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SOIL WATER USE, ROOT DENSITY, AND FRUIT YIELD FOR TWO CITRUS TREE SPACINGS

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Abstract. **Soil water content, root density, and fruit yield measurements were made on 'Hamlin' (*Citrus sinensis* (L.) Osb.) orange trees on Milam (*C. jambhiri* variant) rootstock at 2 tree spacings—19.7 x 14.8 ft (150 tree acre) and 14.8 x 8.2 ft (360 trees/acre). Soil water use per unit land area for the 7- and 8-yr-old trees was not significantly different for the 2 tree spacings. Water use was greatest underneath the canopy dripline and generally decreased with increasing soil depth to 5.5 ft. Root densities of the 7-yr-old trees were greater at 14.8 x 8.2 ft spacing and generally decreased with depth. Fruit yields per acre were greater for the 14.8 x 8.2 ft spacing in the early yrs, were comparable for both spacings during the 7th and 8th yr, and favored the 19.7 x 14.8 ft spacing in the 9th yr.**

Numerous studies have been conducted on Florida citrus to measure its response to irrigation and to quantify its water use. Whitney et al. (8) have reviewed these studies and other studies showing how citrus tree spacing affects fruit yields and root densities, which may be related to water use.

Since 1960, Florida growers have planted trees at closer spacings (2) to achieve higher yields at a young age and quicker returns on their investment. During this same time period, competition for fresh water in Florida has become much keener because of increased use of irrigation in agriculture, the rapid increase in population, and below normal rainfall. The Florida citrus industry is a major user of fresh water with an estimated 300 billion gal of water being pumped annually for citrus irrigation (6).

Because of increased groundwater deficits in the last few yrs, Florida's water management districts have imposed greater restrictions on irrigation for agriculture including citrus. In the future, further restrictions and justifications will probably be imposed unless high rainfall deficits are reduced.

Because of the lack of information about the requirements and management of closely-spaced plantings in Florida, a comprehensive citrus tree spacing experiment was established in 1980 near Babson Park. The first report on this experiment was presented in 1986 and included information on the effects of scion, rootstock, and spacing on tree growth, mineral nutrition, fruit yield and quality, and freeze damage (7).

The objectives of the study in this paper were to measure soil water use, root densities, and fruit yields of 'Hamlin' on Milam rootstock at 2 spacings—14.8 x 19.7 ft (150 trees/acre) and 8.2 x 14.8 ft (360 trees/acre)—within the comprehensive experiment.

Materials and Methods

The comprehensive experiment was a multiple split plot design with 4 replications as described by Wheaton et al. (7). Scion variety was the main plot followed by subplots of tree height, between-row spacing, rootstock, and in-row spacing in that order.

Within the comprehensive experiment, soil water contents were measured in a multiple split plot design with 4 replications of the 'Hamlin' orange trees on Milam rootstock (Table 1). Tree height was the main plot followed by subplots in the order of tree spacing, access tube orientation and location, and sampling depth. Soil water content measurements were made in 1987 and 1988 when all trees were essentially the same height (13 ft or less). 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 1. Each of the 16 experimental plots (2 tree heights x 2 tree spacings x 4 replications) included 4 rows x 7 trees. One of the center trees in one of the 2 center rows was selected for soil water content measurements. The 2 tree spacings represented the lowest and highest tree densities in the comprehensive experiment.

Soil water content measurements were made with a Campbell Pacific Nuclear Model 503 neutron meter in aluminum access tubes placed in the soil adjacent to the selected plot trees (Fig. 1). There were 8 tubes in the 19.7

Table 1. Factors in soil water use experiment.

Factor	Plot	Levels	
Tree height	Main	13 and 18 ft	
Tree spacing	ub	14.8 x 8.2 ft (360 trees/acre), 19.7 x 14.8 ft (150 trees/acre)	
Access tube orientation	Sub	1 (between-row), 2 (in-row)	
Access tube location	Sub	*Distance from tree trunk, inches*	
		Orientation 1 (between-row)	Orientation 2 (in-row)
		1. 30	24
		2. 60	48
		3. 90	72
		4. 120	96
Sampling depth	Sub	1, 2, 3, 4, and 5 ft below soil surface	

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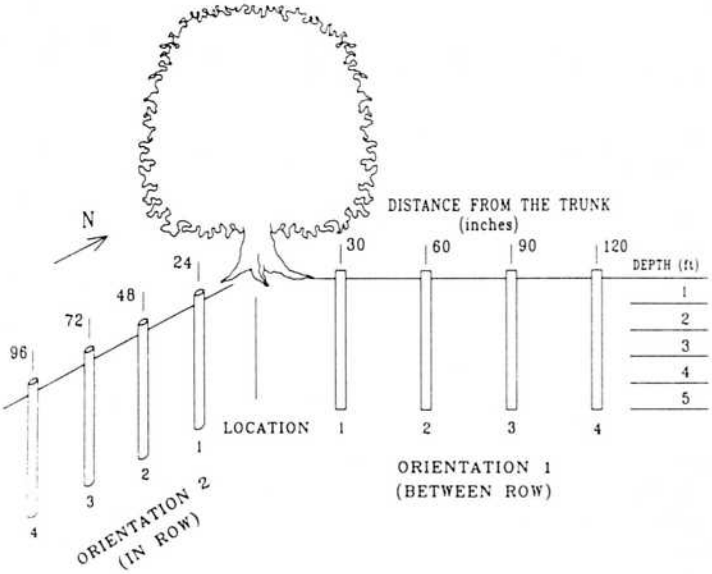
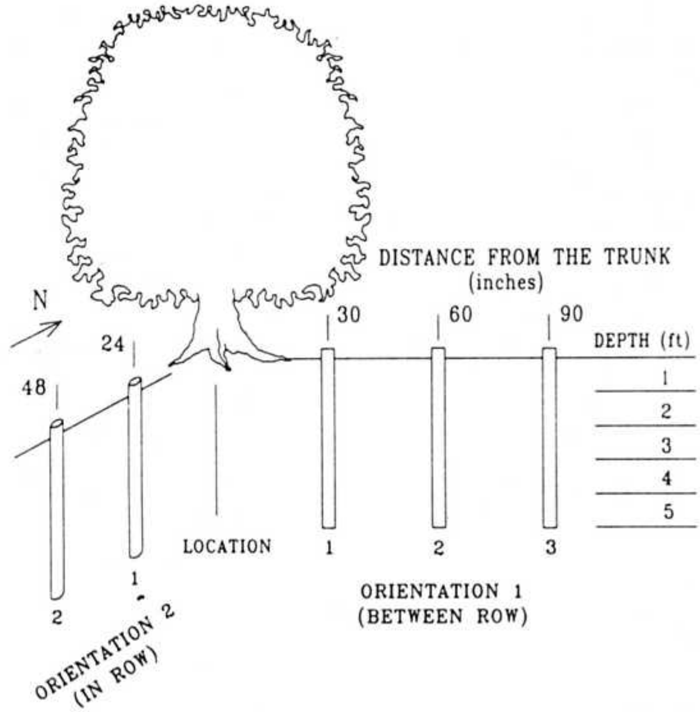
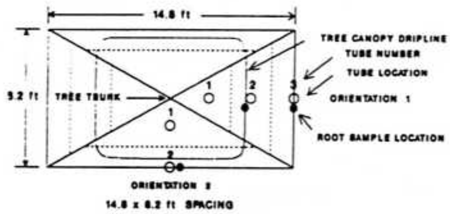


19.7 x 14.8 ft spacing (150 trees/acre)



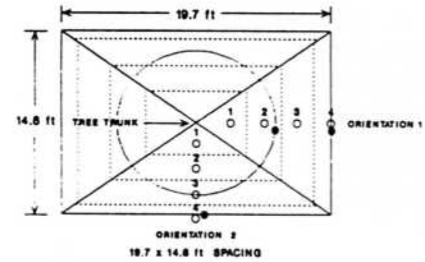
14.8 x 8.2 ft spacing (360 trees/acre)

Fig. 1. Schematics of moisture tube placement in soil adjacent to trees.



AREA REPRESENTED BY TUBE (ft^2)

LOCATION	ORIENT 1	ORIENT 2
1	15.6	32.2
2	27.6	28.5
3	17.5	—



AREA REPRESENTED BY TUBE (ft^2)

LOCATION	ORIENT 1	ORIENT 2
1	21.2	23.8
2	37.4	42.8
3	56.2	64.1
4	31.0	15.1

Fig. 2. Plan view of 14.8 x 8.2 ft and 19.7 x 14.8 ft tree plots showing locations of tree trunk, access tubes, areas represented by the tubes, root sample locations, and the 1987 tree canopy dripline.

x 14.8 ft plots and 5 tubes in the 14.8 x 8.2 ft plots. Within each orientation, the locations 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 1, 2, 3, 4, and 5 ft. 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 adjacent tubes and the plot diagonals.

The neutron meter was calibrated in 1986 by correlating the meter readings (count ratio) with the soil water content (determined gravimetrically) of 96 soil samples taken in the plots. The resulting "least squares" linear regression equation was

$$W = 1.88 (CR) - 0.07$$

where W = inches of soil water per ft of soil depth and CR = count ratio from neutron meter.

Neutron meter readings were taken at approximately weekly intervals on 4 occasions: (1) 1, 9, 16, and 21 April 1987, (2) 3, 10, 17, and 23 December 1987, (3) 22 and 29 March and 6 April 1988, and (4) 7 and 15 November 1988. In each instance prior to taking the readings, the rainfall and/or precipitation from the permanent set overhead irrigation system was sufficient to bring the soil water content to near field capacity. The precipitation between the first and last sets of readings during each occasion was insignificant except for 0.2 inch 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. Weeds and grasses should not have contributed to soil water use since the soil surface in the plots was kept relatively free of ground cover with the use of herbicides.

Root density measurements were made in replications 1, 2, and 4 in July-August 1987 by sampling with a bucket auger to a depth of 8 ft in 1 ft increments. The roots were separated from the soil, dried, and weighed. Samples were taken at 3 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 19.7 x 14.8 spacing, in which case, the root sample location was between 2 access tubes. Fruit yield was measured by weighing the hand-harvested fruit from at least 5 trees in each of the 16 experimental plots from the 1983-84 through the 1989-90 seasons.

More details on materials and methods have been described by Whitney et al. (8).

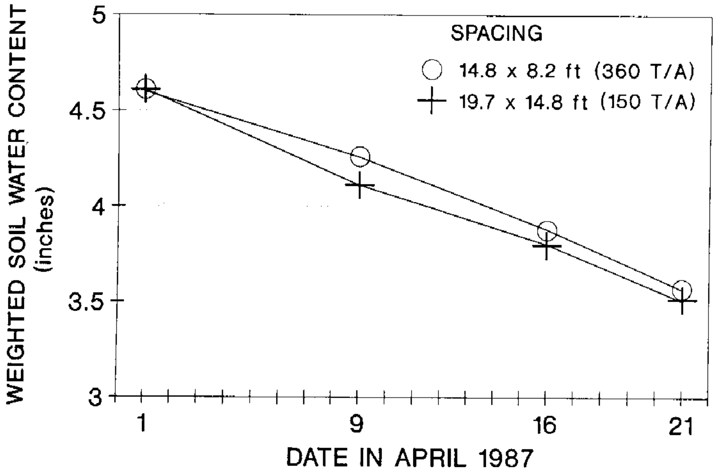


Fig. 3. Weighted soil water content in 5.5 ft soil depth for the two tree spacings during occasion 1.

Table 3. Statistical significance probabilities of F values for those experimental factors[z] with a probability ≤ 0.10.

	Occasion no. and dates			
	1 1 Apr - 21 Apr 87	2 3 Dec - 23 Dec 87	3 22 Mar - 6 Apr 88	4 7 Nov - 15 Nov 88
Height	0.0545	--	--	--
Orientation	0.0001	--	--	0.0024
Location	0.0005	--	0.0615	--
Depth	0.0001	0.0001	0.0001	--

[z]Spacing as a main effect had significance probability values ≥ 0.10.

Results and Discussion

Soil water use. The range of average soil water contents from the first to the last readings on each occasion were ca. 1 to 0.6 inch of water per foot of soil depth, respectively. The rate of soil water use over this range, as indicated by the reduction in weekly water content readings, was nearly constant, e.g., occasion 1 (Fig. 3).

Table 2 is a summary of the soil water use data calculated from the neutron meter readings. The weighted means were calculated by subtracting the final from the initial count ratio reading on each occasion and weighting the readings for the areas listed in Fig. 2. The weighted readings were statistically analyzed by analysis of variance using the GLM procedure in SAS (5). Table 3 summarizes the probabilities (≤ 0.1) of the F values for the main effects of each factor listed in Table 2.

Tree height had a significant effect on soil water use only in April 1987. The reason for this was not apparent because the 7-yr-old trees at both levels of height had grown to approximately the same height (≤ 13 ft) 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 occasions 1 and 4. This may have been related to differences in root density which will be discussed later.

On occasions 1 and 3, soil water use at tube locations within orientation was significantly different. 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 locations 1 (nearest the trunk) and 4 (outside the canopy). Note that data from both orientations of the 19.7 x 14.8 ft spacing plots with 8 access tubes were included in all 4 location means. However, because only 5 access tubes were in the 14.8 x 8.2 ft 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 access tubes in each orientation were at different spacings (24 and 30 inches).

Soil water use was significantly different for the various depths during the first 3 occasions. The greatest soil water

Table 2. Weighted soil water use means[z] on 4 different occasions for levels of main experimental factors in inches of water per month (30 days).

Occasion no and dates	Tree height, ft		Tree spacing, ft		Orientation		Tube location				Depth, ft				
	13	18	14.8 x 8.2	19.7 x 14.8	Bet.-row 1	In-row 2	1	2	3	4	1	2	3	4	5
1 1/4-21/4/87	1.80	1.44	1.54	1.65	1.31	1.93	1.38	1.77	1.71	1.37	0.37	0.38	0.32	0.22	0.19
2 3/12-23/12/87[y]	1.49	1.58	1.61	1.49	1.55	1.50	1.46	1.67	1.50	1.31	0.33	0.37	0.32	0.22	0.15
3 22/3-6/4/88	2.93	2.94	2.87	2.96	2.85	3.04	2.63	3.04	3.08	2.91	0.60	0.63	0.56	0.45	0.43
4 7/11-15/11/88	2.43	1.87	2.15	2.15	1.41	2.87	2.10	2.48	2.03	1.64	0.33	0.41	0.45	0.51	0.24

[z]Means under tree height, tree spacing, orientation, and tube location are based on a 5.5 ft soil depth. Means under depth are based on a 1 ft soil depth.
[y]Water use figures for this occasion do consider 0.2 inch rainfall on14/12.

use was at the 1 and 2 ft depths and then decreased with increasing depth.

Evapotranspiration (ET) was calculated based on a 5.5 ft soil depth and soil water use means listed in Table 2. It was assumed the soil water use measured at the 1 ft depth represented the use rate in the top 1.5 ft of soil. Therefore, the means listed under the 1 ft depth in Table 2 would be multiplied by 1.5. Means for the other depths were assumed to represent a 1 ft depth increment as shown in the table. For December 1987, the ET was 0.05 inch/day; whereas, for March-April 1988, it was 0.10 inch/day. Koo and Sites (4) reported ET values for 15-yr-old 'Marsh' grapefruit trees during November-December to be 0.05 to 0.09 inch/day and during March-April to be 0.11 inch/day. For 25-yr-old 'Valencia' orange trees between January and July, Koo (3) reported ET values of 0.06 inch/day. Crane (1) calculated ET values of up to 0.06 inch/day in mid-sumer for 12-yr-old 'Pineapple, range trees.

Table 4 shows the temperatures and evaporation pan measurements at the Lake Alfred Citrus Research and Education Center (CREC) and measured ET in the experiment. Average pan evaporation rates during occasions 1 and 3 were almost twice those during occasions 2 and 4. The measured ET for the trees was also greater during occasions 1 and 3 than for occasions 2 and 4.

Soil water use was greater during 1988 than 1987. This could have been the result of continued root system and tree size development. Also, the soil water contents (not shown) during occasions 3 and 4 were higher than for occasions 1 and 2.

Soil water use and root density. Figs. 4, 5, and 6 show the soil water use in April 1987 (occasion 1) and the root densities in July-August 1987 for replications 1, 2, and 4. For the 19.7 x 14.8 ft spacing at the between-row drip line (Fig. 5), the soil water use values were averages of locations 2 and 3 in orientation 1 (see Fig. 2). Otherwise, the soil water use values were those for the one tube adjacent to the root sample locations.

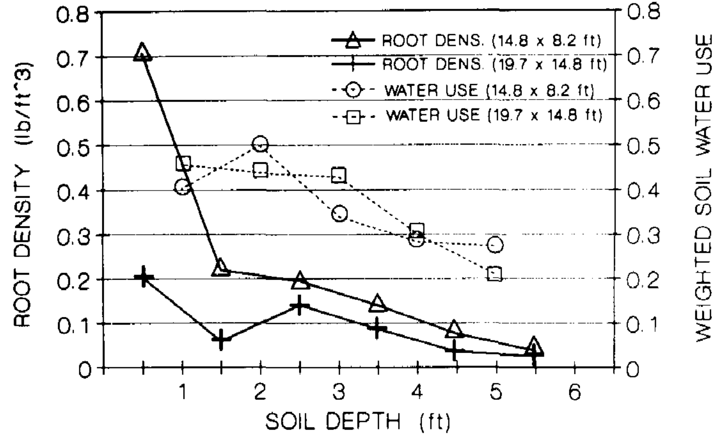


Fig. 4. Root density and weighted soil water use in 1 ft soil depth increments at in-row midpoint in April 1987.

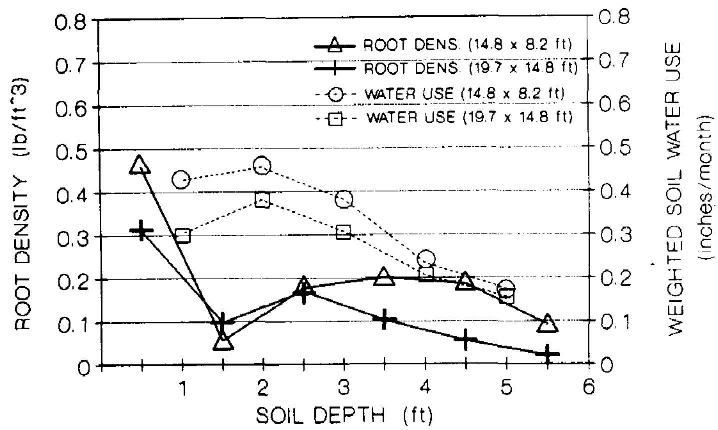


Fig. 5. Root density and weighted soil water use in 1 ft soil depth increments at between-row dripline in April 1987.

Table 4. Average temperatures and evaporation pan measurements[z] at the Lake Alfred CREC[y] and measured evapotranspiration (ET) during water use measurements.

Occasion no. and dates	Dry bulb temperature, °F		Evaporation pan measurements		Measured[x] ET, inches/day
	Maximum mean	Minimum mean	Wind speed, miles/day	Evaporation inches/day	
1					
1 Apr-21 Apr 87	77	52	71	0.26	0.06
2					
3 Dec-23 Dec 87	77	50	45	0.12	0.05
3					
22 Mar-6 Jun 88	84	61	58	0.26	0.10
4					
7 Nov-15 Nov 88	82	55	24	0.16	0.07

[z]Florida Climatological Data, National Climatic Data Center, Ashville, NC.
[y]CREC is located 30 miles northwest of experiment.
[x]Measured ET was calculated from the average soil water use of the 2 tree spacings in Table 2.

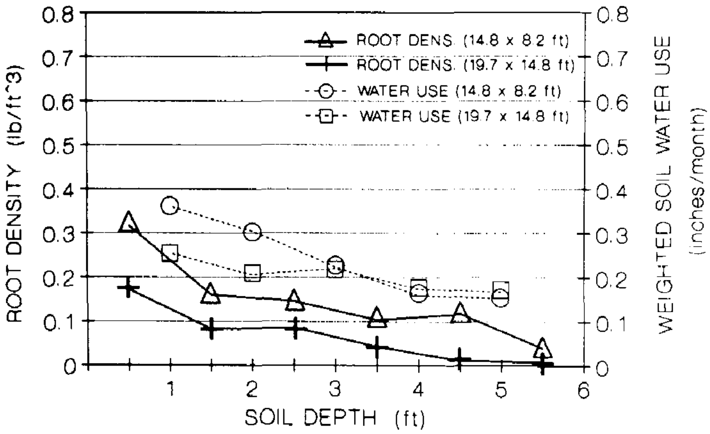


Fig. 6. Root density and weighted soil water use in 1 ft soil depth increments at between-row midpoint in April 1987.

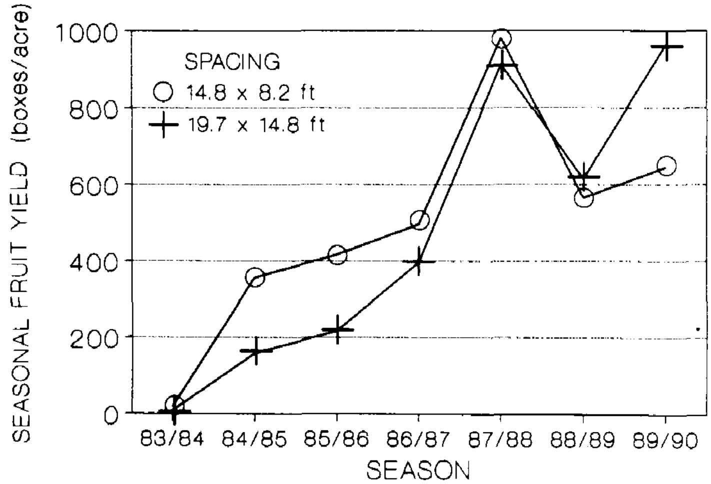


Fig. 7. Seasonal fruit yield for the 14.8 x 8.2 ft (360 trees/acre) and 19.7 x 14.8 ft (150 trees/acre) spacings.

In general, root density and soil water use decreased with increasing soil depth. The root system extended below 5.5 ft, but root densities below this depth (not shown) were generally less than those at the 5.5 ft depth. Also, root densities and, in some cases, soil water use were less for the root sample locations in the 19.7 x 14.8 ft spacing. One might conclude from Figs. 4 to 6 that the 19.7 x 14.8 ft spacing used less water than did the 14.8 x 8.2 ft spacing. However, soil water use nearer the trunk (location 1) was more for the 19.7 x 14.8 ft spacing than for the 14.8 x 8.2 ft spacing and made the average water use about the same for both spacings as shown in Table 2.

As discussed above, soil water use was generally higher in orientation 2 than in orientation 1 (see Table 2). Figs. 4 and 6 show the root densities and soil water use were generally greater for the in-row midpoint (orientation 2) than for 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 (3) and Crane (1) both reported less precipitation and water use under the tree canopy.

Fruit yields. Seasonal fruit yields for the 'Hamlin' on Milam at the 2 tree spacings are shown in Fig. 7. In the early seasons, yields generally increased with age and the closer (14.8 x 8.2 ft) spacing had significantly higher yields for 1983/84 through 1986/87. For 1987/88 and 1988/89, there was not a significant difference in yields, but for 1989/90, yield of the 19.7 x 14.8 ft spacing was significantly higher. The variation in yields for the last 3 seasons may be attributed in part to the trees being in an alternate bearing cycle.

For the 'Hamlin' oranges in this experiment, the 1987/88 and 1988/89 fruit crop yields were developed during 1987 and 1988, respectively, when the water use measurements were made. As stated above, the fruit yields of the 2 tree spacings for both 1987/88 and 1988/89 were not significantly different, just as the soil water use of the 2 tree spacings for both 1987 and 1988 were not significantly different.

Summary and Conclusions

Soil water content, root density, and fruit yield measurements were made on 'Hamlin' orange trees on Milam rootstock at 2 tree spacings—19.7 x 14.8 ft (150 trees/acre) and 14.8 x 8.2 ft (360 trees/acre). Soil water use to a depth of 5.5 ft was not affected by spacing for the 7- and 8-yr-old trees. Of the 2 dimensions in each of the 2 spacings, the in-row orientation (smaller of the 2 spacing dimensions) generally used more water and had higher root densities than did the between-row orientation. Within orientation, soil water use and root densities were greatest underneath the tree canopy dripline. Soil water use and root densities were greatest in the upper 2 ft of soil, and then generally decreased with increasing soil depth. The ET of both spacings was 0.05 inch/day in the fall-winter months and 0.1 inch/day in the spring months. Fruit yields per acre favored the 14.8 x 8.2 ft spacing in the early years, were comparable for both spacings during the 7th and 8th years, and favored the 19.7 x 14.8 ft spacing in the 9th yr.

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