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TREE SPACING AND ROOTSTOCK AFFECT GROWTH, YIELD, FRUIT QUALITY, AND FREEZE DAMAGE OF YOUNG 'HAMLIN' AND 'VALENCIA' ORANGE TREES

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Abstract. **A citrus spacing experiment begun in 1980 included 4 spacings, 2 varieties, and 2 rootstocks. Planting densities ranged from 150 to 360 trees per acre with spacings from 8 x 15 ft to 15 x 20 ft. 'Hamlin' and 'Valencia' Sweet orange (*Citrus sinensis* (L.) Osb.) trees were planted on Milam lemon (*C. jambhiri* Lush) and Rusk citrange (*Poncirus trifoliata* (L.) Raf. x *C. sinensis*) rootstocks. Trees at the 8 ft in row spacing grew together to form a continuous hedgerow in 5 yr and competition between trees reduced trunk growth. Yield increased with increasing tree density during the fourth and fifth seasons. 'Hamlin' trees produced more boxes per acre than 'Valencia' trees during the fourth and fifth seasons. Trees on Rusk citrange rootstock yielded substantially better during these seasons than trees on Milam. The planting was subjected to freezes each year since planting. Trees at closer spacings received less freeze damage during the last 2 winters.**

A limited supply of acreage suitable for citrus, high land values, increasing property taxes, and high production costs, coupled with periodic depressed fruit prices make a high per acre production an economic necessity. Higher density plantings have offered early production in spacing experiments outside Florida (1, 2, 4, 8, 10) and in a Florida experiment with 'Pineapple' orange (5, 6). The concept of higher density plantings has been reviewed (11), and trends toward closer tree spacings (9) have continued to the present time. However, optimal management practices, spacing, scion and stock combinations, and their effects on tree size and productivity have not been established.

The purpose of this report is to describe an experiment begun in 1980 and to report results for the first 5 seasons after planting. The objectives of the experiment were: (a) to determine whether higher density plantings can be managed to realize early production and returns without creating future problems requiring excessive pruning and/or tree removal; (b) to develop production, harvesting, and fruit handling practices which can be utilized in the efficient management of such plantings; (c) to evaluate water and nutrient requirements relative to spacing; and (d) to determine optimal tree spacing and height to maximize profitability for the scion-stock combinations used in this study. The information presented here includes effects of scion, rootstock, and spacing on tree growth, mineral nutrition, fruit yield and quality, and freeze damage to trees from 1980 to 1986.

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Materials and Methods

Factors included in this experiment are listed in Table 1. A multiple split-plot experimental design was used with 4 replications. Scion variety was the main plot followed by smaller subplots of tree height, between-row spacing, rootstock, and in-row spacing in that order. The in-row and between-row spacings listed in Table 1 are presented in the text, tables, and figures rounded to the nearest foot; i.e., 8 x 15 ft instead of 8.2 x 14.8 ft spacing. Plot size was 4 rows x 6 trees with the center 10 trees (2 rows x 5 trees) used for collecting data. The appropriate analysis of variance model was used for statistical analysis of all data, and any treatment differences presented were significant at the 1 or 5% level. The experiment is located on a 25-acre site in Polk County, FL, between the towns of Babson Park and Frostproof. A permanent overhead sprinkler irrigation system to provide uniform application was installed prior to planting the trees.

'Hamlin' and 'Valencia' were selected as scion varieties to represent early and late varieties and because they were not included in the previous major Florida spacing experiment (5, 6). Milam and Rusk citrange were selected as a vigorous and moderately vigorous rootstock, respectively. Including several scion/stock combinations permits evaluation of the horticultural adaptability of various combinations to the constraints of higher density plantings. Tree height treatments have not been started as trees have not yet reached the required heights.

Trees for this experiment were grown in a commercial nursery. Trees were headed out at a 24 inch height which resulted in a tree slightly larger than usual at the time of planting. A heading height higher than normal was used to reduce the number of low branches to facilitate future mechanical harvesting or fruit handling studies. Trees were planted at the experimental site in February, 1980 and a regular commercial young tree care program was followed for the first 3 yr, followed by commercial grove cultural practices.

Trunk circumference measurements were made annually 8 inches above the ground. Beginning in the fall of 1984, leaf samples were collected annually for mineral

Table 1. Experimental factors and tree density.

Scion	Rootstock	Tree height (ft)
Hamlin	Milam	13.1
Valencia	Rusk citrange	18.0
Spacing (ft)		
In row	Between row	Trees per acre
8.2	14.8	360
8.2	19.7	270
14.8	14.8	200
14.8	19.7	150

Experimental design:
Main plot—Scion
Subplot 1—Tree height
Subplot 2—Between-row spacing
Subplot 3—Rootstock
Subplot 4—In-row spacing

analyses. A 60-leaf sample from spring flush nonfruiting twigs was collected from each plot and analyzed for N, P, K, Ca, and Mg using standard procedures (7). Freeze damage was determined by visually rating tree condition on a 0-10 scale with 0 being a dead tree and 10 being a completely healthy tree showing no visible damage.

Fruit yield was determined by weighing the fruit harvested from each 10-tree plot. At harvest, a random fruit sample was collected for determination of average fruit size (weight per fruit), external fruit color, and juice quality. External fruit color was measured on a 20-fruit sample using a Hunter Color Difference Meter. Juice quality factors including percent juice, total soluble solids (brix), and acid were determined using standard automatic extraction and computerized test equipment found in Florida processing plants.

Results and Discussion

The planting was damaged by a series of freezes during the first 6 yr after planting (Table 2). These freezes, beginning a few weeks after planting, probably reduced the rate of tree development and limited early production. Nevertheless, the planting grew well and came into commercial production in the 1984/85 season, 4 yr after planting. Tree growth, fruit quality, and fruit yield data need to be interpreted with consideration of this freeze history. For example, some of the effects of spacing on fruit quality and yield may be related to reduced freeze damage at closer spacings.

Tree growth. Tree growth, measured as increase in trunk circumference, was affected by rootstock, in row, and between row spacing, but not by scion variety. Trunk circumference of trees on Milam rootstock was significantly larger than for trees on Rusk citrange, 14.1 and 12.4 inches, respectively, in March, 1986. During the first 3 yr, there was no effect of tree density on the rate of trunk growth (Fig. 1). During years 4 through 6, competition between trees became evident as trees at the higher density grew more slowly than more widely spaced trees. This reduced growth rate at higher densities began before the tree canopies grew together and filled their allocated space.

Hedging to maintain a 6.5 ft clear space was begun in the 15 ft between row spacing in the spring of 1985 and for the 20 ft rows in 1986. Hedging after harvesting the 'Hamlin' but before harvesting the 'Valencia' fruit was begun in 1986 and will be continued in future years. One concern with 'Valencia' at close between row spacings is the maintenance of good production with an annual hedging program. Starting hedging at an early date when only minor cuts are required may avoid yield loss associated with major hedging started at a later date.

Average tree height in July, 1986 was slightly over 11 ft. Tree height was greater for trees on Milam rootstock

Table 2. Freezes and their effects, 1980 to 1986.

Feb.	1980	Trees planted
Mar.	1980	Frost, partial defoliation, slow recovery and tree growth
Jan.	1981	Freeze, defoliation, bark splitting, wood damage
Jan.	1982	Freeze, defoliation, wood damage, partial girdles
Dec.	1983	Severe freeze, fruit frozen, defoliation and wood damage
Jan.	1985	Severe freeze, fruit damage, leaf and wood damage
Dec.	1985	Freeze, twig damage in top of tree, some fruit damage
Mar.	1986	Frost, bloom, and new flush killed

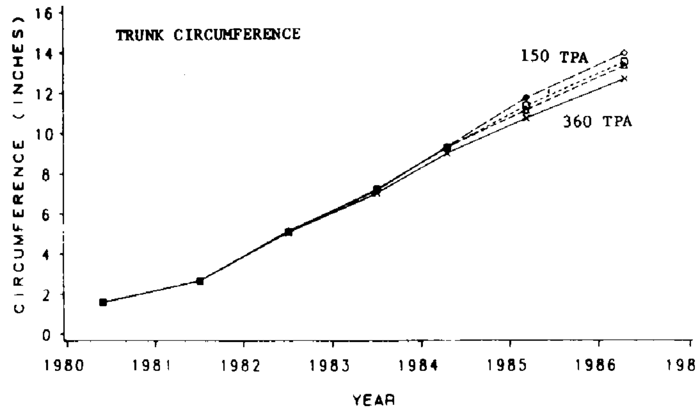

Fig. 1. Effect of tree density on trunk circumference. Values are averaged over scion and rootstock. Tree densities ranged from 150 to 360 trees per acre (TPA).

and for the closer in row spacing. Trees have not been topped thus far, but topping will be performed annually as required to maintain the 2 tree heights.

Mineral nutrition. Leaf analysis indicated major elements were at near optimal levels both seasons (Table 3). Leaf K was low in 1985 but increased in 1986. Small effects of rootstock on leaf mineral composition were observed. In 1986, leaf N, P, Ca, and Mg were slightly higher and K was lower for trees on Rusk citrange rootstock.

Few effects of spacing on leaf mineral composition were observed although leaf Mg was higher for the 8 ft in row spacing both years. Fertilizer was applied on a per tree basis when the trees were small, but was applied on a constant per acre basis for the past several seasons. Absence

Table 3. Effect of scion, stock, in row, and between row spacing on leaf mineral content.[z]

	Leaf mineral content (%)				
	N	P	K	Ca	Mg
		1985			
Scion					
Hamlin	2.6	0.13	0.78	3.8	0.49
Valencia	2.7	0.13	0.90	3.9	0.46
Stock					
Milam	2.6	0.12 a	0.87	4.0 b	0.48
Rusk	2.7	0.15 b	0.81	3.8 a	0.47
In-row					
8 ft	2.7 b	0.13	0.85	3.9	0.49 b
15 ft	2.6 a	0.13	0.83	3.9	0.46 a
Between-row					
15 ft	2.7	0.13	0.85	3.9	0.47
20 ft	2.6	0.13	0.83	3.9	0.48
		1986			
Scion					
Hamlin	2.6	0.16	1.4	2.7 a	0.38
Valencia	2.6	0.17	1.5	3.1 b	0.38
Stock					
Milam	2.5 a	0.16 a	1.6 b	2.8 a	0.37 a
Rusk	2.7 b	0.17 b	1.3 a	3.0 b	0.40 b
In-row					
8 ft	2.6	0.16 a	1.5	2.9	0.39 b
15 ft	2.6	0.17 b	1.5	2.9	0.37 a
Between-row					
15 ft	2.6	0.16	1.5	2.8	0.37
20 ft	2.6	0.16	1.4	2.9	0.39

[z]Mean separation within each factor by Duncan's multiple range test, 5% level. Absence of letters indicates no significant difference.

of spacing effects on leaf mineral composition indicates that the fertilizer application rate has been adequate for all tree densities.

Fruit quality. Effects of rootstock and spacing on fruit size and juice quality were observed (Table 4). Fruit was damaged by freezing temperatures both seasons and 'Valencia' fruit were harvested early during the 1984/85 season to avoid excessive fruit drop and obtain yield and fruit quality data.

Fruit size was influenced by scion both years and by spacing in 1985/86. Fruit were smaller on trees at the closer in row and between row spacings. Percent juice and brix were substantially higher for trees on Rusk citrange than for trees on Milam rootstock. The difference in the 1985/86 season was very large with 42.7% juice for Milam and 52.8% for Rusk. Because of these differences, pounds solids per box was much higher for Rusk than for Milam. Effects of spacing on juice acidity were not consistent from one year to the next. External fruit color was slightly better each year for trees on Milam rootstock, and effects of spacing on color were minor and not consistent over the 2-yr period (data not shown).

Juice content, brix, and the resulting pounds solids per box were low both seasons. These low values are characteristic of both immature trees and freeze damaged fruit. Values were much lower for Milam than for Rusk rootstock. Fruit from lemon-type rootstocks is generally lower in juice content and soluble solids than for citrange rootstocks. Because of the lower soluble solids, freeze damage to fruit on lemon rootstocks is more severe and results in greater loss of juice (3). The large differences in fruit quality between rootstocks therefore may partially be due to differential freeze damage sustained by the fruit.

Fruit yield. Variety, rootstock, and spacing all affected yield expressed as boxes per tree, boxes per acre, or pounds solids per acre (Table 4). Yield per tree was greater for 'Hamlin' than for 'Valencia', larger for Rusk than for Milam, and greater for the 20 ft than for the 15 ft between row spacing. The yield per tree was similar for the 8 ft and 15 ft in row spacing even though the trees for the 8 ft spacing had grown together, indicating little competition between trees at the closer spacing in fruiting potential at this time.

The effects of spacing on yield were greater when yield was expressed on a per acre basis. Average yield over all treatments for the fourth season (1984/85) was nearly 200 boxes per acre and was over 300 boxes per acre for the fifth season after planting. The increase in yield with increasing tree density was linear for these 2 seasons (Fig. 2). At the highest density (8 x 15 ft), 'Hamlin' produced 330 boxes per acre in 1984/85 and 500 boxes per acre in 1985/86. 'Valencia' at the 8 x 15 ft spacing yielded approximately 200 boxes in 1984/85 and 340 boxes per acre in 1985/86.

Pounds solids per acre was similar for 'Hamlin' and 'Valencia', the higher juice content partially offsetting the lower production of 'Valencia'. Pounds solids per acre during the 1985/86 season was much higher for Rusk than for Milam, reflecting the combined benefits of higher juice content, brix, and production. Yield expressed as pounds solids per acre was higher for the closer in row and between row spacings because of the greater fruit production.

Freeze damage. Freeze damage to trees was less severe at the closer spacings for the January 1985 freeze and for freezes during the 1985/86 winter (Fig. 3). Visual ratings of tree condition following the freezes indicated tree condi-

Table 4. Effect of scion, stock, in row, and between row spacing on fruit size, quality, and yield.

Factor	Size (lb./fruit)	Quality: % Juice	Brix	% Acid	PS/box[z]	Yield: Box/tree	Box/acre	PS/acre
1984/85								
Scion								
Hamlin	0.34 a[y]	40.4 a	9.6	0.40 a	3.5	0.9 b	231 b	820
Valencia	0.37 b	45.2 b	9.6	0.62 b	3.9	0.6 a	153 a	610
Stock								
Milam	0.35	41.9 a	9.2 a	0.51	3.5 a	0.7 a	177 a	610 a
Rusk	0.36	43.7 b	10.0 b	0.51	3.9 b	0.9 b	207 b	820 b
In-row								
8 ft	0.36	43.7 b	9.7 b	0.53 b	3.8 b	0.8	246 b	940 b
15 ft	0.35	41.9 a	9.5 a	0.49 a	3.6 a	0.8	138 a	490 a
Between-row								
15 ft	0.35	42.9	9.6	0.52	3.7	0.7 a	206 b	770 b
20 ft	0.36	42.7	9.6	0.50	3.7	0.9 b	178 a	660 a
1985/86								
Scion								
Hamlin	0.42 a	43.9 a	9.1	0.48 a	3.6 a	1.6 b	375 b	1432
Valencia	0.50 b	51.6 b	9.4	0.57 b	4.4 b	1.0 a	251 a	1146
Stock								
Milam	0.47 b	42.7 a	8.8 a	0.50 a	3.4 a	1.0 a	254 a	851 a
Rusk	0.45 a	52.8 b	9.7 b	0.55 b	4.6 b	1.6 b	372 b	1728 b
In-row								
8 ft	0.45 a	48.3	9.4	0.53	4.1	1.2	389 b	1630 b
15 ft	0.47 b	47.2	9.1	0.52	3.9	1.4	238 a	949 a
Between-row								
15 ft	0.45 a	47.7	9.2	0.51 a	4.0	1.2 a	337 b	1382 b
20 ft	0.47 b	47.8	9.3	0.54 b	4.0	1.4 b	290 a	1196 a

[z]PS = pounds solids.
[y]Mean separation within each factor by Duncan's multiple range test, 5% level. Absence of letter indicates no significant difference.

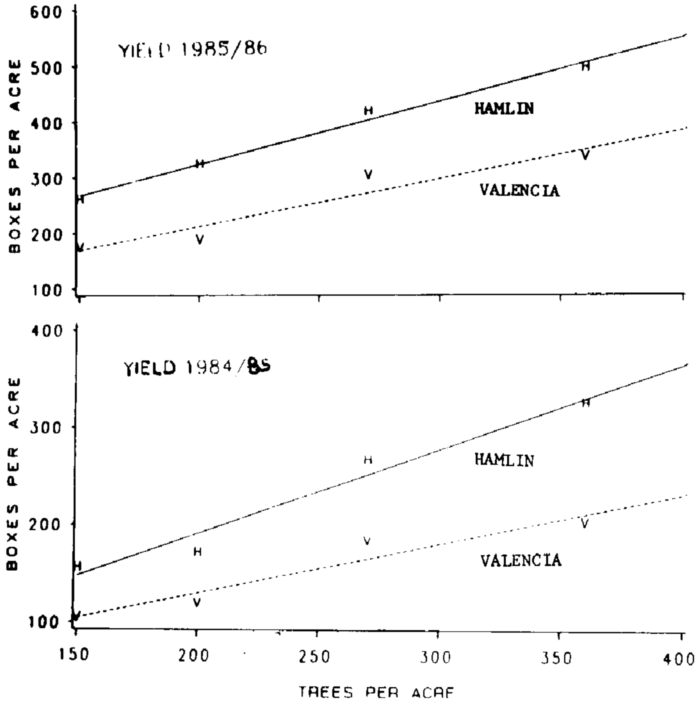

Fig. 2. Effect of tree density on fruit yield. Values are averaged over rootstock.

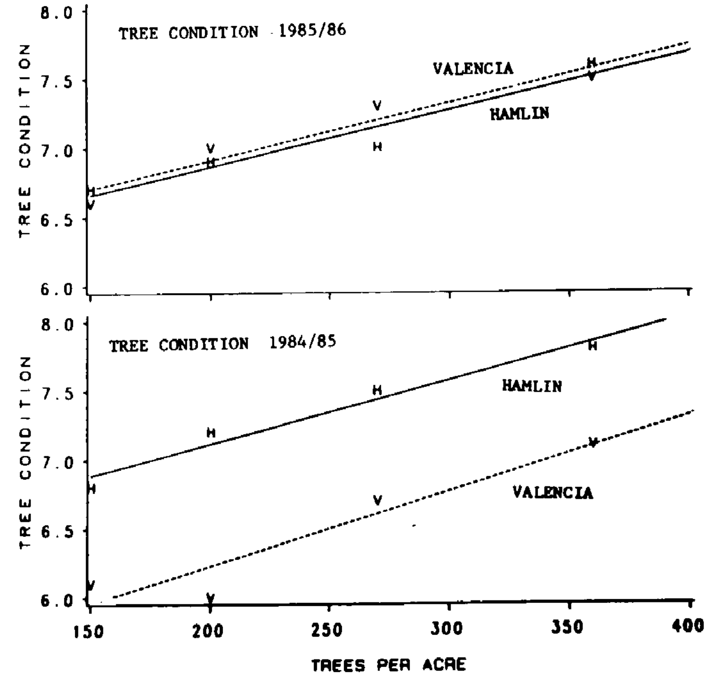

Fig. 3. Effect of tree density on freeze damage. Tree condition values range from 0 for a dead tree to 10 for a tree receiving no freeze damage.

tion improved linearly with increasing tree density. 'Hamlin' and 'Valencia' differed in degree of freeze damage in 1984/85 but not in 1985/86. Differences in freeze damage between the 2 rootstocks were not detected in this experiment during the last 2 winters, although citranges are considered more cold tolerant than Milam.

Advantages of higher tree densities during the first 6 yr included substantially higher production and reduced freeze damage. A portion of the yield advantage of the close in row spacing may be due to reduced freeze damage, perhaps giving the higher densities a relatively better record than if freezes had not occurred. The reduction in tree growth rate at higher densities due to competition among trees may be desirable and has not been associated with a lower yield per tree thus far. In the future, larger trees at the wider spacing may have higher yield per tree, but yield per acre may continue as high or higher for closely spaced trees.

Few disadvantages of the higher densities have been observed to date. Initial tree and planting costs are higher and there are a few more row middles per acre for equipment travel. After the first 3 yr, irrigation, fertilizer, and herbicide (trunk to trunk) were all supplied on a per acre basis equally to all tree densities, so requirements did not depend on spacing. Standard grove equipment and production practices can be used on both 15 and 20 ft between row spacings when hedged regularly to maintain a 6.5 ft middle. Commercial harvesting equipment would have to be modified to operate at the 15 ft row spacing.

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