	180	240	240	240
2	190	270	240	180	240	240	240
3	310	410	370	290	400	400	400
4	80	110	110	90	120	120	120
5	190	290	240	180	240	240	240
6	310	440	370	290	400	400	400
7	200	320	320	290	400	400	400
8	80	120	110	90	120	120	120
9	190	300	230	180	240	240	240
10	310	450	370	290	400	400	400
11	190	320	320	290	400	400	400

Table 5. Amount of water applied (mm) Emek Hefer experimental orchard

Treatment	1983	1984	1985	1986	1987	1988	1989
1	710	530	832	568	633	595	
2	772	559	630	568	606	642	
3	783	575	695	558	634	690	
4	730	584	707	512	585	642	
5	729	485	710	548	603	750	
6	732	577	730	502	608	848	
7	720	637	685	513	705	695	
8	711	539	720	529	595	770	
9	740	563	768	545	635	840	
10	725	536	725	540	590	755	
11	677	560	621	473	584	640	

Table 6. Effect of irrigation and fertilization on the crop yield (emek Hefer 1986)

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average

			30	60	100	
1	1 M weekly	10	11.1 cd			11.1
2, 3	1 M daily	10	17.2 bc 27.5a			22.3
4, 5, 6	8 D	4	7.6 d	16.8 bc	15.0 bcd	31.1
8, 9, 10	4 D	8	9.8 cd	16.0 bcd	21.8 ab	15.9
7	8 D	2	13.8 bcd			13.8
11	2 D	8	16.3 bc			16.3
Average			C8.7	AB 15.3	A 18.9	

Table 7. Effect of irrigation and fertilization on fruit yield (t/ha) Emek
Hefer Jan. 1987

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		78.2 ab		
2, 3	1 M daily	70		76.1 ab	82.7 ab	79.4
4, 5, 6	8 D	4	68.5 b	77.3 ab	78.9 ab	74.9
8, 9, 10	4 D	8	67.1 b	75.1 ab	93.8 a	78.6
7	8 D	2			68.4 b	
11	2 D	8			76.0 ab	
Average			C 66.5	B 76.7	A 85.1	

Table 8. Effect of irrigation and fertilization on the average single fruit weight Emek Hefer Jan. 1987

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		209 bcd		209
2, 3	1 M daily	70		217 bcd	211 bcd	214
4, 5, 6	8 D	4	208 bcd	212 bcd	229 abc	216
8, 9, 10	4 D	8	205 cd	215 bcd	196 d	205
7	8 D	2			242 a	242
11	2 D	8			231 ab	231
Average			C 206	B 213	A 222	

Table 9. Effect of irrigation and fertilization on the number of fruit per ha
Emek Hefer, Jan. 1987

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	10		373632 b		272623 b
2, 3	1M daily	10		364880 b	389900 ab	377390 ab
4, 5, 6	8 D	4	314835 b	391980 ab	349863 b	352226 b
8, 9, 10	4 D	8	330681 b	384612 b	478716 a	398003 a
7	8 D	2			295236 b	295236 bc
11	2 D	8			360288 b	260288 b
Average			B 322758	A 369879	A 374883	

Table 10. Effect of irrigation and fertilization on fruit yield (t/ha) Emek
Hefer, Jan. 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		55.4		
2, 3	1 M daily	70		48.0 bc	55.7 bc	51.8
4, 5, 6	8 D	4	39.6 c	52.1 bc	70.0 ab	56.3
8, 9, 10	4 D	8	49.5 bc	46.8 bc	71.7 a	56.0
7	8 D	2			59.2 ab	
11	2 D	8			57.2 ab	
Average			C 44.6	B 50.6	A 63.39	

Table 11. Effect of irrigation and fertilization on the average single fruit weight (g) Emek Hefer, Jan. 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		224 ab		224
2, 3	1 M daily	70		234 a	215 ab	224
4, 5, 6	8 D	4	230 ab	221 ab	226 ab	226
8, 9, 10	4 D	8	211 ab	232 a	207 ab	217
7	8 D	2			227 a	227
11	2 D	8			203 b	223
Average			224 a	228 a	216 b	223

Table 12. Effect of irrigation and fertilization on the number of fruit per ha
Emek Hefer, Jan. 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		257000 ab		257000
2, 3	1M daily	70		205100 bc	251900 ab	228500
4, 5, 6	8 D	4	172200 c	235700 b	313300 a	240400
8, 9, 10	4 D	8	234600 b	201700 b	346400 a	260900
7	8 D	2			260800	
11	2 D	8			281800	
Average			B203400	B225000	A292300	

Table 13. Effect of irrigation and fertilization on fruit yeild (t/ha) Emek Hefer, Jan. 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		62.5 bcd		
2, 3	1 M daily	70		62.5 bcd	71.7 abc	67.1
4, 5, 6	8 D	4	46.2 d	57.8 cd	80.0 ab	61.3
8, 9, 10	4 D	8	53.1 d	53.2 d	84.1 a	63.4
7	8 D	2			73.6 abc	
11	2 D	8			76.0 abc	
Average			C 49.6	B 59.0	A 77.1	

Table 14. Effect of irrigation and fertilization on the average weight of a single fruit Emek Hefer, Jan. 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		192		192
2, 3	1 M daily	70		202	178	190
4, 5, 6	8 D	4	204	202	203	203
8, 9, 10	4 D	8	190	193	199	194
7	8 D	2			206	
11	2 D	8			204	
Average			197	197	198	

Table 15. Effect of irrigation and fertilization on the number of fruit per ha
Emek Hefer, Jan. 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		326080 bcd		
2, 3	1M daily	70		312750 cd	363600 abcd	338175
4, 5, 6	8 D	4	232250 e	311670 cde	400000 ab	314640
8, 9, 10	4 D	8	283330 ed	305880 cde	428580 a	339263
7	8 D	2			357180 abcd	NS
11	2 D	8			374480 ab	
Average			C257790	B314020	A384770	

Table 16. Effect of irrigation and fertilization on N-NO₃ content of leaves (ppm), Emek Hefer, October 1983)

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		122 a		122
2, 3	1 M daily	70		106 ab	113 a	109
4, 5, 6	8 D	4	101 ab	95	100 ab	99
8, 9, 10	4 D	8	73 c	91 b	99 ab	88
7	8 D	2			96 b	96
11	2 D	8			77 bc	77
Average			B 87	AB 9.8	A104	NS

Table 18. Effect of irrigation and fertilization on % PK content of leaves Emek Hefer, October 1983

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		.045		
2, 3	1 M daily	70		.038	.043	.040
4, 5, 6	8 D	4	.034	.038	.039	.037
8, 9, 10	4 D	8	.035	.043	.040	.039
7	8 D	2			.044	.044
11	2 D	8			.043	.043
Average drip			.040	.041	.042	NS

Table 19. Effect of irrigation and fertilization on % K content of leaves Emek Hefer, October 1983

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		.60		.60
2, 3	1 M daily	70		.64	.64	.64
4, 5, 6	8 D	4	.55	.57	.59	.57
8, 9, 10	4 D	8	.65	.58	.65	.62
7	8 D	2			.69	.69
11	2 D	8			.63	.63
Average			.60	.62	.62	.61

Table 20. Effect of irrigation and fertilization on leaf mineral composition
(% dw) Emek Hefer October 1987.

N in water ppm	Mg	ashed (total)			water soluble		
		N	P	K	NO ₃ ppm	P	K
30	0.63	1.62	0.161	0.98	88.71 b	0.070 b	1.01 b
60	0.64	1.77	0.167	0.99	98.4 b	0.079 ab	1.03 b
100	0.63	1.82	0.174	1.08	146.0 a	0.089 a	1.13 a
Average	0.633	1.754	0.168	1.02	112.13	0.080	1.06
F	0.01	1.74	0.41	1.56	26.01	3.41	4.67
P _r ≥ F	0.991	0.188	0.669	0.22	0.0001	0.043	0.014

Table 21. Effect of irrigation and fertilization on leaf mineral composition (% dw)
(M – microsprinklers; D – drip) Emek Hefer October 1987

Treatment	Mg	ashed (total)			water soluble		
		N	P	K	NO ₃ ppm	P	K
M	0.66	1.76	0.155	1.06	113.52	0.082 ab	1.041
D ₈	0.63	1.71	0.177	0.98	103.19	0.072 b	1.087
D ₄	0.61	1.80	0.172	1.02	119.67	0.087 a	1.056
Average	0.63	1.75	0.168	1.02	112.13	0.080	1.061
F	0.95	0.48	1.73	0.79	0.95	2.60	0.53
P _r ≥ F	0.40	0.62	0.190	0.46	0.39	0.086	0.59

Table 22. Effect of irrigation and fertilization on N-NO₃ (ppm) content of leaves Emek Hefer, October 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		81.3 c		81.3
2, 3	1 M daily	70		97.4 c	161.3 ab	129.4
4, 5, 6	8 D	4	39.7 d	81.1 c	141.0 b	87.3
8, 9, 10	4 D	8	37.1 d	90.6 c	141.9 b	88.0
7	8 D	2			176.7 a	
11	2 D	8			109.6 bc	
Average			C 34.8	D 87.6	A 146.1	

Table 23. Effect of irrigation and fertilization on P (%) content of leaves Emek Hefer, October 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		0.052 abc		
2, 3	1 M daily	70		0.046 c	0.067 ab	0.052
4, 5, 6	8 D	4	0.048 bc	0.050 abc	0.053 abc	0.050
8, 9, 10	4 D	8	0.047 bc	0.061 abc	0.061 abc	0.056
7	8 D	2			0.070 a	
11	2 D	8			0.070 a	
Average			C 0.048	AB 0.052	A 0.064	

Table 24. Effect of irrigation and fertilization on K (%) content of leaves Emek Hefer, October 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		0.75 b		0.75
2, 3	1 M daily	70		0.84 ab	0.99 a	0.91
4, 5, 6	8 D	4	0.78 ab	0.83 ab	0.82 ab	0.81
8, 9, 10	4 D	8	0.78 ab	0.81 ab	0.80 ab	0.79
7	8 D	2			0.76 ab	0.76
11	2 D	8			0.76 ab	0.76
Average			A 0.78	A 0.81	A 0.86	

Table 25. Effect of irrigation and fertilization on Mg (%) content of leaves.
Emek Hefer, October 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		0.34 bcd		
2, 3	1 M daily	70		0.34 bcd	0.31 cd	0.33
4, 5, 6	8 D	4	0.35 abcd	0.32 cd	0.32 cd	0.33
8, 9, 10	4 D	8	0.27 d	0.39 ab	0.37 abc	0.34
7	8 D	2			0.38 abc	
11	2 D	8			0.42 a	
Average		B 0.31	A 0.35	A 0.36		

Table 26. Effect of irrigation and fertilization on N-NO₃ content of leaves
Emek Hefer, October 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		75.6 ef		75.6 B
2,3	1 M daily	70		88.7 de	180.6 a	134.6 BC
4,5,6	8 D	4	34.6 g	118.9 cd	166.6 ab	106.7 CD
8,9,10	4 D	8	42.0 g	78.0 e	183.7 a	101.2 DE
7	8 D	2			191.3 a	191.3 A
11	2 D	8			145.4 bc	145.4 B
Average			C 38.3	B 90.3	A 174.0	

Table 27. Effect of irrigation and fertilization on P (%) content of leaves (Emek Hefer, October 1989)

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		.053 cd		.053 B
2, 3	1 M daily	70		.066 abc	.070 a	.068 A
4, 5, 6	8 D	4	.054 bcd	.066 abc	.065 abc	.062 AB
8, 9, 10	4 D	8	.046 d	.064 abc	.065 abc	.058 AB
7	8 D	4			.066 abc	.066 A
11	2 D	8			.069 bc	.069 A
Average			B .050	A .062	A .067	

Table 28. Effect of irrigation and fertilization on K (%) content of leaves
Emek Hefer, 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		.086 bc		0.86 B
2,3	1 M daily	70		0.92 bc	1.16 a	1.04 A
4,5,6	8 D	4	0.64 d	0.89 bc	1.12 a	0.88 AB
8,9,10	4 D	8	0.66 d	0.82 cd	1.16 a	0.90 AB
7	8 D	2			0.98 abc	0.98 AB
11	2 D	8			1.04 ab	1.04 A
Average			C 0.65	C 0.87	A 1.10	

Table 29. Effect of irrigation and fertilization on Mg (%) content of leaves
Emek Hefer, October 1988

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		0.40		0.40
2, 3	1 M daily	70		0.41	0.39	0.39
4, 5, 6	8 D	4	0.42	0.42	0.40	0.41
8, 9, 10	4 D	8	0.42	0.44	0.43	0.43
7	8 D	2			0.43	0.43
11	2 D	8			0.43	0.43
Average			0.42	0.41	0.41	NS

Table 30. Effect of irrigation and fertilization on TSS content of fruit
Emek Hefer, January, 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		14.1 a		14.1 AB
2, 3	1 M daily	70		14.1a	13.5 abcd	13.8 AB
4, 5, 6	8 D	4	13.0 de	13.2 cd	12.8 e	13.0 C
8, 9, 10	4 D	8	13.8 ab	13.4 bcd	13.5 abcd	13.7 AB
7	8 D	2			13.7 abc	13.6 B
11	2 D	8			14.1 a	14.1 A
Average			A 13.4	A 13.7	A 13.5	

Table 31. Effect of irrigation and fertilization on Acid (% titratable) content
Emek Hefer, October 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		1.48 abc		1.48 AB
2, 3	1 M daily	70		1.61 a	1.54 ab	1.58 A
4, 5, 6	8 D	4	1.48 abc	1.46 abc	1.44 bc	1.46 AB
8, 9, 10	4 D	8	1.49 abc	1.48 abc	1.50 abc	1.49 AB
7	8 D	2			1.36 c	1.36 D
11	2 D	8			1.58 ab	1.58 A
Average			A 1.48	A 1.51	A 1.48	

Table 32. Effect of irrigation and fertilization on TSS/Acid ratio

Emek Hefer, January 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		9.5 a		9.46 A
2, 3	1 M	70		8.7 a	8.8 a	8.75 A
4, 5, 6	8 D	4	8.8 a	9.1 a	10.9 a	9.61 A
8, 9, 10	4 D	8	9.39 a	9.1 a	9.0 a	9.15 A
7	8 D	2			10.2 a	10.22 A
11	2 D	8			8.9 a	8.88 A
Average			A 9.1	A 9.1	A 9.6	

Table 33. Effect of irrigation and fertilization on juice content (%) of the fruit (Emek Hefer, January 1989)

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M weekly	70		38.1 a		38.1 A
2, 3	1 M	70		41.9 a	39.1 a	40.5 A
4, 5, 6	8 D	4	41.8 a	39.7 a	41.3 a	40.1 A
8, 9, 10	4 D	8	41.2 a	40.2 a	39.0 a	40.1 A
7	8 D	2			38.8 a	38.8 A
11	2 D	8			40.6 a	40.6 A
Average			A 41.5	A 40.0	A 39.8	

Table 34. Effect of irrigation and fertilization on peel thickness (mm) of fruit at harvest time Emek Hefer, January 1989

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average

			30	60	100	
1	1 M weekly	70		8.31 a		8.32 A
2, 3	1 M daily	70		8.13 a	8.06 a	8.01 A
4, 5, 6	8 D	4	6.56 b	7.48 a	7.81 a	7.25 B
8, 9, 10	4 D	8	7.35 a	8.25 a	7.77 a	7.79 A
7	8 D	2			8.35 a	8.35 AB
11	2 D	8			7.73 a	7.73 AB
Average			B 6.90	A 8.04	A 7.94	

Table 35. Effect of irrigation and fertilization on leaf water potential
Emek Hefer 1987

Treatment No.	Emitters per tree	Flow L/H/E	ppm N			Average
			30	60	100	
1	1 M	70		1.68		
2, 3	1 M daily	70		1.63		
4, 5, 6	8 D	4	1.72	1.67	1.75	
8, 9, 10	4 D	8			1.75	
7	8 D	2			1.76	
11	2 D	8			1.75	
Average			1.72	1.66	1.75	NS

Table 36. Effect of irrigation and fertilization on photosynthesis and related parameters (Emek Hefer, 1987)

(lt - leaf temperature; Ct - chamber temperature; A - net assimilation rate; Cs - leaf conductance; Ci - intercellular (CO₂))

Treatment No.	lt °C	Ct °C	A μmol ⁻¹ s ⁻¹	Cs μmol m ⁻² s ⁻¹	Ci
4	32.8 B	34.5	6.75 B	93 B	248
5	31.5 A	34.8	9.75 A	212 A	274
6	31.3 A	35.0	10.54 A	189 A	264
8	38.1 B	34.7	6.18 B	103 AB	264
9	32.1 A	35.3	9.40 AB	145 AB	255
10	31.9 A	35.0	10.91 A	176 A	258

Fig. 1A Sensor Operation Chart.

Fig 1. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 2. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 100 cm horizontal distance from the dripper

Fig 4. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 3. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 5. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 6. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 7. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 8. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 9. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 10. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

Fig 11. Seasonal readings of soil moisture content by neutron probe at 30-60 and 90-120 cm soil depth and 60 cm horizontal distance from the dripper

UNITED STATES

Final Report 1989

BARD Project No. 1-648-83

"Optimization of Water and Fertilizer Application by Automated Low Volume Irrigation for Citrus"

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The final report is presented in 2 sections. The first section includes rainfall, evapotranspiration, water applied in each irrigation treatment and yield. The second section covers tree response namely mineral composition of leaves, fruit quality and fruit production.

The Florida portion of this project was delayed by the severe freeze of 1985. The damage to the trees was so severe that it was uncertain if the trees would recover. Extensive pruning was done in 1985-86. Irrigation systems which included drip, spray and undertree sprinklers were installed in 1985-86 and irrigation treatments started in February, 1986. Difficulties were encountered with drip emitters. Pressure compensating emitters made by Netafim Irrigation were used. The emitters began to lose their pressure control ability soon after irrigation treatments started. Netafim representatives worked closely with the project and replaced about 50% of the emitters. The problem continued to plague us, so the Netafim emitters were replaced with Plastif flow regulated drippers in 1988. The Plastif emitters performed satisfactorily.

Irrigation scheduling was controlled by electro soil moisture tensiometers using tensions at 10 and 30 cb for the 2 irrigation treatments. These tensions were maintained for irrigation scheduling between 1986 and 1989 except part of 1988 when soil sensors were tested.

One of the objectives of the project was to test the feasibility of using sensors to schedule irrigation. The AGWA-II soil matric potential sensors measure heat dissipation in a porous ceramic. The heat dissipated by the ceramic medium is directly proportional to the quantity of water contained within the ceramic's void spaces. Therefore, the more water contained in the ceramic, the more heat is dissipated, and the lower the sensor readings are. This corresponds to a higher soil matric potential which makes more water available to the plant roots.

The experience with Agwatronics, Inc. sensors was a sad and frustrating encounter. One year after the order for the sensors and data acquisition system was placed, Mr. Claude J. Phene, II, President of the company, and his technician came to Lake Alfred to install and calibrate the system. It did not work. Mr. Phene has been back 4 times between 1988 and 1989 to make the system work. He failed on all 4 occasions. The computer printouts recorded no soil water fluctuations at all. It was apparent that the sensors did not function on sandy soil as they would

function on finer texture soils. Similar experience was encountered with gypsum blocks in previous studies. It was also possible that Mr. Claude Phene, II, did not fully understand the sensors developed by his father. The experience with Agwatronic sensors was a complete failure.

Nitrogen treatments in the experiment were supposed to maintain N concentration in the soil solution at 30, 60 and 100 ppm. Difficulties were encountered in extracting soil solution on sandy soil. What little solution that was able to collect showed the N data were highly variable. In the 30 cb irrigation treatment plots, no solution was extracted at all. The very low water holding capacity on well-drained sandy soil in Florida was probably the cause. The soil water content at field capacity (0.1 atm) for Astatula fine sand was 3-5% by weight depending on the depth of sampling. The inability to collect sufficient soil solution samples for N measurements, N treatments were changed to 146, 213 and 291 kg/ha/yr using ammonium nitrate solutions. The ammonium nitrate solution contained 21% N. The revised treatments started with the fall application of 1988 and maintained through 1989.

Data in this report include also data collected in 1989 after the Project was terminated in March, 1989. Valencia, being a late season cultivar, fruit production and fruit quality data were not available until June, 1989.

Section I

Rainfall, Evapotranspiration and Irrigation

Rain

Monthly rain data measured at the BARD project field site are shown in Fig. 1. Data were highly variable and ranged from 0 to 250 mm/month. Figure 2 shows the average annual rainfall from 1986 through 1989 at the research site. July, August and September were the wettest months, followed by March and November. These data show the typical summer rainy season as well as the dry, normally high irrigation months of April and May.

Pan Evaporation and ETp

Class A pan evaporation was used as an index of evapotranspiration (ET) for this work. Daily pan evaporation was measured at the Lake Alfred Citrus Research and Education Center, approximately 3 kilometers from the field research site. Figure 3 shows pan evaporation data summarized for the same months as the rainfall data in Fig. 1. As compared to rainfall, pan evaporation was much less variable from year-to-year. In no case did any of the monthly values vary by more than 10% from the average value for any month.

Potential evapotranspiration, ETp, was calculated by multiplying the pan evaporation data by 0.70. The results of these calculations are shown in Fig. 4. This figure demonstrates that peak climate demands occurred in May, followed approximately equally by June and April. Lower ETp data were obtained during the summer months of July and August because of the reduced solar radiation levels due to cloud cover during those months. The high ETp in April and May was a result of the generally clear skies during these normally dry months.

ETp and Rain

In Figs. 5-8, both monthly ETp and rain are overlaid on the same scale. These figures illustrate that ETp primarily exceeded rain during the spring and early summer months. In all years, April and May were among the months where rainfall was least adequate. These figures also illustrate that rain normally equals or exceeds ETp during the summer rainy season, and during many fall and early spring months.

ET and Effective Rain

In Florida, citrus ET occurs at less than potential rates. ET was calculated on a monthly basis as 0.85 times ETp. In Figs. 9-12, monthly distributions of citrus ET values for 1986-89 are shown.

Because of the high infiltration rate and relatively low slope of the Astatula fine sand soil at the research site, surface runoff was assumed to be negligible, and all rain was assumed to have infiltrated. However, because of the low soil water-holding capacity, all of the rain was not effective in meeting crop ET requirements. Despite the deep root zones of citrus on deep sandy soils, some rain was lost to drainage.

A modification of the Soil Conservation Service (SCS) effective rainfall procedure (U.S. Dept. Agric., SCS, Technical Release 21, 1970) was used to estimate monthly effective rainfall from monthly rain and ET. The modification assumed that all monthly rain amounts of less than 50 mm were entirely effective. This was believed to be a good assumption because of the deep rooting characteristics typical of the citrus grown for this research.

Figures 9-12 compare estimated ET and effective rain for this research. These figures demonstrate that the most critical irrigation needs occurred during late spring and early summer, especially in April and May, as shown by the differences in ET requirements and effective rainfall. The area between each pair of curves represents the depth of irrigation required.

From Fig. 9, rain was inadequate to meet ET requirements throughout most of 1986. Total annual rain was only 1014 mm. In 1987 (Fig. 10), rain was 1320 mm, and the areas between the two curves was much reduced except during April, May and June. In 1988 (Fig. 11), rain was 1120 mm, which was intermediate to the two previous years, and the areas between the two curves was also intermediate.

In 1989 (Fig. 12), rain was only 278 mm during the first 6 months as compared to an average of 445 mm for the other 3 years. This resulted in much greater differences between ET and effective rainfall in 1989 as compared to the earlier years. These climate data correlate well with the distributions in the irrigation data shown in the following figures.

Irrigation Data

In this research, drip and spray micro irrigation systems were compared with undertree sprinkler systems. Each irrigation treatment was automatically controlled based on soil water potentials measured with electric switching tensiometers. Tensiometers were set to initiate irrigations at 10 and 30 cb suctions. Thus, different irrigation amounts were applied as a function of irrigation system type and soil water potential.

Soil Water potential: In this work, irrigations were scheduled at soil water tensions of 10 and 30 cb (soil water potentials of -10 and -30 cb). Figures 13 and 14 summarize annual irrigation depths applied with the 3 irrigation methods for the 10 and 30 cb treatments, respectively. These figures also present the overall average depth of water applied for each irrigation method and soil water potential treatment.

In all cases, the 10 cb water applications greatly exceeded the 30 cb applications. Annual irrigation depths also followed the patterns in climate data observed and previously discussed in Figs. 9-12.

Irrigation applications were greatest in the driest year (1986). For the 10 cb treatments, irrigation depths were reduced due to greater rainfall in 1987, and then increased due to higher rainfall in 1988. For the 30 cb treatments, irrigation depths applied were also both reduced in

1987 and 1988 as compared to 1986. For both the 10 and 30 cb treatments, irrigation depths were large for the first half of 1989, due to the low rain during that time.

Figures 13 and 14 show that about twice as much irrigation was applied by drip irrigation with the 10 cb as compared to the 30 cb treatment. About 4 times as much was applied at 10 cb with the spray and sprinkler systems as compared to the 30 cb treatment. This occurred because the volume of the soil irrigated was much greater for the spray and sprinkler systems as compared to the drip system. Thus, the smaller drip irrigated soil volume was more rapidly depleted from the 10 cb to the 30 cb level, and 30 cb drip irrigations occurred more frequently than with the other system types.

Overall, total water application depths were greatest for the sprinkler, followed by spray and then drip systems for the 10 cb treatments. For the 30 cb treatments, the greatest amount of irrigation was applied with the drip, followed by the sprinkler and spray systems. These differences in application amounts occurred due to the different volumes of soil irrigated and the differences in the volumes of water applied per irrigation with the three different irrigation methods.

Drip Irrigation: Figures 15 and 16 show the monthly distributions of drip irrigation depths for the 10 and 30 cb treatments, respectively. The extremely large values in 9/86 (Figs. 15 and 16) and 12/86 (Fig. 15) resulted from mechanical problems with the irrigation systems that caused these systems to apply more water than required by the soil water potential. Otherwise, these data followed the patterns in climate data discussed in Figs. 9-12.

In Fig. 17, the monthly distribution of 4-year average data are shown for both the 10 and 30 cb treatments. Again, with the exceptions of the months during which mechanical problems occurred, the previously discussed climate data patterns are apparent in the irrigation patterns observed. These average data correlated well with the rainfall distribution shown in Fig. 2.

Spray Irrigation: Figures 18 and 19 show the monthly distributions of spray irrigation depths for the 10 and 30 cb treatments, respectively. These irrigation data followed the climate data patterns discussed in Figs. 9-12 well, with irrigations concentrated during dry spring and early summer months, and lesser peaks during dry fall and winter months. Again, mechanical problems caused excess applications to be made in May and June 1986, March 1988, and March 1989, but much of these applications were ineffective because of the low water-holding capacity of the sandy soil.

In Fig. 20, the monthly distribution of 4-year average data are shown for both the 10 and 30 cb treatments. Again, the previously discussed climate data patterns are very apparent in the irrigation patterns observed.

Sprinkler Irrigation: Figures 21 and 22 show the monthly distributions of sprinkler irrigation depths for the 10 and 30 cb treatments, respectively. As with the micro irrigation systems, these

irrigation data followed the climate data patterns discussed in Figs. 9-12, with irrigations concentrated during dry spring and early summer months, and other peaks during dry fall and winter months in 1986 and 1988.

Again, mechanical problems caused excess applications to be made, primarily in the 10 cb treatments. Excess 10 cb applications occurred in May and October 1986, June 1987, February and March 1988, and March, 1989. Only one excess 30 cb application occurred (June 1986). The other large depths of water shown reflect the fact that much larger volumes of water were applied per application with the sprinkler as compared to the micro irrigation systems.

In Fig. 23, the monthly distribution of 4-year average data are shown for both the 10 and 30 cb treatments. Again, the previously discussed climate data patterns are very apparent in the irrigation patterns observed. An apparent anomaly is the October peak which exceeds those in May and June. However, this occurred because every October during the study period was very dry and irrigations were scheduled every year. In May and June, one year out of four required no irrigation, thus reducing the average value calculated. Also, an excess irrigation application of about 10 mm was made in October, 1986, due to mechanical problems.

Time of Year: Figure 24 presents the 4-year average irrigation requirements for all 10 cb irrigation treatments. In this figure, the largest peak in irrigation requirements occurs in May and June, while a lesser peak is centered around October.

Figure 25 presents the 4-year average irrigation requirements for all 30 cb irrigation treatments. In this figure, the largest peak in irrigation requirements occurs in May and June, while lesser peaks show the normally dry months of February and October-December. The September drip irrigation peak was a result of the large drip irrigation application in 1986 which was due to equipment failure.

These figures demonstrate that despite Florida's large average annual rainfall, definite seasonal patterns exist, and the seasonal patterns cause seasonal patterns in irrigation applications. Dry periods in late spring and late fall cause irrigation to be required during those periods. The combination of high ETp and low rainfall in late spring causes irrigation requirements to be much greater at that time than during the fall months.

Yields

Citrus yield results are shown in Figs. 26-28 for all irrigation systems for all years. Figure 26 shows the average yield of each irrigation-system type versus the nonirrigated control for each year. Although all irrigated treatments had greater yields than the control for all years except 1988-89, greater variations occurred among years than among treatments. Yields increased each year from 1986-87, and the highest yields occurred in 1988-89, possibly because trees were still recovering from freeze damage that occurred in 1985.

Figure 27 shows the yield effects of water potentials used for irrigation scheduling. Yields of both 10 and 30 cb treatments were greater than those of the controls in 2 out of 3 years. Yields of 10 cb treatments

tended to be greater than those of the 30 cb treatments, but differences were not statistically significant because of variability among replications.

Figure 28 summarizes yield effects of irrigation system and water potentials. Yields of spray and sprinkler treatments tended to be greater for the 10 cb as compared to the 30 cb tensions, while drip treatment yields were slightly greater for the 30 cb water tensions. Again, yield differences were not statistically significant because of the small differences in means and relatively large variability among replications.

Summary

In summary, irrigation applications were strongly influenced by year-to-year climate conditions. Year-to-year variability in irrigation applications was primarily caused by variability in rainfall, as potential evapotranspiration was fairly constant from year-to-year.

Despite Florida's large average annual rainfall, definite seasonal patterns exist, and the seasonal patterns cause seasonal patterns in irrigation applications. Low rainfall and high ETP in late spring cause peak irrigation requirements at that time. Low rainfall and low ETP cause a smaller peak in irrigation requirements to occur in the fall.

No yield differences occurred due to irrigation system. Although some trends were found toward increased yields with irrigation at 10 cb as compared to 30 cb for spray and sprinkler systems, differences were not statistically significant. All irrigated treatments out-yielded all nonirrigated control treatments.

Section II

Leaf Analysis, Fruit Production and Fruit Quality

Leaf Analysis: Leaf samples were collected annually in August from 1986-89 and analyzed for the macronutrient elements (Table 1). Significant differences were found among the 3 irrigation systems but no consistent trends were established. In the irrigation frequency treatments, plots irrigated at 10 cb had higher leaf P, K and Ca contents than leaves from the 30 cb plots. The 10 cb treatments were irrigated more frequently than the 30 cb treatments.

Differences in leaf N content were not fully established until 1989 after the N treatments were revised. No difference was found in leaf N content between 1986-88 when attempts to fertilize on the basis of N in soil solution were unsuccessful.

Juice Quality: Juice quality measurements reflected the irrigation treatments (Table 2). Among the 3 irrigation systems, juice from fruit of the sprinkler irrigation treatments had higher soluble solids than those from the drip and spray irrigation treatments. All 3 irrigation systems received about the same quantity of irrigation water between 1986 and 1989. Sprinkler irrigation treatment covered the entire ground surface while drip and spray irrigation systems covered only a portion of the ground surface. From the standpoint of wetted area, sprinkler irrigation received less water than drip and spray irrigations, which may have resulted in higher soluble solids content in the juice. The no irrigation control had the highest soluble solids and acid contents. Soluble solids per box of 41 kg fruit is the way Florida citrus growers are paid.

Juice quality measurements from the irrigation frequency treatments showed fruit from the 30 cb plots had higher juice, soluble solids, acid and soluble solids contents per box of fruit than fruit from the 10 cb plots. The soluble solids and acid ratio was just the opposite. The data were not always significant but the trends were consistent. Fruit from the no irrigation control had the highest soluble solids and acid contents but the lowest soluble solids and acid ratio. These findings are similar to trends found in other irrigation studies.

No difference in juice quality measurements was found due to nitrogen treatments.

No significant difference in fruit production was found except in the irrigation frequency treatments of 1987 (Table 3). In the irrigation frequency treatments, the 10 cb produced more fruit than the 30 cb treatment in all 3 years, although only the 1987 data were significant. In the N rate treatments, the higher N rates produced more fruit than the low rate in 1986 and 1988. The data were not significant. The no irrigation control plots produced less fruit in 1986 and 1987 than the irrigated plots. There was no difference in fruit production in 1988.

Fruit weight expressed as gram per fruit is a measurement of both weight and size of fruit. No difference in fruit weight was found due to irrigation and fertility treatments. The no irrigation control plots

produced smaller and lighter weight fruit than fruit from the treatment plots.

A financial summary of the Project is enclosed.

Publication: Smajstrla, A. and R. C. J. Koo. 1986. Use of tensiometers for scheduling of citrus trickle irrigation. Proc. Fla. State Hort. Soc. 99:51-56.

Future Plans: Due to the severe freeze of 1985 and other delays, the experiment came into full operation in 1988-89 after the BARD grant was terminated. It is our intention to continue the experiment on a limited scale in 1990.

Cooperating Investigator

Name: Robert C. J. Koo

Signature

Robert C. J. Koo
Robert C. J. Koo

Institution

Name: University of Florida, IFAS-CREC

Signature of Authorizing Official

Walter J. Kender
Walter J. Kender

Table 1. Effects of irrigation and nitrogen rates on mineral composition of Valencia orange leaves (Average of 4 replications).

Treatment	N				P				K			
	86	87	88	89	86	87	88	89	86	87	88	89
<u>Irrigation system</u>	%	%	%	%	%	%	%	%	%	%	%	%
Drip	2.64	2.83	2.68	2.82	0.124	0.132	0.120	0.119	1.40	1.88	1.79	1.56
Spray	2.61	2.84	2.68	2.83	0.126	0.135	0.123	0.115	1.41	1.86	1.75	1.60
Sprinkler	2.60	2.94	2.58	2.86	0.129	0.140	0.125	0.115	1.38	1.86	1.68	1.57
Significance	n.s.	***	***	n.s.	n.s.	***	n.s.	***	n.s.	n.s.	***	n.s.
<u>Irrigation frequency</u>												
10 cb	2.61	2.85	2.66	2.87	0.127	0.135	0.124	0.119	1.40	1.86	1.77	1.62
30 cb	2.62	2.89	2.64	2.80	0.126	0.135	0.122	0.114	1.40	1.87	1.72	1.54
Significance	n.s.	*	n.s.	***	n.s.	n.s.	n.s.	***	n.s.	n.s.	*	***
<u>Nitrogen rate (kg/ha)</u>												
146	2.62	2.86	2.63	2.77	0.129	0.137	0.123	0.120	1.42	1.85	1.72	1.57
213	2.62	2.86	2.65	2.82	0.126	0.135	0.122	0.117	1.40	1.86	1.80	1.56
291	2.61	2.88	2.66	2.95	0.125	0.135	0.124	0.113	1.38	1.89	1.71	1.60
Significance	n.s.	n.s.	n.s.	***	n.s.	n.s.	n.s.	***	n.s.	n.s.	**	n.s.
NI control ²	2.71	2.79	2.66	2.73	0.118	0.133	0.114	0.124	1.45	1.80	1.73	1.70

²No irrigation control—data not included in statistical analysis.

Statistical symbols: n.s.—not significant; *—significant at 90% probability; **—significant at 95% probability; ***—significant at 99% probability.

Table 1. Effects of irrigation and nitrogen rates on mineral composition of Valencia orange leaves (Average of 4 replications). (Continued)

Treatment	Ca				Mg			
	86	87	88	89	86	87	88	89
<u>Irrigation system</u>	%	%	%	%	%	%	%	%
Drip	2.64	2.72	2.43	2.47	0.354	0.344	0.361	0.336
Spray	2.64	2.36	2.48	2.57	0.340	0.318	0.340	0.332
Sprinkler	2.83	2.58	2.65	2.81	0.331	0.335	0.324	0.326
Significance	*	***	n.s.	***	n.s.	**	***	n.s.
<u>Irrigation frequency</u>								
10 cb	2.79	2.63	2.60	2.59	0.343	0.324	0.346	0.324
30 cb	2.62	2.47	2.41	2.64	0.341	0.340	0.338	0.339
Significance	**	*	*	n.s.	n.s.	**	n.s.	*
<u>Nitrogen rate (kg/ha)</u>								
146	2.70	2.57	2.58	2.59	0.347	0.337	0.348	0.333
213	2.74	2.58	2.48	2.60	0.333	0.319	0.335	0.321
291	2.66	2.51	2.45	2.66	0.345	0.341	0.344	0.340
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.
NI control ^z	2.65	2.25	2.32	2.51	0.353	0.329	0.377	0.358

^zNo irrigation control—data not included in statistical analysis.

Statistical symbols: n.s.—not significant; *—significant at 90% probability;

—significant at 95% probability; *—significant at 99% probability.

Table 2. Effects of irrigation and nitrogen rates on juice quality of Valencia orange (Average of 4 replications).

Treatments	Juice by wt			Soluble solids			Acid			SS/A ratio			SS/41 kg box		
	86	87	88	86	87	88	86	87	88	86	87	88	86	87	88
<u>Irrigation system</u>	%	%	%	%	%	%	%	%	%				kg	kg	kg
4 Drip	62.1	64.5	62.9	12.57	12.43	13.79	0.85	0.91	0.98	14.82	13.64	14.10	3.19	3.27	3.5
8 Spray	60.9	63.4	62.8	12.50	12.68	13.59	0.86	0.93	0.92	14.51	13.66	14.78	3.11	3.29	3.4
6 Sprinkler	61.6	64.4	63.0	12.38	12.81	13.92	0.85	0.98	0.96	14.65	13.05	14.47	3.12	3.37	3.5
Significance	***	n.s.	n.s.	n.s.	*	**	n.s.	***	***	n.s.	***	***	**	n.s.	**
<u>Irrigation frequency</u>															
8 10 cb	61.5	63.9	62.3	12.34	12.67	13.73	0.84	0.93	0.95	14.66	13.62	14.49	3.10	3.31	3.4
7 30 cb	61.6	64.3	63.4	12.63	12.60	13.81	0.86	0.95	0.96	14.66	13.27	14.41	3.18	3.31	3.5
Significance	n.s.	n.s.	***	***	n.s.	n.s.	*	n.s.	n.s.	n.s.	**	n.s.	***	n.s.	***
<u>Nitrogen rate (kg/ha)</u>															
6 146	61.7	64.7	63.3	12.49	12.62	13.80	0.86	0.95	0.95	14.56	13.39	14.51	3.14	3.32	3.5
0 213	61.5	64.2	62.5	12.52	12.65	13.72	0.84	0.93	0.95	14.88	13.62	14.49	3.15	3.32	3.5
3 291	61.4	63.5	62.8	12.46	12.64	13.78	0.86	0.95	0.96	14.54	13.33	14.35	3.12	3.28	3.5
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
NI control ²	63.1	64.9	62.6	12.71	12.51	14.20	0.87	0.96	1.00	14.64	13.13	14.46	3.26	3.32	3.6

²No irrigation control—data not included in statistical analysis.

Statistical symbols: n.s.—not significant; *—significant at 90% probability; **—significant at 95% probability;

***—significant at 99% probability.

Table 3. Effects of irrigation and nitrogen rates on fruit production and fruit weight of Valencia orange (Average of 4 replications).

Treatment	Fruit production ^y			Wt per fruit		
	86	87	88	86	87	88
<u>Irrigation system</u>	<u>Box/tree</u>			<u>Gram</u>		
Drip	3.88	3.65	4.05	191	209	197
Spray	3.61	3.62	4.56	189	208	194
Sprinkler	3.54	3.66	4.50	190	200	195
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<u>Irrigation frequency</u>						
10 cb	3.74	3.74	4.52	192	206	196
30 cb	3.62	3.54	4.22	188	205	195
Significance	n.s.	*	n.s.	n.s.	n.s.	n.s.
<u>Nitrogen rate (kg/ha)</u>						
146	3.55	3.64	4.20	191	203	193
213	3.63	3.75	4.42	190	206	199
291	3.86	3.54	4.50	187	207	195
Significance	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
NI control ^z	3.17	3.27	4.44	181	194	176

^zNo irrigation control--data not included in statistical analysis.

^yFruit production: box = 41 kg.

Statistical symbols: n.s.--not significant; *--significant at 90% probability; **--significant at 95% probability; ***--significant at 99% probability.

Fig. 1 Monthly rainfall from 1986 to July, 1989.

AVERAGE RAIN, 1986-89

LAKE ALFRED BLOCK 22

Fig. 2 Average annual rainfall from 1986 to July, 1989.

EVAPORATION (MM)

Fig. 3 Monthly pan evaporation from 1986 to July, 1989.

POTENTIAL EVAPOTRANSPIRATION

LAKE ALFRED CREC

Fig. 4 Potential evapotranspiration (ETp) from 1986 to July, 1989.

ETp AND RAIN - 1986

LAKE ALFRED BLOCK 22

Fig. 5 Monthly ETp and rainfall for 1986.

ETp AND RAIN - 1987

LAKE ALFRED BLOCK 22

Fig. 6 Monthly ETp and rainfall for 1987.

ETP AND RAIN - 1988

LAKE ALFRED BLOCK 22

Fig. 7 Monthly ETP and rainfall for 1988.

ETp AND RAIN - 1989

LAKE ALFRED BLOCK 22

Fig. 8 Monthly ETp and rainfall for January to July, 1989.

MONTHLY DEPTH (MM)

ET AND EFFECTIVE RAIN - 1986

LAKE ALFRED BLOCK 22

Fig. 9 Monthly Evapotranspiration (ET) and effective rain, 1986.

MONTHLY DEPTH (MM)

ET AND EFFECTIVE RAIN - 1987

LAKE ALFRED BLOCK 22

Fig. 10 Monthly Evapotranspiration (ET) and effective rain, 1987.

MONTHLY DEPTH (MM)

ET AND EFFECTIVE RAIN - 1988

LAKE ALFRED BLOCK 22

Fig. 11 Monthly Evapotranspiration (ET) and effective rain, 1988.

ET AND EFFECTIVE RAIN - 1989

LAKE ALFRED BLOCK 22

Fig. 12 Monthly Evapotranspiration (ET) and effective rain, January through June, 1989.

IRRIGATION, 10 CB 1986-1989

Fig. 13 Annual total (1986-1989) and average irrigation for 10 CB treatment.

IRRIGATION, 30 CB

1986-1989

Fig. 14 Annual total (1986-1989) and average irrigation for 30 CB treatment.

Fig. 15 Monthly drip irrigation at 10 CB (1986 to July, 1989).

DEPTH (MM)

DRIP IRRIGATION

30 CB

Fig. 16 Monthly drip irrigation at 30 CB (1986 to July, 1989).

DRIP IRRIGATION

AVERAGE, 1986-1989

Fig. 17 Average monthly drip irrigation from 1986 to July, 1989.

DEPTH (MM)

SPRAY IRRIGATION

Fig. 18 Monthly spray irrigation at 10 CB (1986 to July, 1989).

DEPTH (MM)

SPRAY IRRIGATION

30 CB

Fig. 19 Monthly spray irrigation at 30 CB (1986 to July, 1989).

DEPTH (MM)

SPRAY IRRIGATION

AVERAGE, 1986-1989

Fig. 20 Average monthly spray irrigation from 1986 to July, 1989.

SPRINKLER IRRIGATION

Fig. 21 Monthly sprinkler irrigation at 10 CB (1986 to July, 1989).

SPRINKLER IRRIGATION

30 CB

Fig. 22 Monthly sprinkler irrigation at 30 CB (1986 to July, 1989).

SPRINKLER IRRIGATION

AVERAGE, 1986-1989

Fig. 23 Average monthly sprinkler irrigation from 1986 to July, 1989.

IRRIGATION, 10 CB

AVERAGE, 1986-1989

Fig. 24 Average monthly irrigation of all irrigation systems at 10 CB (1986-1989).

IRRIGATION, 30 CB

AVERAGE, 1986-1989

Fig. 25 Average monthly irrigation of all irrigation systems at 30 CB (1986-1989).

CITRUS YIELD

IRRIGATION METHODS - ALL YEARS

Fig. 26 Yields of all irrigation method treatments and the non-irrigated control for each year.

CITRUS YIELD

WATER TENSIONS - ALL YEARS

41

YIELD, MG/HA

Fig. 27 Yields of both soil water tension treatments and the non-irrigated control for each year.

CITRUS YIELD WATER TENSIONS -- ALL YEARS

42

YIELD, MG/HA

Fig. 28 Three year average yields for all irrigation method and soil water tension treatments and the non-irrigated control.

F. Description of Cooperation

The cooperating investigators were in contact and Bravdo has visited Lake Alfred several times and has also delivered a seminar on the joint project, to the experimental station staff. There were some disagreements regarding the experimental approach and this was reflected in the performance and the results in reports of both countries.

G. Evaluation of the Research Achievements with Respect to the Aims of the Original Research Proposal and the Benefit to Agriculture

In Israel the achievements as well as the benefit to agriculture were significant. It was proven that conversion of a typical 25-year-old orchard from overhead sprinkler irrigation to drip fertirrigation combined with proper canopy management can greatly contribute to increase productivity up to about 90 t/ha.

The findings concerning the effectiveness of root restriction in water and mineral uptake in a dry climate where all the water consumption is solely dependent on the irrigation is significant from the economical as well as the physiological and the environmental aspects. Economically, one dripline per row is cheaper compared to any other irrigation method, considering the length of the lines and low thickness and diameter requirements due to the low rate of water flow and pressure fall.

From the physiological point of view the fast adjustment of an old and established root system to a low soil volume irrigation and the possible root restriction effect on the reproductive to vegetative growth ratio, seems to be a very attractive field for further research and development. The environmental aspects and implications concerned are the possibilities of the computerized automated irrigation system used in this project to minimize percolation of water and minerals and thereby underground water contamination.

In conclusion, it was well demonstrated that the profitability of the Israeli citrus industry can undergo a dramatic improvement by adopting the methods developed herein.

In Florida, no significant effect of the irrigation and fertilization methods or doses were apparent. This may be attributed to a few reasons:

1. Freezing damage which occurred several times during the experiment period.
2. Insufficient root development in the drip treatment due to application of the nitrogen partially through the drip system and partially by spreading, unlike Israel. Phosphorous and potassium were applied only by spreading.
3. It is the opinion of the American principal investigator Dr. Koo that the differences in the results obtained in both countries are due to the differences in climate. However, a few growers in Florida who use the methods developed in the Emek Hefer experiment in Israel, are getting excellent results. It seems therefore that it is essential to repeat the experiment in Florida and this time using the following principles:
  1. Apply all fertilizers through the irrigation system.
  2. Study the effect of NpK fertilizer doses.
  3. Place the electrotensiometers a proper distance so that drip treatments would not receive half the amounts of the irrigation water but rather comparable water quantities.

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