CITRUS TREE SPACING EFFECTS ON SOIL WATER USE, ROOT DENSITY, AND FRUIT YIELD

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ABSTRACT

Soil water content, root density, and fruit yield measurements were made on 'Hamlin' orange trees on Milam rootstock at two tree spacings–6 × 4.5 m (370 trees/ ha) and 4.5 × 2.5 m (889 trees/ ha). Soil water use per unit land area for the seven- and eight-year-old trees was not significantly affected by tree spacing. Water use was greatest underneath the canopy dripline and generally decreased with increasing soil depth to 1.65 m. Root densities of the seven-year-old trees were greater at the 4.5 × 2.5 m spacing and generally decreased with depth. Fruit yields per ha were greater for the 4.5 × 2.5 m spacing in the early years, were comparable for both spacings during the seventh and eighth years, and favored the 6 × 4.5 spacing in the 9th year. KEYWORDS. Citrus trees, Spacing, Soil water use.

INTRODUCTION

Competition for fresh water in Florida has become much keener since 1960 because of increased use of irrigation in agriculture, the rapid increase in population, and below normal rainfall. The Florida citrus industry pumps an estimated 1150 billion liters of water annually for irrigation (Stanley et al., 1980) and is a major user of fresh water.

Numerous studies have been conducted on citrus to measure its response to irrigation and to quantify its water use. Koo and Sites (1955) and Koo (1963) demonstrated orange yield increases of up to 34% in response to irrigation. Smajstrla et al. (1985) measured the evapotranspiration (ET) of two-year-old orange trees with a lysimeter system. At a soil water tension of 20 cb (45% soil water depletion) and no ground cover, they measured an average daily ET of 1.0 mm from August through December, and 1.5 mm from March through October. Koo and Sites (1955) reported the water use by 15-year-old Marsh grapefruit trees at a 7.6 × 7.6 m spacing over a 15-month period in Florida. ET ranged from a low of 1.2 mm/day in the winter to a high of 4.3 mm/day in the summer, while over a 12-month period, a total of 99 cm of water was required. In another study, Koo (1961) measured an average ET of 1.6 mm/day on a 25-year-old Valencia orange tree over 15 weeks between January and July.

Since 1960, Florida growers have planted trees at closer spacings (Florida Agricultural Statistics Service, 1986) to achieve higher yields at a young age and quicker returns on their investment. To use water efficiently, Florida's citrus growers and water management districts need to know if higher tree populations use greater amounts of water. Crane (1984) found that orange tree planting densities from 215 to 716 trees/ ha did not significantly alter soil water use by 12-year-old bearing orange trees.

Tree spacing affects root densities, which may be related to water use. Kaufmann et al. (1972) found that root densities in nine-year-old orange trees generally increased with tree densities from 222 to 797 trees/ ha. In 16-year-old orange trees (215 to 716 trees/ ha), Castle (1980) measured higher root densities at higher tree densities.

As with many fruit crops, citrus fruit yields per unit of land area are related to tree spacing in the early bearing years (Boswell et al., 1975; Phillips, 1974; Wheaton et al., 1986). However, as the trees grow and compete, fruit yields per unit land area become independent of tree spacing, and may even decline at the closer spacings (Boswell et al., 1975; Koo and Muraro, 1982).

Because of the lack of research information about the management of closely spaced plantings, a comprehensive citrus tree spacing experiment (Wheaton et al., 1986) was planted in Candler fine sand near Babson Park, FL in 1980. The objectives of the study reported in this article were to measure the soil water use, root densities, and fruit yields of Hamlin orange trees at two spacings – 6.0 × 4.5 m (370 trees/ ha) and 4.5 × 2.5 m (889 trees/ ha) within the comprehensive experiment.

METHODS AND EQUIPMENT

COMPREHENSIVE EXPERIMENT

The five factors and design of the split plot comprehensive experiment with four replications are shown in Table 1. For the first three years, a regular commercial young tree care program was followed;

TABLE 1. Factors in comprehensive experiment

Factor	Plot	Levels
Scion	Main	Hamlin and Valencia sweet orange
Tree height	Sub 1	4 m, 5.5 m
Between-row spacing	Sub 2	4.5 m, 6.0 m
Rootstock	Sub 3	Rusk Citrange, Milam lemon
In-row spacing	Sub 4	2.5 m, 4.5 m

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subsequently, equal quantities of pesticides, fertilizers, and water were applied per unit land area. Herbicides were used to keep the grove floor essentially free of vegetative cover. Supplemental irrigation was applied through a permanent set overhead system. The trees were allowed to compete for space in-row while a 2 m middle was maintained (pruned) between-row for vehicular traffic associated with production and harvesting. Measurements were made on tree growth, leaf mineral composition, fruit quality, fruit yields, and other parameters.

Soil Water Use Experiment

Soil water content, root density, and yield were measured in a multiple split plot experimental design with four replications of the 'Hamlin' orange tree on Milam rootstock (Table 2). Tree height was the main plot followed by subplots in the order of tree spacing, access tube orientation and location, and sampling depth. Even though tree height was included as a factor, all trees were essentially the same height (4 m or less) because they had not grown enough to exceed the minimum height. The tree height factor was included in this experiment for future studies when the trees will have grown enough to be maintained at the heights shown in Table 2. Each of the 16 experimental plots (2 tree heights × 2 tree spacings × 4 replications) included 4 rows × 7 trees. The center trees in one of the two center rows was selected for soil water content measurements in 1987 and 1988. The two tree spacings were the lowest and highest tree densities in the comprehensive experiment.

Aluminum access tubes (3.9 cm I.D. and 183 cm long), with a neoprene stopper in each end of the tubes to keep out moisture and foreign material, were placed in the soil adjacent to the selected plot trees (fig. 1). There were eight tubes in the 6 × 4.5 m plots and 5 tubes in the 4.5 × 2.5 m plots. Within each orientation, the location of all tubes were numbered consecutively from the tree trunk, and the highest numbered tube represented the approximate midpoint between adjacent trees. Sampling depths were 30, 60, 90, 120, and 150 cm. The tubes as a group were assumed to be positioned in the soil containing most of the roots of the plot tree, but each tube within the plots represented a different area (fig. 2). The calculated areas were bounded by separation lines midway between

TABLE 2. Factors in soil water use experiment

Factor	Plot	Levels
Tree height	Main	4 and 5.5 m
Tree spacing	Sub	4.5 × 2.5 m (889 trees/ ha) 6.0 × 4.5 m (370 trees/ ha)
Access tube orientation	Sub	1 (between-row), 2 (in-row)
Access tube location	Sub	Distance from tree trunk (cm) Orientation 1 (between-row) / Orientation 2 (in-row) 1. 75 / 60 2. 150 / 120 3. 225 / 180 4. 300 / 240
Sampling depth	Sub	30, 60, 90, 120, and 150 cm below soil surface

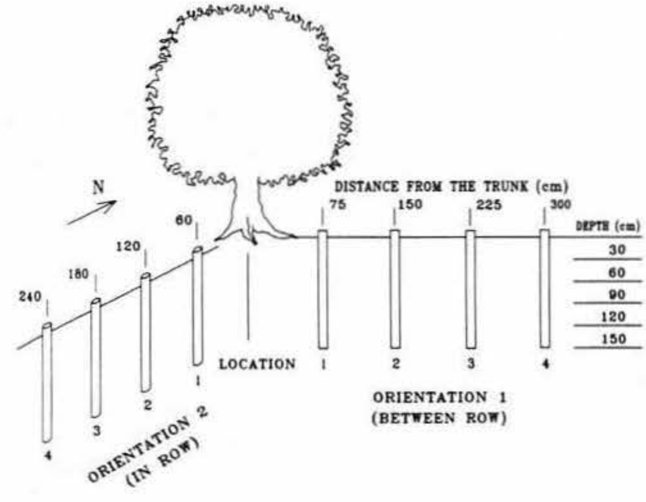

Figure 1–Schematic of moisture tube placement in soil adjacent to trees. For 370 trees/ha, there were four moisture tube locations in each orientation. For 889 trees/ha, there were moisture tube locations 1, 2, and 3 in orientation 1 and moisture tube locations 1 and 2 in orientation 2.

adjacent tubes and the plot diagonals.

A Campbell Pacific Nuclear* Model 503 neutron meter was used to make soil water content determinations. The meter was calibrated in 1986 by correlating its 256 s count ratio readings at a 30 cm depth with soil water contents, which were determined gravimetrically. After the count ratio reading was made, two soil samples were taken, each at a horizontal distance of 15 cm on opposite sides of a tube. Soil bulk density measurements were also made from these samples. Forty-eight neutron meter readings (one from each of the 16 plots on three dates) were correlated with the water contents of 96 soil samples. The calibration readings were all taken from the highest numbered tube in orientation 1.

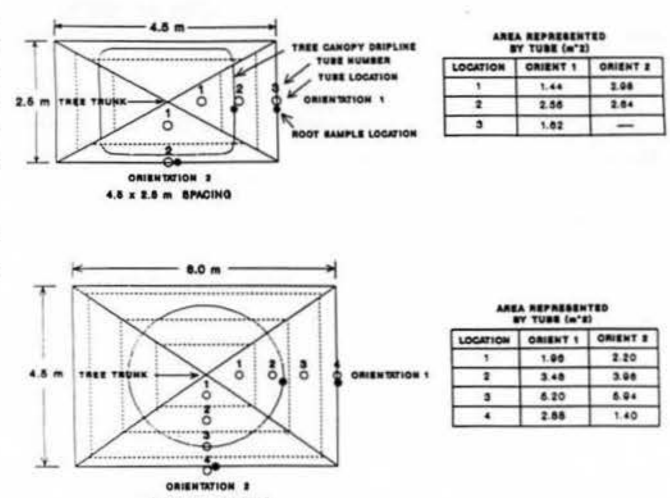

Figure 2–Plan view of 4.5 × 2.5 m and 6.0 × 4.5 m tree plots showing locations of tree trunk, access tubes, areas represent the tubes, root sample locations, and the 1987 tree canopy dripline.

*Mention of commercial names does not constitute an endorsement by the University of Florida, and is provided for information only.

Data points from the mm of soil water per m of soil depth and the count ratio of the neutron meter were fitted to a "least squares" linear regression analysis. The resulting equation 1 was based on the average soil bulk density of 1.5 g/cm^3 from the 96 soil samples and had a coefficient of determination of 0.82.

$$W = 156.6\,(CR) - 5.9 \qquad (1)$$

where

W = mm of soil water per m of soil depth from soil samples

CR = count ratio from neutron meter.

Neutron meter readings were taken at approximately weekly intervals on four occasions: (1) 1, 9, 16, and 21 April 1987; (2) 3, 10, 17, and 23 December 1987; (3) 22, 29 March and 6 April 1988; and (4) 7 and 15 November 1988. In central Florida, these months are normally periods of lower rainfall. In each instance, precipitation (rainfall and/or irrigation) prior to taking the readings was sufficient to bring the soil water content to near field capacity. The first set of readings was taken within two or three days after the precipitation had ceased.

Each set of 520 readings was made in the same sequence over a two-day period with the 4 m tree height plots read on the first day and the 5.5 m tree height plots read on the second day. This procedure made the time lapse about the same between subsequent readings. All readings, excluding those for calibration, were made with 16 s counts because it greatly reduced the time required for making the readings with little apparent sacrifice in accuracy. When compared during calibration, the 16 and 256 s count readings varied by an average of 1.2%.

Precipitation between the first and last sets of readings during each occasion was insignificant except for 5 mm of rain during occasion 2 on 14 December. Using the first set of readings on each occasion as a baseline, changes in soil water content between subsequent readings were calculated as soil water use.

Root density measurements, g roots per L of soil volume, were made in replications 1, 2, and 4 in July-August 1987 by sampling with a bucket auger to a depth of 240 cm in 30 cm increments. The roots were separated from the soil, dried, and weighed. Samples were taken at three locations (between-row midpoint, between-row dripline, in-row midpoint) in each plot (fig. 2). Locations of all root sampling sites corresponded closely to an access tube location except for the between-row dripline location in the 6 × 4.5 m spacing, in which case, the root sample location was between two soil water tubes. Fruit yield was measured by weighing the fruit from each of the 16 experimental plots from the 1983-84 through the 1989-90 seasons.

Results and Discussion

Soil Water Use

Soil water contents in this experiment ranged from maximum values of 70 to 80 mm of water per m of soil depth, to minimum values of 50 to 55 mm of water per m of soil depth. The rate of soil water use over this range, as indicated by the reduction in weekly water content

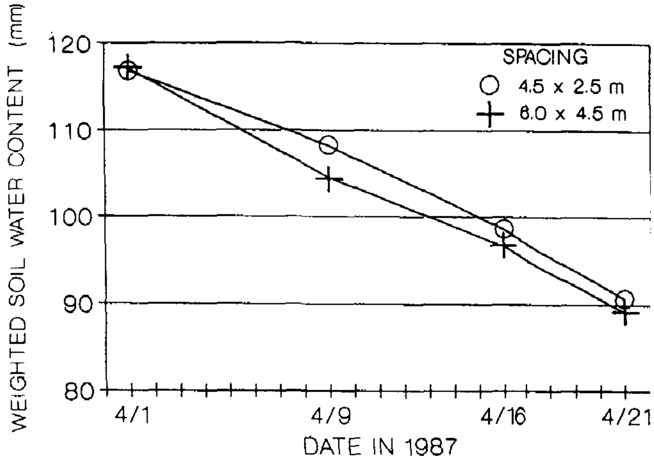

Figure 3–Weighted soil water content in 1.65 m soil depth for the two tree spacings during occasion 1.

readings, was nearly constant, e.g., occasion 1 (fig. 3).

Table 3 is a summary of the soil water use data calculated from the neutron probe readings on each of the four occasions. The weighted means were calculated by subtracting the final from the initial count ratio readings on each occasion and weighting the readings for the areas listed in figure 2. The weighted readings were statistically analyzed by analysis of variance using the GLM procedure in SAS (1985).

Table 4 summarizes the probabilities (≤ 0.1) of the F values for the main effects (means listed in Table 3) of each factor and their second-order interactions. Tree height had a significant ($P = 0.0545$) effect on soil water use only in April 1987. The reason for this was not apparent, because the seven-year-old trees at both levels of height had grown to approximately the same height (≤ 4 m) and might be considered a statistical anomaly.

Tree spacing did not significantly affect soil water use on any of the occasions. Even though there were numerical differences in soil water use, no definite trend was exhibited.

Soil water use was significantly greater in orientation 2 (in-row) than orientation 1 (between-row) on two occasions. On occasions 1 and 3, soil water use at tube locations within orientation was significantly affected. Soil water use was greater at locations 2 and 3 which were in the vicinity of the dripline of the tree canopy (fig. 2) compared to location 1 (nearest the trunk) and 4 (outside the canopy). Note that data from both orientations of the 6.0 × 4.5 m spacing were included in all four location means. Due to the closer tree spacing in the 4.5 x 2.5 m spacing plots, data from both orientations were included in the means of locations 1 and 2 only, data from orientation 1 in the location 3 mean, and no data in the location 4 mean. In addition, the tubes in each orientation were at different spacings.

Soil water use was significantly different for the various depths during the first three occasions. The greatest soil water use was at the 30 and 60 cm depths, and then decreased with increasing depth.

The spacing × location interaction on the second occasion resulted because soil water use at location 2 in the 4.5 × 2.5 m spacing was 30% higher than at locations 1 and

TABLE 3. Weighted soil water use means* on four different occasions for levels of main experimental factors in mm of water per day

Occasion no. and dates	Tree height (m)		Tree spacing (m)		Orientation Bet.-row	Orientation In-row	Tube location				Depth (cm)				
	4	5.5	4.5 × 2.5	6 × 4.5	1	2	1	2	3	4	30	60	90	120	150
1 4/1-4/21/87	1.52	1.22	1.30	1.40	1.11	1.63	1.17	1.50	1.45	1.16	0.31	0.32	0.27	0.19	0.16
2 12/3-12/23/87†	1.26	1.34	1.36	1.26	1.31	1.27	1.24	1.41	1.27	1.11	0.28	0.31	0.27	0.19	0.13
3 3/22-4/6/88	2.48	2.49	2.43	2.51	2.41	2.57	2.23	2.57	2.61	2.46	0.51	0.53	0.47	0.38	0.36
4 11/7-11/15/88	2.06	1.58	1.82	1.82	1.19	2.43	1.78	2.10	1.72	1.39	0.28	0.35	0.38	0.43	0.20

* Means under tree height, tree spacing, orientation, and tube location are based on a 1.65 m soil depth. Means under depth are based on a 30 cm soil depth.
† Water-use figures for this occasion do consider 5 mm rainfall on 12/14.

3; whereas, soil water use was more uniform at all four locations in the 6.0 × 4.5 m spacing. On the first two occasions, the orientation × location interactions were consistent. Soil water use at locations 2 and 3 in orientation 1 was substantially more than at locations 1 and 4, whereas in orientation 2, soil water use generally increased from location 1 to 4. The location × depth interactions resulted from soil water use being greater at locations 2 and 3 than at locations 1 and 4 for the 30, 60, and 90 cm depths; however, at 120 and 150 cm depths, soil water use decreased from location 1 to location 4 on occasion 2, but increased from location 1 to location 4 on occasion 3.

Evapotranspiration (ET) was calculated based on a 165 cm soil depth and the soil water use means at the depths listed in Table 3. It was assumed the soil water use measured at 30 cm represented the top 45 cm of soil (although the values shown in Table 3 assume a 30-cm depth), and the other readings each represented a 30 cm depth increment. For December 1987, the ET was 1.3 mm per day; whereas, for March-April 1988, it was 2.5 mm per day. Koo and Sites (1955) reported ET values for 15-year-old 'Marsh' grapefruit trees during November-December to be 1.3 to 2.2 mm per day and 2.9 mm per day during March-April. ET values of 1.6 mm per day were reported by Koo (1961) for 25-year-old 'Valencia' orange trees between January and July. Crane (1984) calculated ET values of up to 1.5 mm/day in midsummer for 12-year-old 'Pineapple' orange trees. For one-year-old 'Valencia' orange trees maintained with no ground cover and at 20 cb soil water tension, Smajstrla et al. (1985) measured an average ET of 1.2 mm per day between August and December.

TABLE 4. Statistical significance probabilities of F values for those experiment factors* and their second-order interactions* with a probability ≤ 0.10

	Occasion no. and dates 1 4/1-4/21/87	2 12/3-12/23/87	3 3/222-4/6/88	4 11/7-11/15/88
Height	0.0545	--	--	--
Orientation	0.0001	--	--	0.0024
Location	0.0005	--	0.0615	--
Depth	0.0001	0.0001	0.0001	--
Height × orientation	--	0.0566	--	--
Spacing × location	--	0.0863	--	--
Orientation × location	0.0902	0.0329	--	--
Orientation × depth	0.0914	--	0.0835	--
Location × depth	--	0.0003	0.002	--

* Spacing as a main effect and second-order interactions not listed had significance probability values ≥ 0.10.

Table 5 shows the temperatures, evaporation pan measurements, ETs, and crop coefficients during the soil water content measurements. Average pan evaporation (PE) rates during occasions 1 and 3 were almost twice those during occasions 2 and 4. The potential ET was calculated as 70% of the evaporation pan measurements (Jones et al., 1984). The measured ET was the average of the soil water use of the two tree spacings in Table 3. Calculated crop coefficients, K_c, varied from 0.3 to 0.6. Jones et al. (1984) reported crop coefficients for bearing citrus (Lake Alfred) of approximately 0.65 and 1.0 for April and November/December, respectively, using the Penman equation to estimate potential ET.

Soil water use was greater during 1988 than 1987. This could have been the result of continued root system and tree size development, and the fact that the average soil water contents during occasions 3 and 4 were higher than for occasions 1 and 2.

Soil Water Use and Root Density

Figures 4, 5, and 6 show soil water use in April 1987 and root densities in July-August 1987 in replications 1, 2, 4. The soil water use values for the between-row dripline (fig. 5) were averages of locations 2 and 3 in orientation 1 of the 6 × 4.5 m spacing. Otherwise, the soil water use values were those for the one tube adjacent to the root sample locations shown in figure 2.

In general, root density and soil water use decreased with increasing depth. The root system extended beyond 165 cm but root densities below this depth (not shown) were generally less than those at the 165 cm depth. Also, root density and in some cases soil water use were less for the root sample locations in the 6 × 4.5 m spacing. One might conclude from these figures that the 6 × 4.5 m spacing used less water than the 4.5 × 2.5 m spacing. However, soil water use nearer the trunk (location 1, fig. 1)

TABLE 5. Average temperatures and evaporation pan measurements* at the Lake Alfred CREC† and evapotranspiration (ET) and crop coefficients during water use measurements

Occasion no. and dates	Dry bulb temperature (°C) Maximum mean	Minimum mean	Evaporation pan measurements Wind speed (km/day)	Evaporation (mm/day)	Potential ET‡ (mm/day)	Measured§ ET (mm/day)	Crop‖ coefficient (K_c)
1 4/1-4/21/87	25	11	115	6.6	4.6	1.4	0.3
2 12/3-12/23/87	25	10	73	3.0	2.1	1.3	0.6
3 3/22-4/6/88	29	16	93	6.6	4.6	2.5	0.5
4 11/7-11/15/88	28	13	39	4.0	2.8	1.8	0.6

* Forida Climatological Data, National Climatic Data Center, Ashville, NC.
† CREC is located 50 km northwest of experiment.
‡ Calculated from an evaporation pan coefficient of 0.7.
§ Measured ET was the average soil water use of the two tree spacings in Table 3.
‖ Measured ET ÷ potential ET.

was more for the 6 × 4.5 m spacing than the 4.5 × 2.5 m spacing, and made the average water use about the same for both spacings as shown in Table 3.

As discussed in the above section, soil water use was generally higher in orientation 2 than orientation 1 (see Table 3). Figures 4 and 6 show the root densities and soil water use were generally greater for the in-row midpoint (orientation 2) than the between-row midpoint (orientation 1).

Soil water use and root densities were generally higher for the dripline location (fig. 5) when compared to the between-row midpoint location outside the canopy (fig. 6). Also, with respect to location, the initial soil water content always averaged lowest at location 1, suggesting the total precipitation was lowest near the tree trunk or greater water use had occurred by the time the initial readings were taken. Koo (1961) and Crane (1984) both reported less precipitation and water use under the tree canopy.

Fruit Yields

Seasonal fruit yields for the two tree spacings for 1983-84 to 1989-90 are shown in figure 7. In the early seasons, yields generally increased with age and the higher density (4.5 × 2.5m) spacing had significantly ($P = 0.05$) higher yields for 1983/84 through 1986/87. For the next two seasons, 1987/88 and 1988/89, yields associated with the two spacings were not significantly different, and for the 1989/90 season, the yield of the lower density (6 × 4.5 m) spacing was significantly higher than for the 4.5 × 2.5 m spacing. The variation in yields for the last three seasons can be attributed in part to the trees being in an alternate bearing cycle (heavy crop, light crop, heavy crop, etc.).

For the Hamlin oranges in this experiment, the tree normally bloomed (crop set) in February/March and the crop was normally harvested the following December/January. Therefore, the 1987/88 and 1988/89 fruit crop yields were grown and developed during 1987 and 1988, respectively, when the water use measurements were made. As stated above, the fruit yields of the two tree spacings for both 1987/88 and 1988/89 were not significantly different, just as the soil water use of the two tree spacings for both 1987 and 1988 were not significantly different.

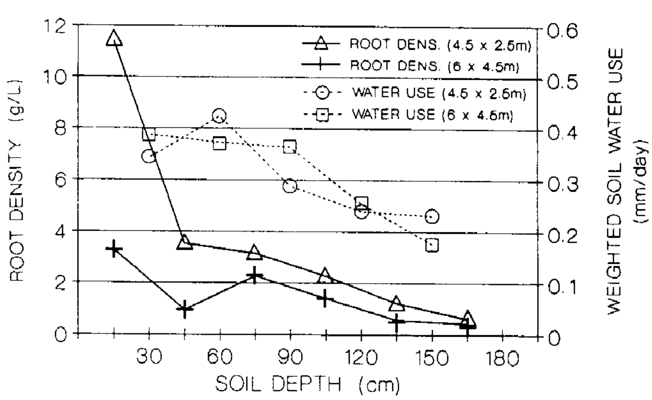

Figure 4–Root density and weighted soil water use in 30-cm soil depth increments at in-row midpoint in April 1987.

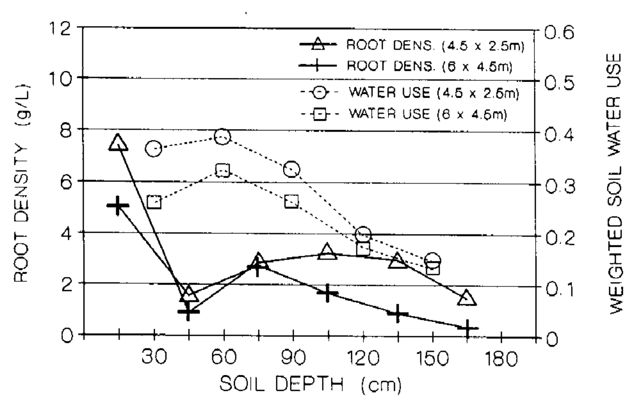

Figure 5–Root density and weighted soil water use in 30-cm soil depth increments at between-row dripline in April 1987.

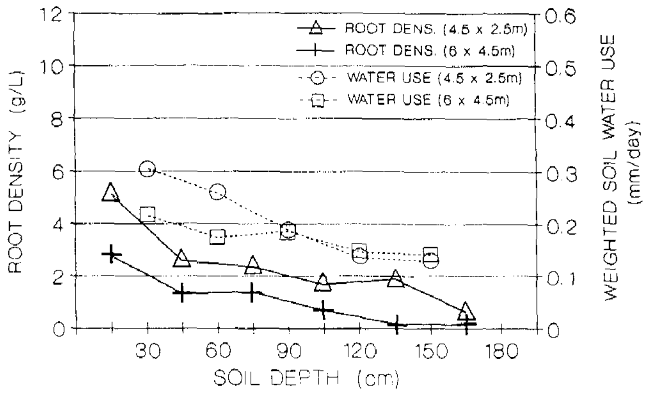

Figure 6–Root density and weighted soil water use in 30-cm soil depth increments at between-row midpoint in April 1987.

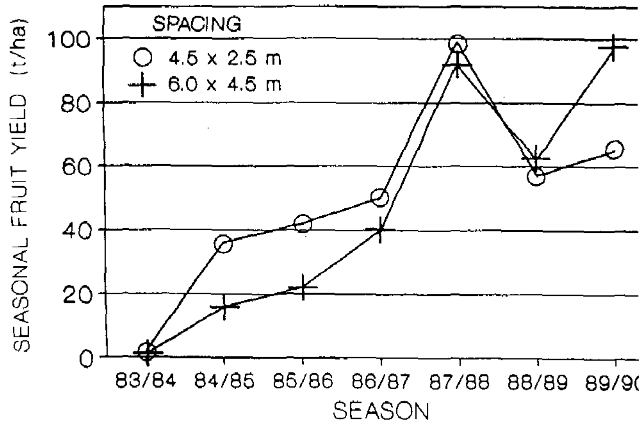

Figure 7–Seasonal fruit yield for the 4.5 × 2.5 m (889 trees/ha) and 6 × 4.5 m (370 trees/ha) spacings.

Summary and Conclusions

Soil water content, root density, and fruit yield measurements were made on Hamlin orange trees on Milam rootstock at two tree spacings–6 × 4.5 m (370 trees/ ha) and 4.5 × 2.5 m (889 trees/ ha). Soil water use to a depth of 1.65 m was not affected by spacing for the seven- and eight-year-old trees. Of the two dimensions in each of the two spacings, the in-row orientation (smaller of the two spacing dimensions) generally used more soil water and had higher root densities than did the between-row orientation. Within orientation, soil water use and root density were greatest underneath the tree canopy dripline. Soil water use and root densities were greatest in the upper 60 cm of soil, and then generally decreased with increasing soil depth. The ET of both tree spacings were 1.3 mm/day in the fall-winter months and 2.5 mm/day in the spring months. Fruit yields per ha favored the 4.5 × 2.5 m spacing in the early years, were comparable for both spacings during the seventh and eighth year, and favored the 6 × 4.5 m spacing in the ninth year.

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References

Boswell, S.B., C.D. McCarty, K.W. Hench and L.N. Lewis. 1975. Effect of tree density on the first ten years of growth and production of 'Washington' navel orange trees. *J. Amer. Soc. Hort. Sci.* 100(4): 370-373.

Castle, W.S. 1980. Fibrous root distribution of 'Pineapple' orange trees on rough lemon rootstock at three tree spacings. *J. Amer. Soc. Hort. Sci.* 105(3): 478-480.

Crane, J.H. 1984. Plant density and water relations of 'Pineapple' orange trees [*Citrus sinensis* (L.) Osbeck]. M.S. thesis, University of Florida, Gainesville.

Florida Agricultural Statistics Service. 1986. Citrus tree inventory. September 11.

Jones, J.W., L.H. Allen, S.F. Shih, J.S. Rogers, L.C. Hammond, A.G. Smajstrla and J.D. Martsolf. 1984. Estimated and measured evapotranspiration for Florida climate, crops, and soils. Tech. Bull. 840. IFAS, University of Florida, Gainesville.

Kaufmann, M.R., S.B. Boswell and L.N. Lewis. 1972. Effect of tree spacing on root distribution of 9-year-old 'Washington' navel orange. *J. Amer. Soc. Hort. Sci.* 97(2): 204-206.

Koo, R.C.J. 1961. The distribution and uptake of soil moisture in citrus groves. *Proc. Fla. State Hort. Soc.* 74: 86-90.

———. 1963. Effects of frequency of irrigations on yield of orange and grapefruit. *Proc. Fla. State Hort. Soc.* 76: 1-5.

Koo, R.C.J. and R.P. Muraro. 1982. Effect of tree spacing on fruit production, and net returns of 'Pineapple' oranges. *Proc. Fla. State Hort. Soc.* 95: 29-33.

Koo, R.C.J. and J.W. Sites. 1955. Results of research and response of citrus to supplemental irrigation. *Proc. Soil Sci. Soc. Fla.* 15: 180-190.

Phillips, R.L. 1974. Performance of 'Pineapple' orange at three tree spacings. *Proc. Fla. State Hort. Soc.* 87: 81-84.

SAS Institute Inc. 1985. *SAS™ User's Guide: Statistics, Version 5 ed.*, 433-506. SAS Institute Inc. Cary, NC.

Smajstrla, A.G., L.R. Parsons, K. Aribi and G. Velledis. 1985. Response of young citrus trees to irrigation. *Proc. Fla. State Hort. Soc.* 98: 25-26.

Stanley, J.M., C. Taylor, W.R. Summerhill, Jr. and L.J. Beaulieu. 1980. Citrus energy survey – Use estimates and conservation. Energy Report No. 2. Institute of Food and Agricultural Sciences, University of Florida, Gainesville.

Wheaton, T.A., J.D. Whitney, W.S. Castle and D.P.H. Tucker. 1986. Tree spacing and rootstock affect growth, yield, fruit quality, and freeze damage of young 'Hamlin' and 'Valencia' orange trees. *Proc. Fla. State Hort. Soc.* 99: 29-32.