

Efficient Irrigation and Nitrogen Management for Lemons: Results for 1993-1995¹

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Abstract

Studies are being conducted which aim to improve the efficiency of irrigation and N fertilization for lemons produced on sandy soils in the low desert. The first experiment evaluates the response of 'Lisbon' lemons to various flood irrigation intervals. Irrigation intervals are based on soil moisture depletion (SMD) as calculated from frequent neutron probe soil moisture measurements. Individual treatments were irrigated when total SMD was 25%, 40%, 55%, and 70%, respectively. The second experiment compares the performance of young lemons produced under flood, trickle, and micro-spray irrigation systems. The third experiment evaluates the response of young lemons to water and N combinations (3 by 3 factorial) under micro-spray irrigation. The three irrigation rates were targeted for 30 cnbar, 20 cnbar, and 10 cnbar tension. The three N rates were 0.1, 0.2, and 0.4 kg N/tree. One flood irrigation treatment was added for comparative purposes. Overall, results obtained in experiment 1 during 1994 and 1995 indicate optimal fruit growth and yield is obtained at approximately 40% SMD. The results of experiment 2 show that after 18 months micro-spray irrigation produced significantly more tree growth than flood and drip irrigation methods. Additionally, first year fruit yields were significantly greater for pressurized irrigation compared to flood irrigation. Results from experiment 3 show a linear response in tree growth up to 10 cnbar soil moisture tension. Furthermore, tree growth at 10 cnbar tension was significantly greater than trees irrigated by flood. Yields were also increased to irrigation regime. There were no significant differences in tree growth to N fertilization rates. However, there was a yield increase to N fertilizer rate at the highest soil moisture regime.

Introduction

Much of the citrus produced in southwestern Arizona is grown on sandy soils. Because these soils have a low ion exchange capacity, are highly permeable to water, and are prone to nitrate leaching, achieving efficient water use and N management presents a continuing challenge.

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The majority of citrus planted in the Yuma area is lemon; a crop that accounts for almost 60% of the Arizona citrus production. Lemons are more vigorous than other citrus trees. Yields of lemons are also usually greater than that of other citrus of the same age, but under water stress, fruit size will be compromised and excessive fruit drop will occur (Barbera and Carima, 1988). Water is relatively inexpensive on the Yuma Mesa, and because of the fruit quality problems associated with water stress, many growers believe that maintaining vigorous growth, high fruit yield, and high fruit quality with less water may be difficult. Often from 2.7 to 3.7 m of water per year are used to irrigate citrus on the Mesa, whereas crop consumptive has been estimated to be from 1 m to 1.5m (Erie et al. 1967; Hoffman et al., 1982). However, the increasing water requirements of an expanding population and possible re-adjudication of water rights along the Colorado River require that water for Arizona agriculture be used more efficiently.

Inefficient irrigation practices are probably a significant factor contributing to nitrate-N losses from the sandy soils of the Yuma Mesa. The excess water percolates through the soil and undoubtedly leaches appreciable amounts of N fertilizer below the root zone where it is unavailable to the trees. The Arizona Legislature has recently mandated the implementation of Best Management Practices (BMP's) to reduce the threat of fertilizer N to ground water (Arizona Revised Statutes, Arizona Environmental Quality Act, 1987). These practices involve timing, amounts, and placement of N and irrigation water application (Doerge et al. 1991). Unfortunately, specific information on desirable management practices for citrus is lacking.

Water stress has many effects on plant physiology and productivity involving reactions ranging from cellular levels to entire trees and the interactions between trees within a grove. Water stress is frequently the main limiting factor in obtaining higher yields under a sound set of cultural practices (Marsh, 1973), especially in the high yielding citrus cultivars such as the lemon. Additionally, it has been determined that irrigation at long intervals will subject trees to extended periods of water stress that has a negative influence on the yields, tree canopy development, trunk growth, and total feeder roots below the 60 cm level (Hilgeman and Sharp, 1970).

A search of literature was conducted which revealed that no previous studies have been conducted in the low desert that specifically address the issue of irrigation frequencies and its impact on fruit sizing of Lisbon lemons. However, in a previous study of tree responses in Arizona by Smith et al. (1931), young grapefruit trees, growing in fine sand, were irrigated at one, two, three, four and five week intervals in the summer for three years. Soil moisture remained relatively high in the top three treatments but top and root growth decreased as intervals lengthened. In a study conducted by Hilgeman and Sharp (1970), various tree responses were investigated over a twenty year period under four different irrigation schedules. The trees studied were Valencia oranges in Maricopa county, Arizona. During this study fruit was harvested and graded at the same time each year. The yield results of this study indicate that soil water tension directly influenced the fruit size, but were less marked in the final five years than in the initial five years. Also, the data indicates that the differences chiefly reflected the number of fruit set in those years. Overall, limited information exists on optimal irrigation frequencies for Lisbon lemons on sandy soils.

Previous research conducted by the University of Arizona, Yuma Agricultural Research Center has shown that several pressurized irrigation systems such as trickle, spray, or bubblers improved irrigation efficiency substantially over the traditional flood irrigation. The growth rate of young 'Campbell Valencia' trees irrigated by pressurized systems was greater than trees irrigated by the traditional flood system (Rodney et al. 1977; Roth et al. 1978a). Furthermore other studies showed that mature 'Valencia' oranges can be converted from flood irrigation to any of these pressurized systems without compromising fruit yield and quality (Roth et al., 1995). These systems also resulted in improved N fertilizer use efficiency through better timing and placement of N fertilizer. Leaf tissue data showed appreciably higher N concentrations in trees irrigated by pressurized systems compared to flood irrigation confirming the difficulties of managing N under traditional flood irrigation. No experimentation of this type has been conducted on lemons in Arizona.

While work on low volume pressurized irrigation systems in Arizona orange and grapefruit plantings has been fairly extensive, seldom have they been investigated in lemon groves. Preliminary work by Roth indicated that tree growth on young lemons irrigated via pressurized systems (50 - 80% water savings) was greater than growth of trees subject to border flood irrigation (Roth, unpublished). But, this work was not carried to its conclusion, trees

were not allowed to mature and yield data not taken because of lack of funds. The irrigation systems were removed. Nevertheless, it seems that even though there have been no completed reports on the effects of pressurized irrigation systems on lemon, such systems may hold promise.

Clearly, through research abundant opportunities exist for improving irrigation efficiency and N fertilizer use efficiency for lemons on sandy soils in the low desert. The objectives of these studies are 1) determine the impact of different flood irrigation regimes on sizing, earliness, and quality of Lisbon lemons on sandy soils and 2) compare the performance of young lemons produced under flood, trickle, and micro-jet spray irrigation systems, and, 3) evaluate the response of young lemons to water and N combinations under micro-spray irrigation, and 4) work toward the development of a leaf tissue test that will aid in N management for lemons.

Materials and Methods

Experiment 1 (Flood irrigation studies) These studies were initiated on a mature Lisbon lemon grove planted in 1977. Individual plots consist of three rows of trees within a border. Each row contains three varieties of rootstock (Rough lemon, Macrophylla, and Sour orange). However, yield and quality data were only collected from the trees on 'Macrophylla' and 'Rough Lemon' rootstock.

Treatments consist of four flood irrigation regimes based upon a percentage of soil water depletion as calculated from daily measurements of soil moisture with a neutron probe. Treatments one through four will consist of irrigation regimes of 25%, 40%, 55%, and 70% water depletion. For example, treatment one was irrigated after the soil profile has been depleted of 25% of its water holding capacity. Treatments two, three, and four were irrigated when soil moisture was depleted 40, 55%, and 70%, respectively, of its water holding capacity.

Neutron probe access tubes and tensiometers were installed to calculate soil moisture depletion. As our data base is increased by additional seasons, measurements of soil water depletion with the neutron probe will be compared to ET calculated from the Arizona Meteorological Network (AZMET), pan evaporation (including associated coefficients), and tensions measured by tensiometers. All approaches will be evaluated for their suitability for irrigation scheduling.

Ten fruits on two trees per plot were chosen at random and tagged (following fruit set) to measure fruit diameter as influenced by irrigation regime. Fruit circumference measurements were made every two weeks. Lemons were harvested (ring picked) on September 26, 1994 and October 2, 1995 by a professional harvesting crew. The remaining fruits were harvested on November 22, and December 18, in 1994 and 1995 respectively. After each harvest, the fruits were sorted into seven commercial sizes and graded as to fresh market quality. The number and weight of fresh market and cull fruit for each commercial size was documented.

Fifteen fruits were randomly selected from each tree for juice quality measurements. Quality measurements included peel thickness, percentage juice solid, percentage acid, and total volume of juice. The percentage total dissolved solids were determined with a refractometer and percentage citric acid by titration with a 0.4 NaOH. Analysis of variance on the data was performed using SAS-ANOVA and SAS-GLM.

Experiment 2 (Comparisons of irrigation systems) This experiment is being conducted at a 1.6 ha field at the Yuma Mesa Agricultural Center. Two-year old 'Limoneira 8A Lisbon' lemons on 'Volkameriana' rootstocks were planted and irrigated with trickle, microsprinkler and border flood irrigation. The experimental design is randomized complete block.

Irrigation scheduling is being done with tensiometers, except the border flood treatments that is irrigated according to the current practices (about 274 cm). Tree growth was determined by measuring trunk circumference each March. Fruit will be harvested, total yield calculated, and fruit quality parameters will be measured when the trees bear. Quality parameters include fruit size, fruit maturity date, total soluble solids, acidity and juice percentage. Gas exchange (photosynthesis, transpiration, stomatal conductance, and sub-stomatal CO₂ concentration) is being measured using a portable infra-red gas analyzer. Transpiration is also being measured with sap flow gauges

(Dynamax, Inc., Houston, TX). These gauges contain a heater as well as temperature sensors that measure the vertical temperature gradients in the trunk above and below the heater, the temperature gradient across the heater and the temperature gradient in the insulation. These measurements are used to calculate xylem sap flow (Baker and Van Bavel, 1987). Leaf water potential will be measured using thermocouple psychrometers. Root growth and activity are being measured in multiple locations around selected trees, using minirhizotrons and a portable root periscope. Data collected will allow us to quantify the effects of the irrigations on tree physiology.

Experiment 3 (Microsprinkler Irrigation regime and N rate study). This experiment was established on a 1.8 ha field of young 'Lisbon' lemons located on the Yuma Mesa Agricultural Research Farm. The trees were 'Limoneira 8a Lisbon' on 'Volkameriana' rootstock and were planted September, 1993. This study consists of a 3 by 3 factorial combination of irrigation treatments and N treatments under spray irrigation. The irrigation treatments are structured based on soil water tension as determined by tensiometer. The three irrigation rates were targeted for 30 cnbar, 20 cnbar, and 10 cnbar tension. The three N rates were 0.1, 0.2, and 0.4 kg N/tree. One flood irrigation treatment was added for comparative purposes. The 10 treatments are as follows:

1. Spray irrigation at 30 cnbar tension with 0.1 kg N/tree/yr.
2. Spray irrigation at 30 cnbar tension with 0.2 kg N/tree/yr.
3. Spray irrigation at 30 cnbar tension with 0.4 kg N/tree/yr.
4. Spray irrigation at 20 cnbar tension with 0.1 kg N/tree/yr.
5. Spray irrigation at 20 cnbar tension with 0.2 kg N/tree/yr.
6. Spray irrigation at 20 cnbar tension with 0.4 kg N/tree/yr.
7. Spray irrigation at 10 cnbar tension with 0.1 kg N/tree/yr.
8. Spray irrigation at 10 cnbar tension with 0.2 kg N/tree/yr.
9. Spray irrigation at 10 cnbar tension with 0.4 kg N/tree/yr.
10. Flood irrigation with 0.1 kg N/tree/yr.

The N on the spray irrigation treatment was applied through the system. The N with the flood treatments was applied by hand to the base of each tree. During 1995, we increased the soil moisture regimes slightly (high of 7 cnbar) because there was a linear response to water in 1994. All treatments were replicated four times in a randomized complete block design. Tree growth was determined each September. First year yields were determined in October 1995. The citrus will be graded and juice quality will be determined using standard methods. Leaves will be collected from each plot to improve calibrations for a leaf tissue N test. Total N in leaves and soil will be determined using a micro-kjeldahl procedure. Nitrate-N in leaves will be determined after extraction with a nitrate electrode. All data will be analyzed using an appropriate statistical model. Leaf data will be correlated to tree growth and yields to determine critical N levels.

Results and Discussion

Experiment 1 Seasonal soil moisture levels as determined by neutron probe readings are shown in Figures 1 and 2 for 1994 and 1995, respectively. As anticipated, irrigation frequency decreased with an increase in targeted soil moisture depletion (SMD) level. For example, very frequent irrigations (2 to 3 weekly) were required for the 25% SMD irrigation regime. Conversely, there were only four to five irrigations for the 70% SMD irrigation regime during the entire summer period.

Fruit growth was significantly reduced at the 70% SMD in 1994 (Figure 3). Although there was a trend for reduced growth at 55% SMD, the trend was not significant at the 5% probability level in 1994. In 1995, both 55% and 70% SMD reduced fruit growth (Figure 4).

Yields for the first harvest (ring pick) show that the most frequent (25% SMD) and least frequent (70% SMD) irrigation regimes reduced early yields in 1994 (Table 1). However, in 1995 only the 70% SMD significantly reduced early yield (Table 2). Overall, the combined data from 1994 and 1995 show early yields were maximized between at approximately 40% SMD.

In both seasons, the second harvest resulted in a compensation in yields in those treatments that yield poorly during the first harvest. In 1994 only the 70% SMD resulted in reduced total yields. In 1995 there was a trend for reduced total yields at 70% SMD, the differences were not statistically significant. Nevertheless, the greatest opportunity for profit is during the early harvest and irrigation regimes that reduce early yields would typically reduce profitability. Differences in fruit quality (peel thickness, percentage juice, solid/acid ratio etc.) were generally not statistically significant (data not shown).

Experiment 2 During the first 6 month period the tree growth for the flood irrigation method was superior to drip, and micro-spray irrigation methods (Table 3). However, during this period we were targeting a soil-water tension of 29 cnbar for the pressurized systems. Previous research in Florida and Texas suggested that this level was adequate for maximum growth and yield. Based on results in experiment 3, we realized at the end of 1994 that this was insufficient water. We then targeted 10 cnbar (or highest level in experiment 3 during 1994). Interestingly, after 18 months the micro-spray method significantly increased tree growth over other irrigation methods.

The data for early yield show all pressurized systems produced more fruit than flood irrigation (Table 4). Although differences in fruit size were not significantly different there was a trend for larger size with flood irrigation. Many growers believe that it is difficult to size lemons grown under pressurized irrigation. However, in these studies we believe this small increase in size was associated with the lower number of fruit on trees irrigated by flood. It is difficult to draw meaningful conclusions from first year yields such as those reported for experiment 2. We will closely evaluate the influence of irrigation method on fruit size and yield in coming seasons.

Experiment 3 Tree growth increased linearly to micro-spray water levels indicating the highest targeted irrigation regime (approximately 10 cnbar in 1994 and 7 cnbar in 1995) was superior (Figures 6 and 7). Tree growth for the highest micro-spray irrigation regime was also greater than flood irrigation. There were no significant effects of N on tree growth indicating our lowest rate was sufficient for maximum growth.

The first yields also increased linearly to irrigation regime (Figure 8). Additionally, yields for the highest micro-jet regime were higher than those of flood irrigation. Yields increased to N only at the highest irrigation regime. This may be the result of N leaching or simply the result of the fact that when soil moisture conditions for growth were optimum, larger rates of N were required for maximum yield. As noted for experiment 2, data for first yields should be interpreted with caution. We will evaluate this situation closely in future yield harvests.

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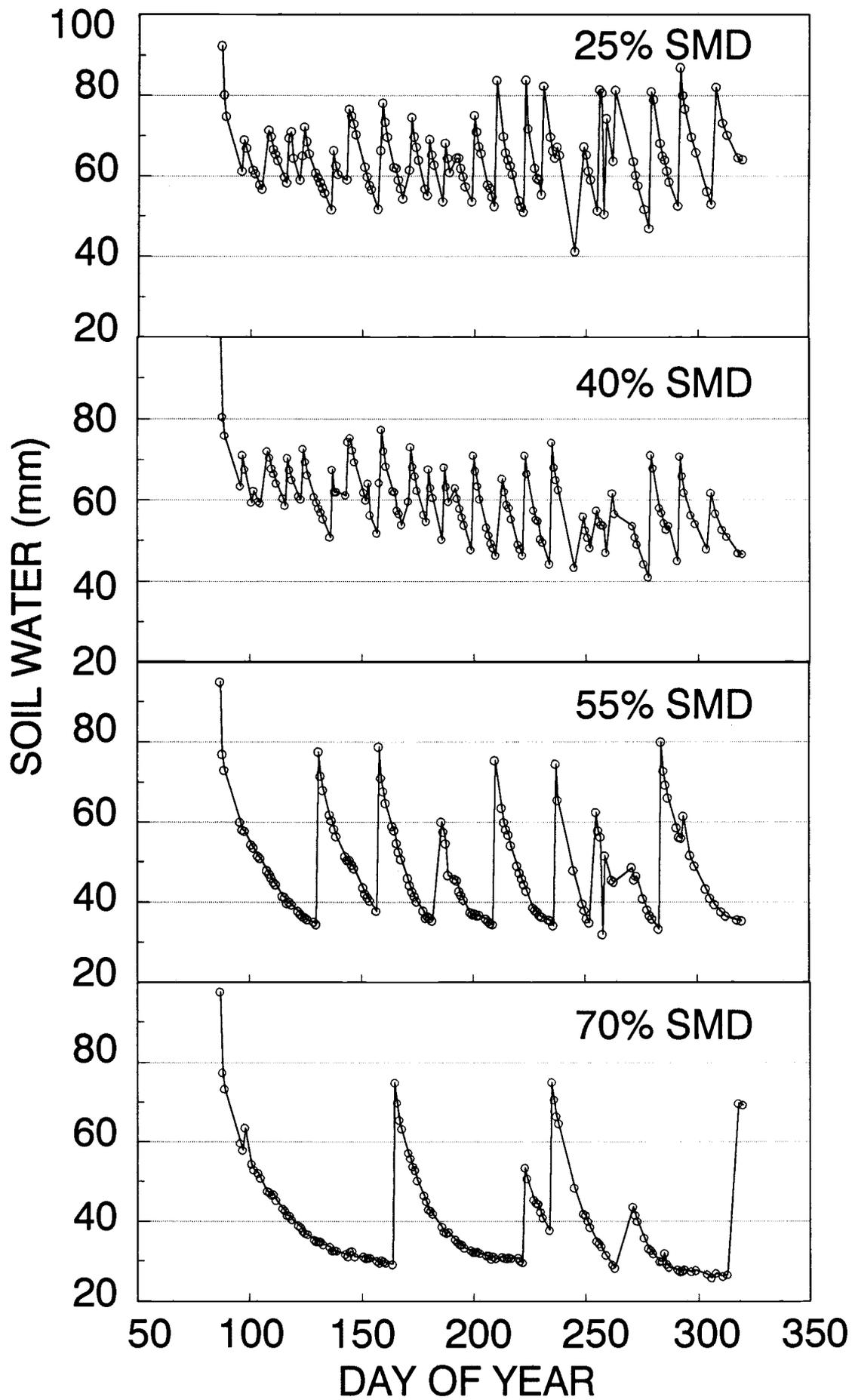


Figure 1. Soil moisture in surface 30 cm in experiment 1 during summer 1994.

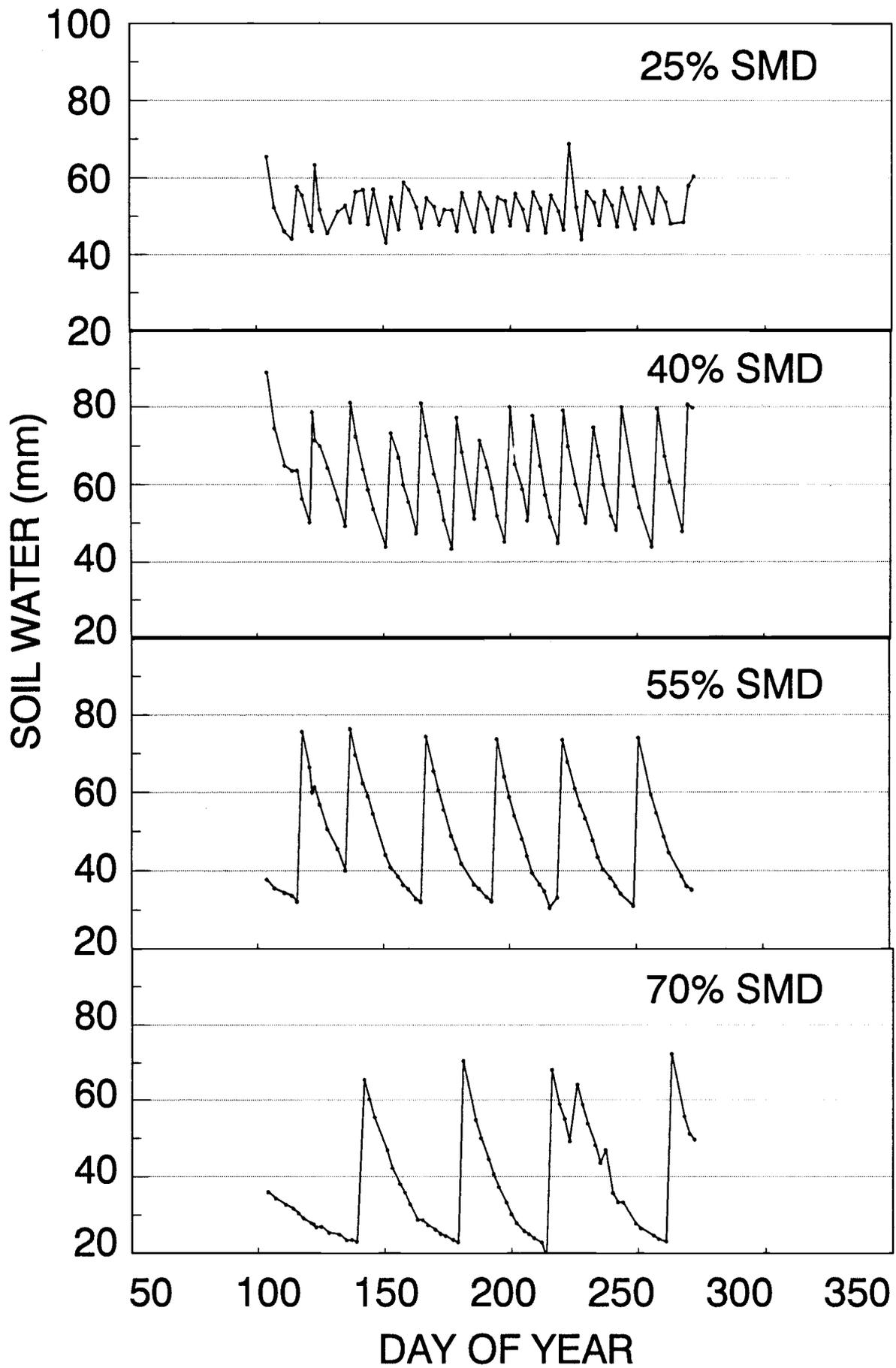


Figure 2. Soil moisture in surface 30 cm in experiment 1 during summer 1995.

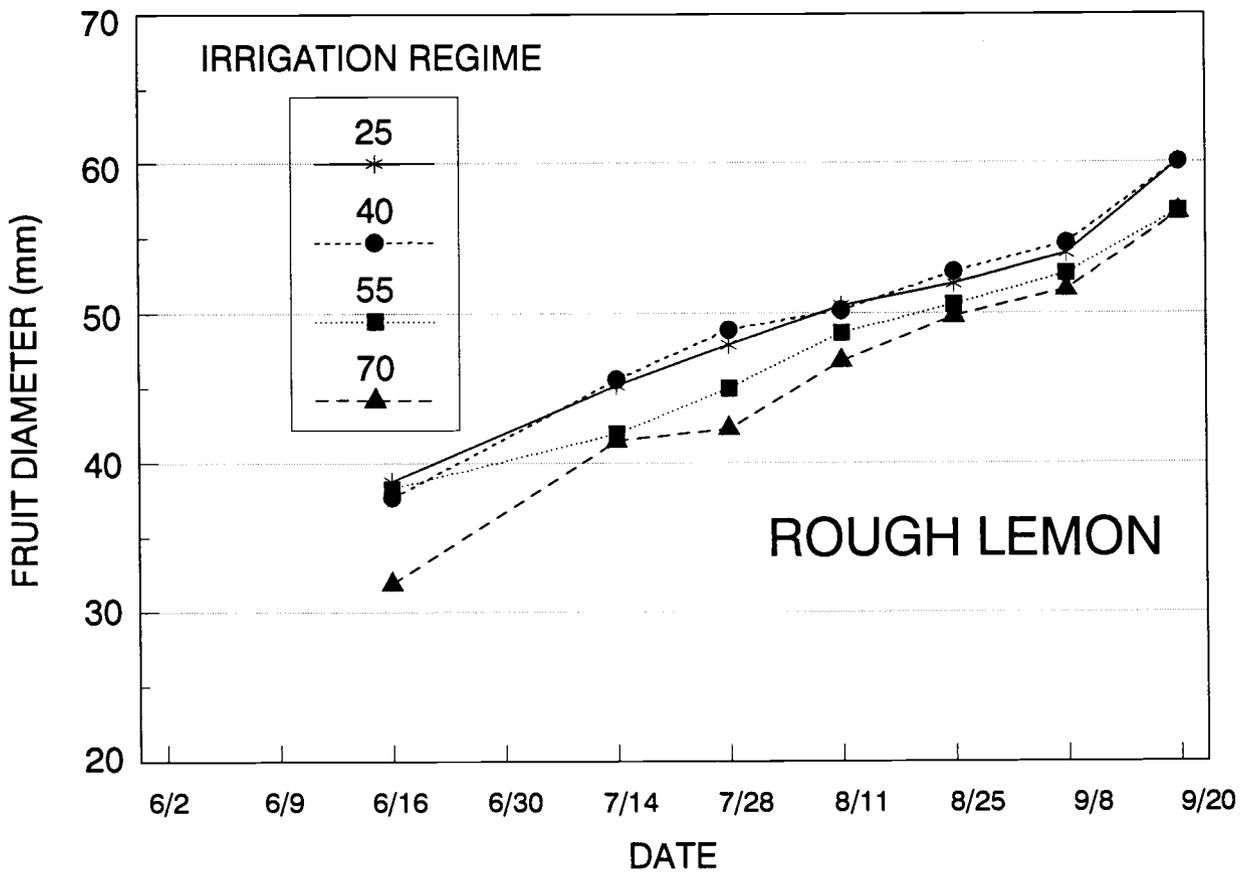
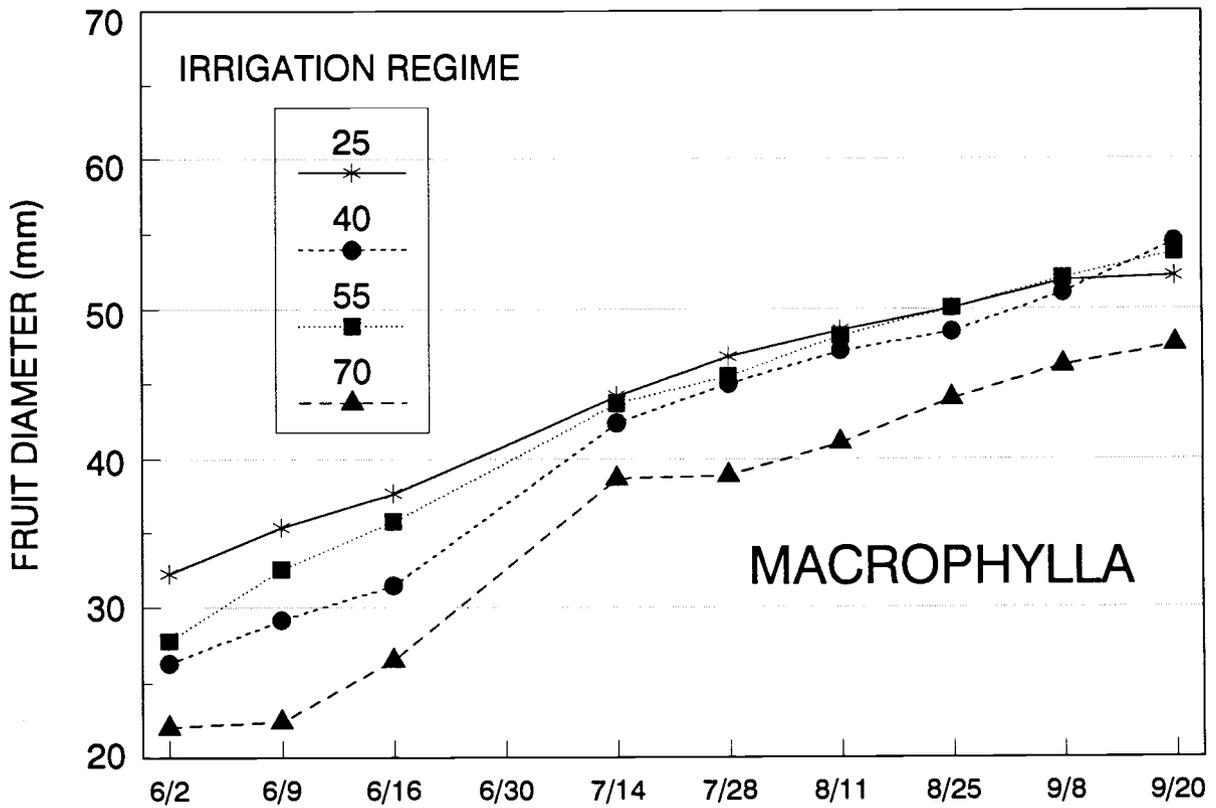


Figure 3. Fruit growth of Lisbon lemons on two rootstocks as influenced by irrigation regime in 1994.

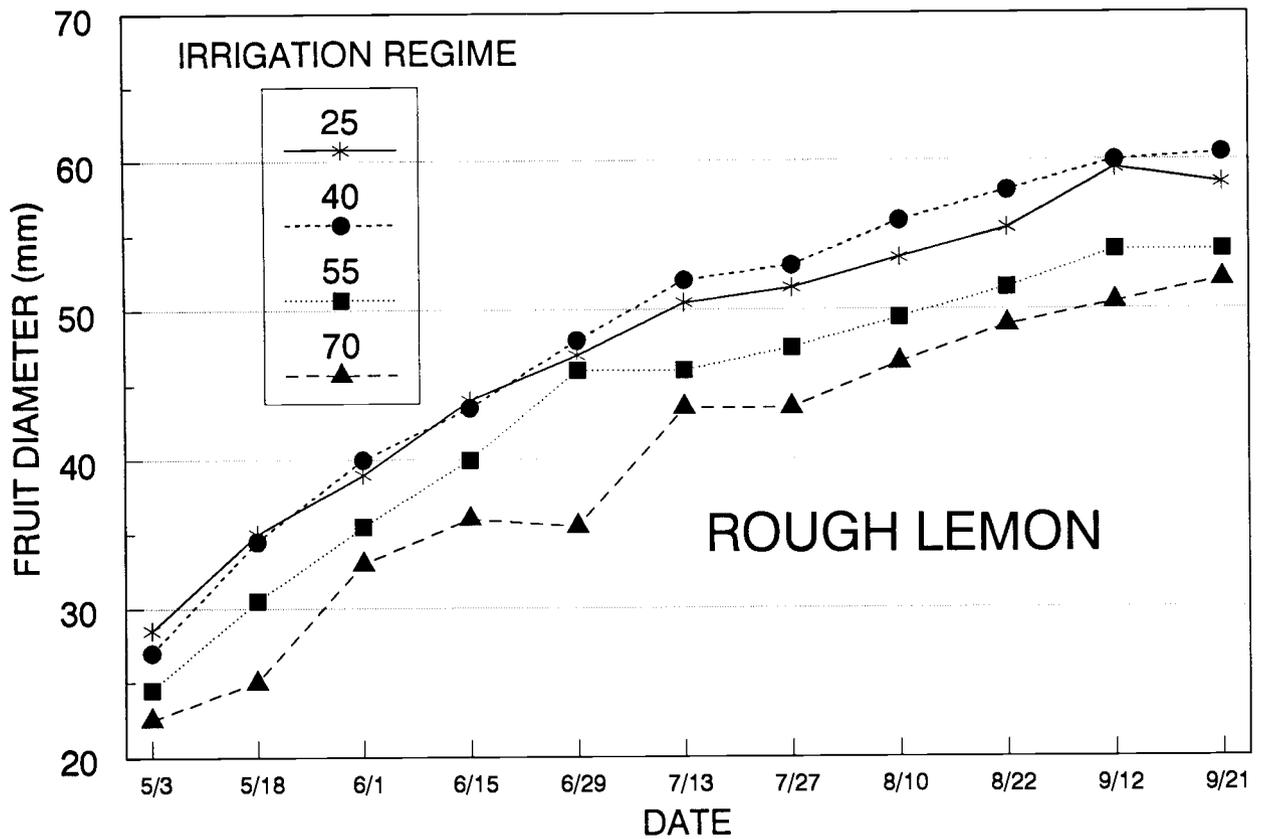
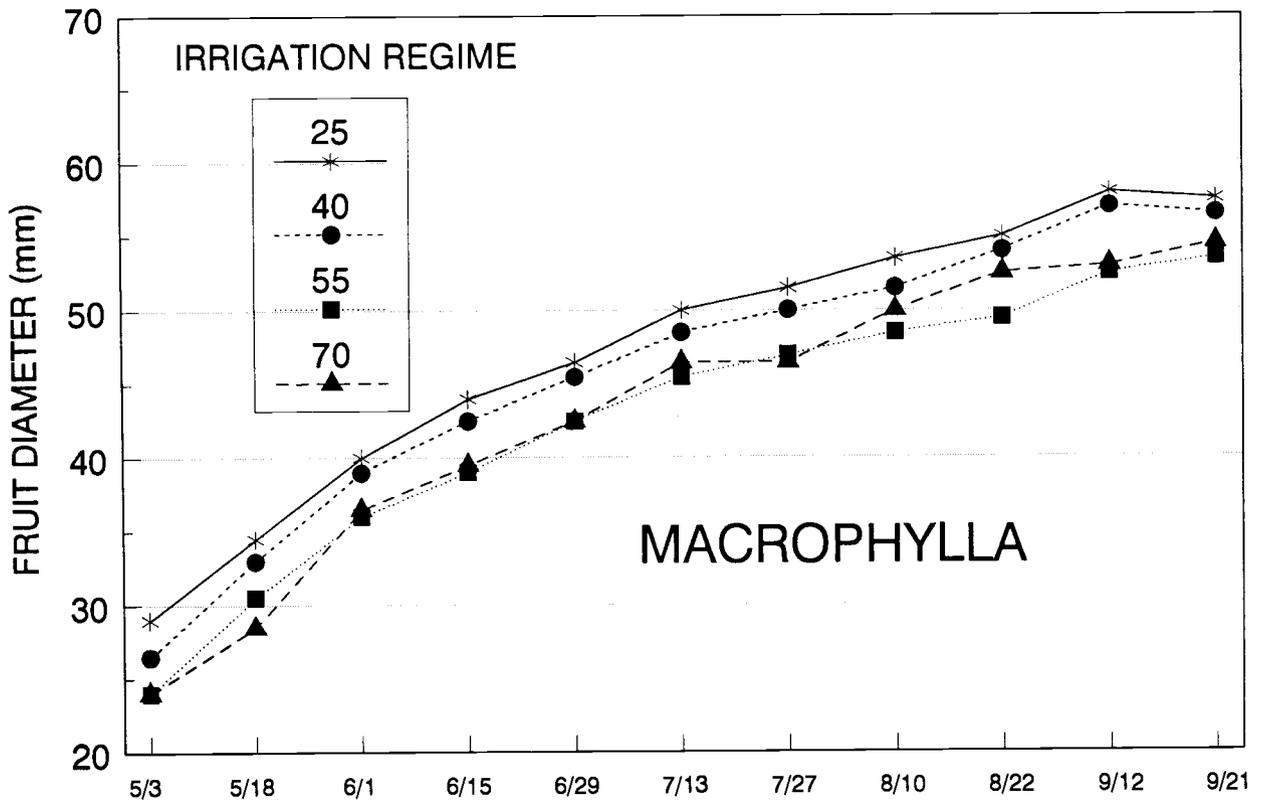


Figure 4. Fruit growth of Lisbon lemons on two rootstocks as influenced by irrigation regime in 1995.

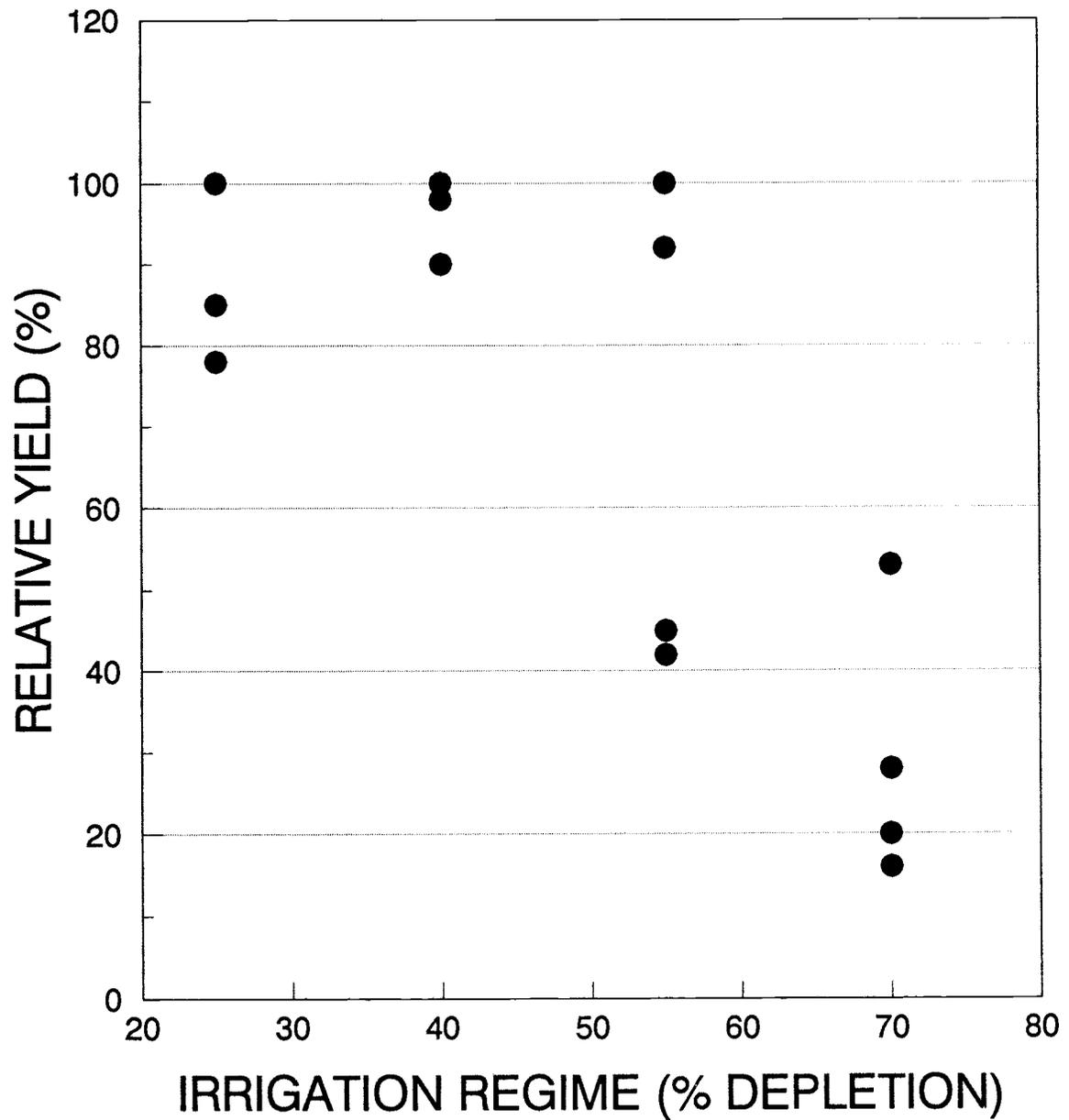


Figure 5.

Relative early yield of lemons in 1994 and 1995 to irrigation regime.

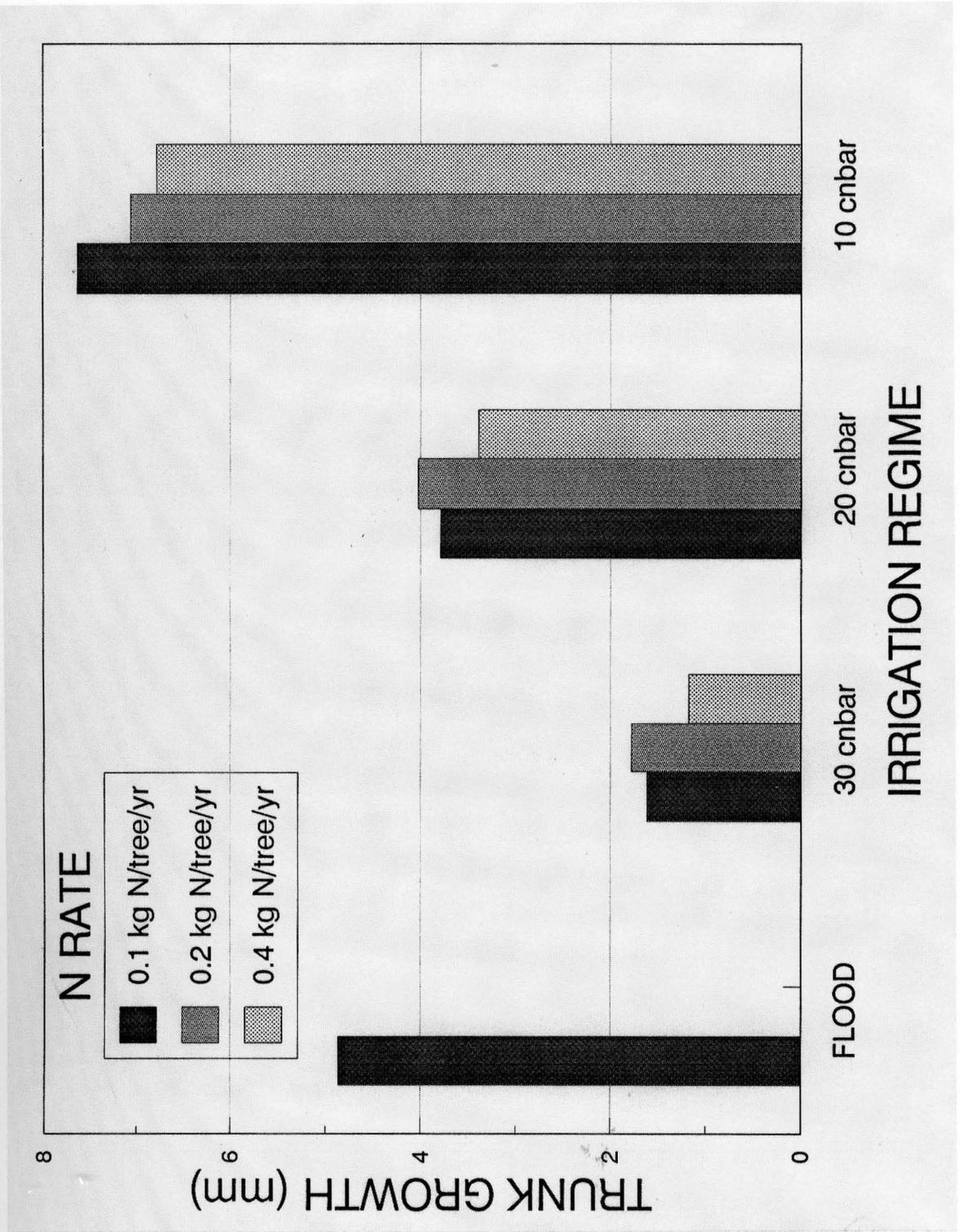


Figure 6. Tree growth of young lemons to irrigation and N during 1994 in experiment 3.

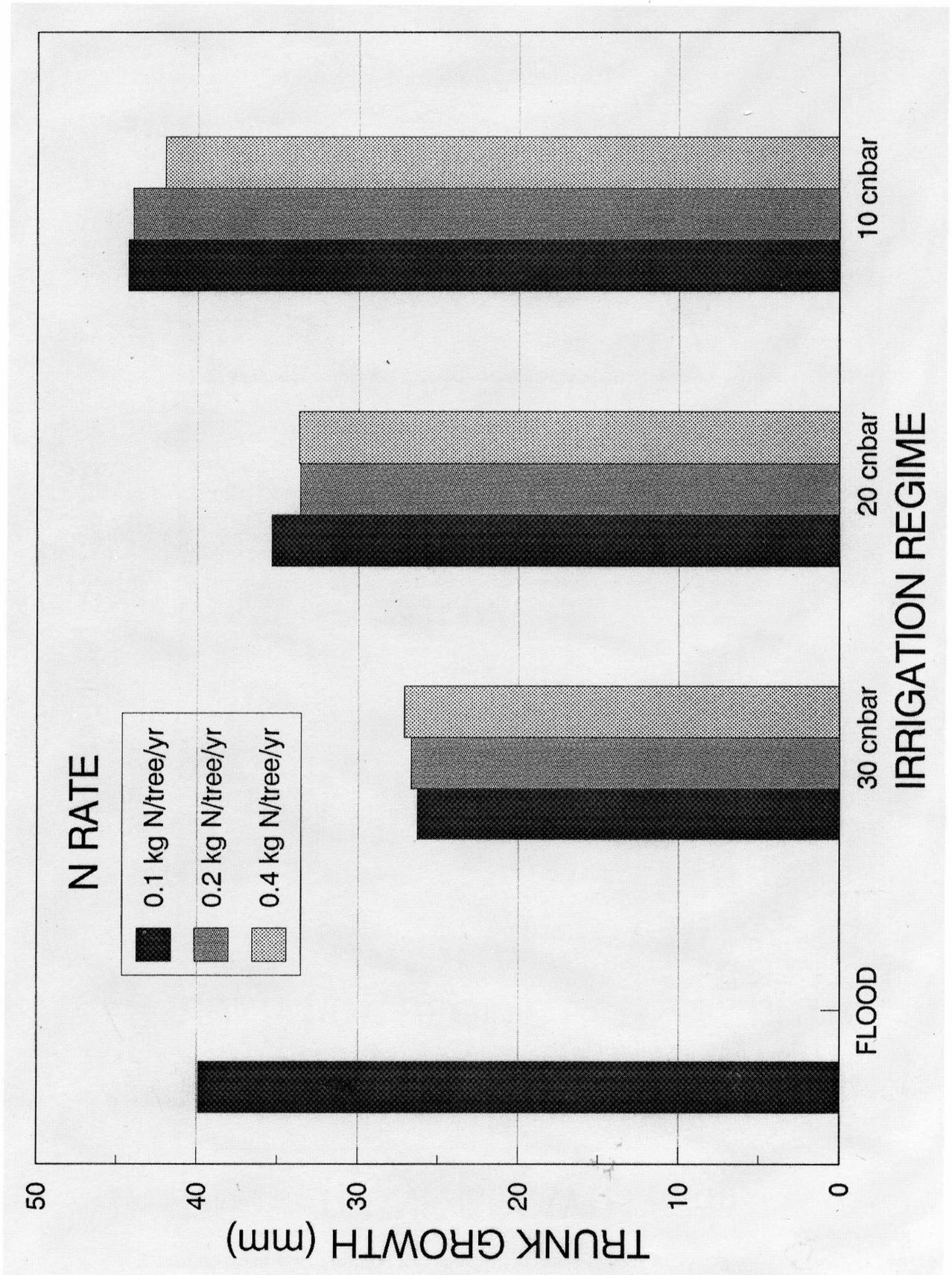


Figure 7. Tree growth of young lemons to irrigation and N during 1995 in experiment 3.

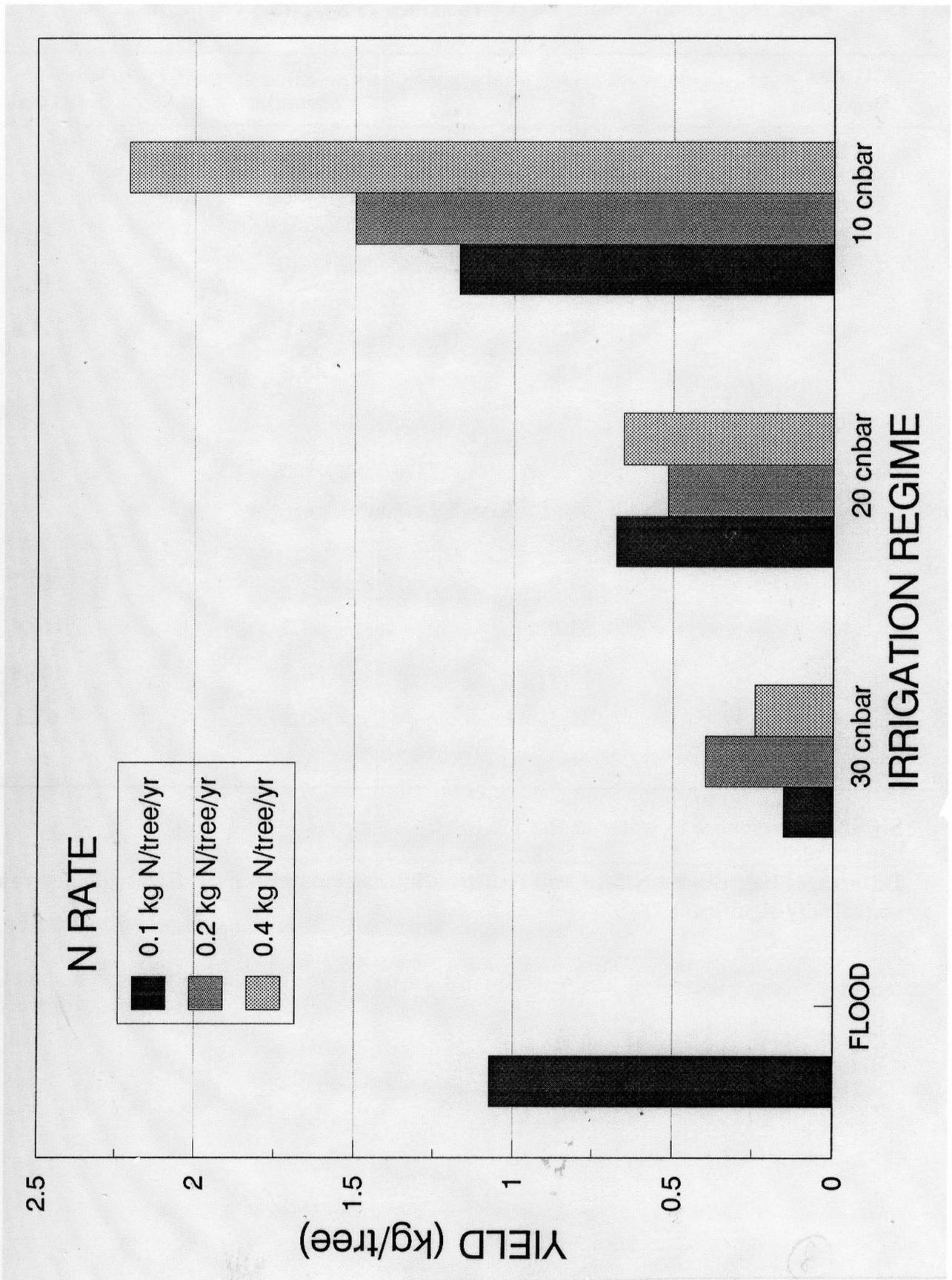


Figure 8. First yield of lemons from young trees as influenced by irrigation and N in experiment 3.

Table 1. Yield of 'Lisbon' lemons on two rootstock to irrigation regime in 1994.

Water Depletion (%)	First	Second	Total
	Macrophylla^a		
	lbs/tree		
25	40.6	70.1	111.1
40	52.1	64.3	117.2
55	47.8	59.1	111.8
70	14.6	48.6	70.3
Sig.	**	NS	--
	Rough Lemon^a		
25	50.9	61.2	110.7
40	53.8	64.3	116.4
55	59.8	58.3	106.8
70	31.5	46.5	63.2
Sig.	**	NS	**

**** Significant response to water at the 1% level.**

^a Differences between rootstocks and rootstock interactions with irrigation regime were not statistically significant.

Table 2. Yield of 'Lisbon' lemons on two rootstock to irrigation regime in 1995.

Water Depletion	First	Second	Total
(%)	Macrophylla^a		
	lbs/tree		
25	169.3	188.7	360.0
40	166.5	160.0	326.0
55	75.4	286.8	362.0
70	33.3	221.3	255.0
Sig.	L**	NS	NS
	Rough Lemon^a		
25	121.7	131.4	253.0
40	119.0	126.9	246.0
55	51.2	205.5	256.0
70	19.7	143.4	163.0
Sig.	L**	NS	NS

**** Significant response to water at the 1% level.**

^a Differences between rootstocks and rootstock interactions with irrigation regime were not statistically significant.

Table 3. Trunk diameters of 'Limoneira 8A Lisbon' trees on *C. volkameriana* irrigated with drip, microjet, microspray and flood irrigation.

Treatment	Trunk Diameter (mm)				
	September 1993 ^z	March 1994	1993 - 1994 Increase	March 1995	1994 - 1995 Increase
Drip ^y	16.08 ab ^x	16.21 bc	0.13 b	28.24 b	12.03 bc
Microjet	17.09 a	17.23 ab	0.13 b	28.27 b	11.04 c
Microspray	15.80 b	15.96 c	0.15 b	31.45 a	15.49 a
Flood	16.71 ab	17.52 a	0.81 a	30.49 a	12.97 b

^z September 1993 measurement was taken at planting.

^y Values are means of 8 trees.

^x Means separation by Duncan's Multiple Range Test, 5% level. Values followed by the same letter are not significantly different.

TABLE 4. Lemon yield and average fruit weight under 4 common irrigation delivery systems in Yuma, Arizona.

Treatment	1995 Total Yield (kg)	Average Fruit Weight (g)
Drip ^z	1.57a	120a
Microjet	1.04bc	99a
Microspray	1.46ab	106a
Flood	0.86c	121a

^z Means separation within columns using Duncan's Multiple Range test at the 5% level. There is a 95% chance that values within a column that are followed by different letters are different. Values within the same column that are followed by the same letter are not different.