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TREE VIGOR IMPORTANT IN CITRUS TREE SPACING AND TOPPING

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Abstract. **The importance of matching tree vigor to the space allocated for growth of the tree was documented in an experiment that included 'Hamlin' and 'Valencia' orange varieties, Milam lemon and Rusk citrange rootstocks, topping heights of 12 and 18 ft, between-row spacings of 15 and 20 ft, and in-row spacings of 8 and 15 ft. The four spacing combinations provided tree densities of 150, 200, 270, and 360 trees per acre. Trees on Milam rootstock were vigorous, and Rusk citrange rootstock provided trees of moderate vigor. During the first 8 yr, tree vigor was unimportant and production increased as tree density increased for all variety, rootstock, and spacing combinations. However, as trees matured and were confined to their allocated space by hedging and topping, production and fruit quality declined for trees that were too vigorous for the space allocated to them. Planting densities ranging from 120 to 250 trees per acre are desirable for citrus under Florida conditions, but the density selected must be appropriate for the vigor of the variety and rootstock selected.**

The benefits of higher tree densities which provided improved production during the early years of a citrus grove led to an increase in average tree densities in Florida from 80 trees per acre (TPA) in 1960 to 140 TPA in 1994 (Fig. 1). Groves achieved better early production as a result of higher planting densities and better management. There are reports, however, of declining yield in some of these higher density groves after trees are hedged and topped to control size. Trees may reach this containment size as early as 8 to 10 yr after planting.

Experiments in Florida and other citrus producing areas consistently demonstrated the yield advantage of higher tree density for young groves. In a Florida experiment with 'Pineapple' orange on rough lemon rootstock planted at 87, 145, and 290 TPA, yield and financial returns during the first 10 yr were greatest at the highest density (Koo and Muraro, 1982). Another Florida experiment included four scion varieties and 16 rootstocks, and showed good early production in a planting of 800 TPA (Wheaton et al., 1990). Yield also increased with increasing tree density during the first years of production in the experiment that is the subject of this paper (Wheaton et al., 1986).

Similar benefits of higher tree density on early production have been reported from other citrus growing areas with tree densities ranging from 90 to 4000 trees per acre (Boswell et al., 1975, 1982; Cary, 1981; Hutton, 1986; Patil, 1987; Tachibana et al., 1987). This relationship between yield in young groves and tree density holds true over a wide range of tree densities (Fig. 2). Data from several experiments around the world are combined and show that cumulative yield during the first 9 yr increases with increasing tree density from less than 100 to over 4000 TPA.

As trees mature and fill their allocated spaces, there appears to be little or no advantage of higher tree densities for citrus (Wheaton et al., 1978). Ideally, a yield plateau is reached at this mature stage where high yield can be maintained for a number of years, but growers report production begins to decline in some groves after 8 to 10 yr. These are usually blocks with a relatively vigorous rootstock and planted at above average tree density. Trees appear to become more vegetative and produce excessive regrowth following pruning which suggests tree vigor may be too high for the allocated canopy volume. Experiments in both Japan (Tachibana et al., 1987) and Florida (Koo and Muraro, 1982) showed highest production of *mature* trees at intermediate tree densities. The Japanese practice of planting at very high densities and thinning trees over time demonstrates an understanding that allocated space and final tree size must be in balance.

Yield of vigorous trees in our long-term spacing experiment declined after 8 yr for some combinations of rootstock, topping height and tree density. Factors responsible for this decline in production are the subject of this paper. Previous reports on this experiment included yield and fruit quality information of young trees (Wheaton et al., 1986), water use and root density data (Whitney et al., 1991), equipment and harvesting considerations (Whitney et al., 1994), and yield, fruit quality, and economic analyses through tree age 13 (Wheaton et al., 1995). The purpose of this report is to document the importance of tree vigor in this experiment and in making decisions about spacing, hedging, and topping of citrus in Florida.

Materials and Methods

Treatments in this experiment (Table 1) include combinations of variety, rootstock, topping height, between-row spacing and in-row spacing. The experimental design and grove management were described previously (Wheaton et al., 1995) and are briefly summarized here. Trees were planted in 1980 at a site near Babson Park, FL on a deep, well-drained, Candler sand. Trees were irrigated with a permanent overhead sprinkler system, and standard production, equipment, and harvesting methods were used throughout the experiment. After age 4, trees at all spacings received

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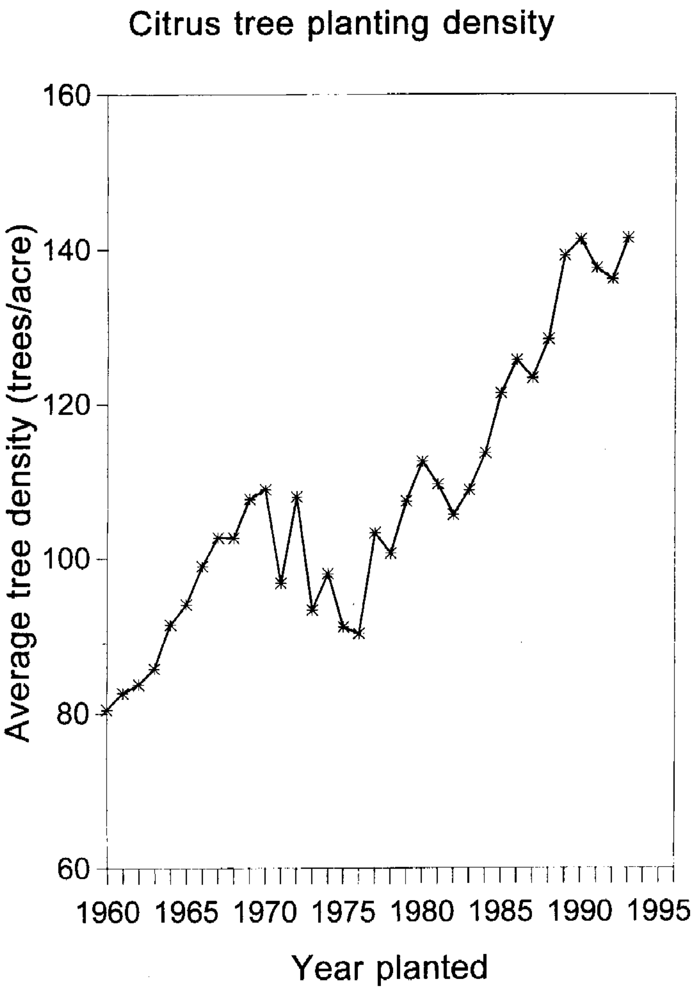

Figure 1. Average tree density of Florida orange groves by year planted (from Freie and Gaskalla, 1994).

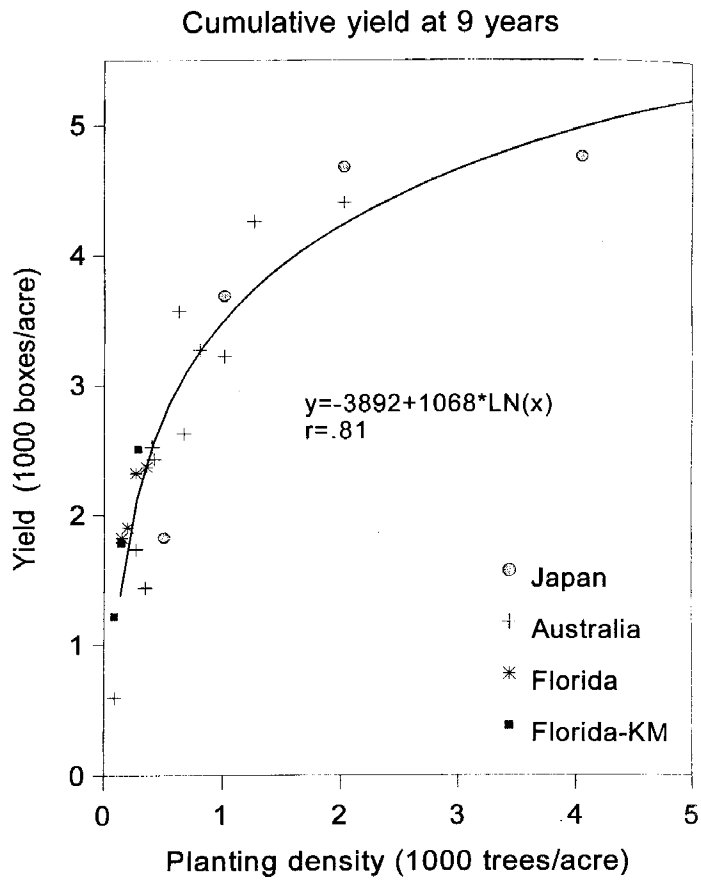

Figure 2. Cumulative yield through tree age 9 for citrus planted at a wide range of tree densities. Experiments are in Japan (Tachibana et al., 1987), Australia (Hutton, 1986), Florida (this study), and Florida - KM (Koo and Muraro, 1982).

equal quantities of water, fertilizer, and pest management on a per grove acre basis, not a per tree basis. The experiment was designed and analyzed (analysis of variance) as a multiple split-plot experiment with four replications. Plot size was four rows × seven trees with the center 10 trees (two rows × five trees) used for data collection. The experiment was designed in metric units and the English units used here are the nearest integer equivalent of the metric dimension.

Milam lemon rootstock was selected as a vigorous stock, and Rusk citrange as a stock with moderate vigor (Castle et al., 1993). Tree hedging and topping were begun as soon as necessary for tree size control. Annual hedging was begun in 1985 and 1986 for the 15 and 20 ft between-row spacings, respectively. Hedging angle was 7 degrees from vertical toward the top of the tree. Hedging width was set to maintain an open middle of 6.5 ft until 1991 and 7.0 ft thereafter. During most years, all trees were hedged in early spring, shortly after the 'Hamlin' but before the 'Valencia' harvest. Topping was also begun as soon as trees exceeded the targeted tree height. Annual topping was begun in 1987 and 1991 for the 12 and 18 ft heights, respectively. During 1991 to 1993, trees at the 12 ft height were topped in the spring and fall of each year in an attempt to reduce regrowth and improve fruiting of trees on Milam rootstock. Measurements included tree growth, yield, fruit quality, leaf analysis, and pest populations. Financial analyses were based on discounted cash flow and the internal rate of return (IRR).

Results

Tree vigor was of minor importance during the first 8 yr. All variety and rootstock combinations at all spacings grew rapidly and produced well. After 8 yr, however, yield declined for trees on Milam topped at 12 ft and planted at the higher tree densities. Production from these trees partially recovered in recent years.

Tree size. Trees on Milam and Rusk both grew rapidly during the early years (Fig. 3). Tree canopies on Milam continued to grow rapidly, reaching the 12 ft topping height at age 7 and the 18 ft topping height at age 11 (Fig. 4). Annual topping at 12 ft for trees on Milam resulted in regrowth of 3 to 4 ft each year. Topping in both late spring and fall was begun in 1991 to induce less regrowth and encourage fruit production. The fertilizer rate was also reduced at this time from 210 to 180 lb N per acre per year. These changes appeared to help, but trees on Milam have maintained high vigor up to the present time.

Although initial growth of trees on Rusk was as rapid as on Milam, vigor on Rusk trees declined as the trees got older. Rusk trees stopped height growth at approximately 12 ft. The Rusk trees scheduled for topping at 18 ft never reached that height. They are only 12 to 13 ft high and apparently will re-

Table 1. Experiment factors, levels and tree densities.

Factor and level (multiple split plot)	
Scion cultivar	
'Hamlin' (early-maturing orange) *Citrus sinensis* (L.) Osb.	
'Valencia' (late-maturing orange) *C. sinensis*	
Tree height	
12 ft	
18 ft	
Between-row spacing	
15 ft	
20 ft	
Rootstock	
Milam lemon (vigorous) *C. jambhiri* Lush hybrid?	
Rusk citrange (moderate vigor) *C. sinensis* × *Poncirus trifoliata* (L.) Raf.	
In-row spacing	
8 ft	
15 ft	
Tree spacing	**Trees per acre**
Between × in-row	
15 × 8 ft	360
20 × 8 ft	270
15 × 15 ft	200
20 × 15 ft	150

main at that height over a long period of time without topping. Thus, topping height was not a factor and trees on Rusk in the 12 and 18 ft plots are similar in size.

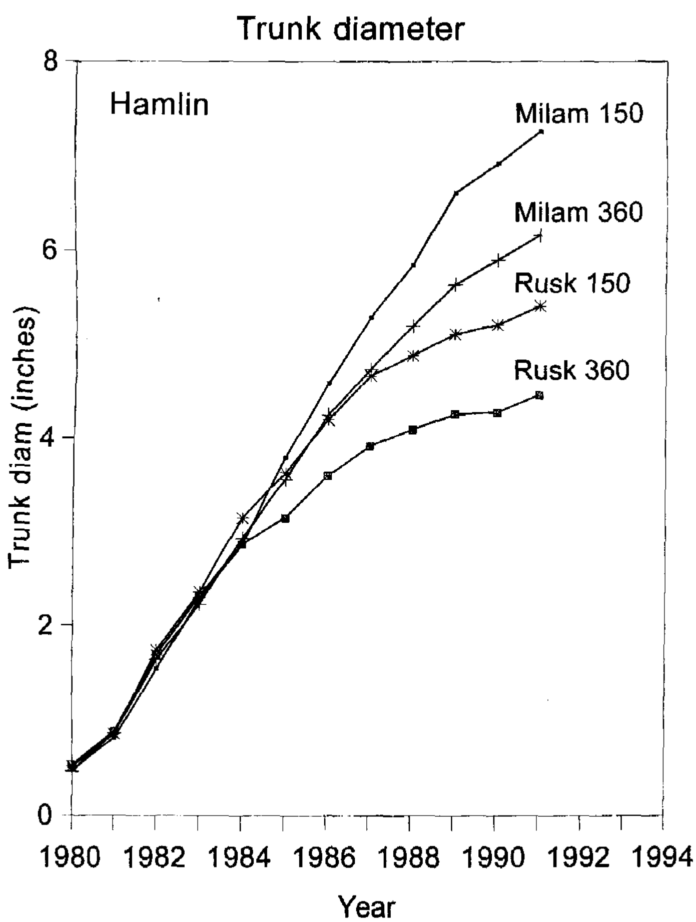

Figure 3. Tree size (trunk diameter) of 'Hamlin' on Milam and Rusk rootstocks planted at 150 and 360 TPA. Significant effects ($P < 0.05$) of rootstock and planting density were present in 1984 and subsequent years.

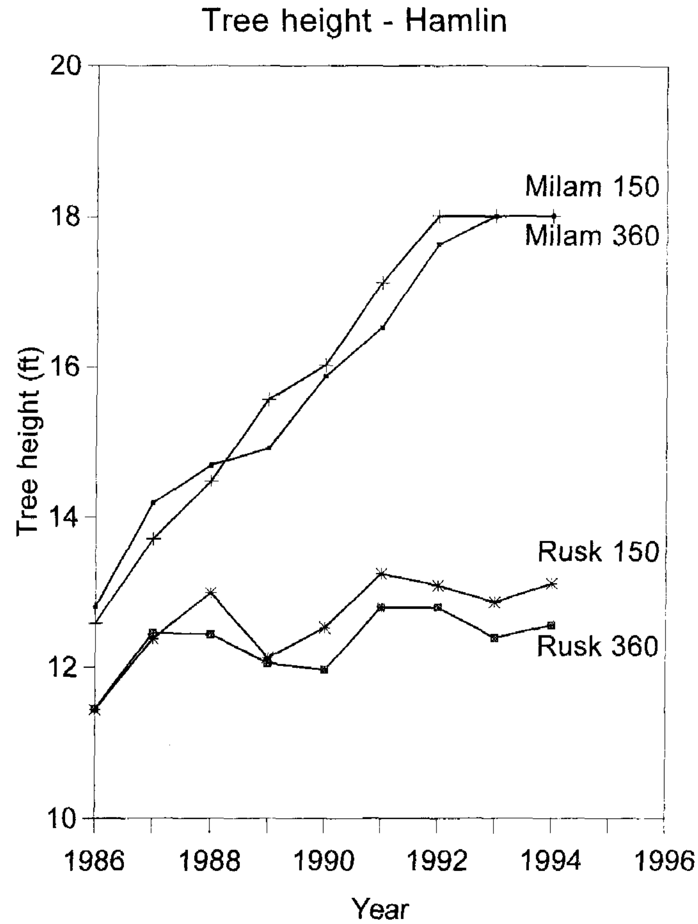

Figure 4. Tree height of 'Hamlin' on Milam and Rusk rootstocks planted at 150 or 360 TPA. Trees on Rusk grew only to approximately 12 ft high so topping height was not a factor for these trees. Height of Milam and Rusk trees differed significantly ($P < 0.05$) each year.

Yield. Production increased with tree age and with increasing tree density during the first 8 yr and rootstock vigor had little effect on yield (Fig. 5). As trees matured, the importance of rootstock vigor on productivity became very apparent.

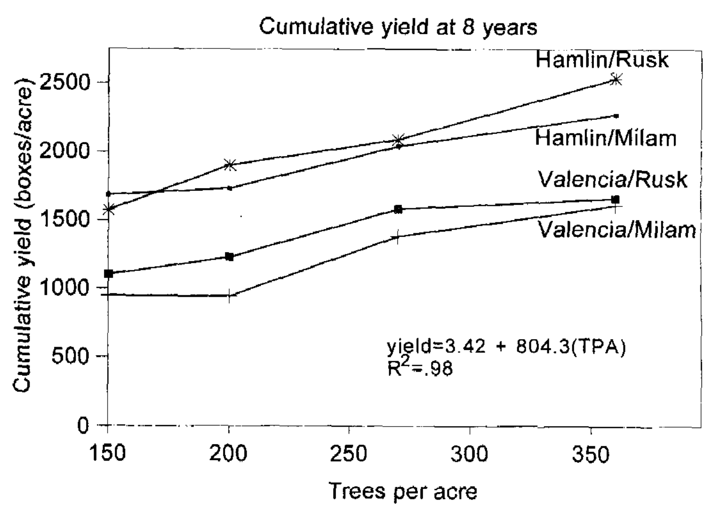

Figure 5. Cumulative yield at tree age 8 of 'Hamlin' and 'Valencia' trees on Milam and Rusk rootstocks averaged over topping height. The regression equation is for the average of all variety and rootstock combinations.

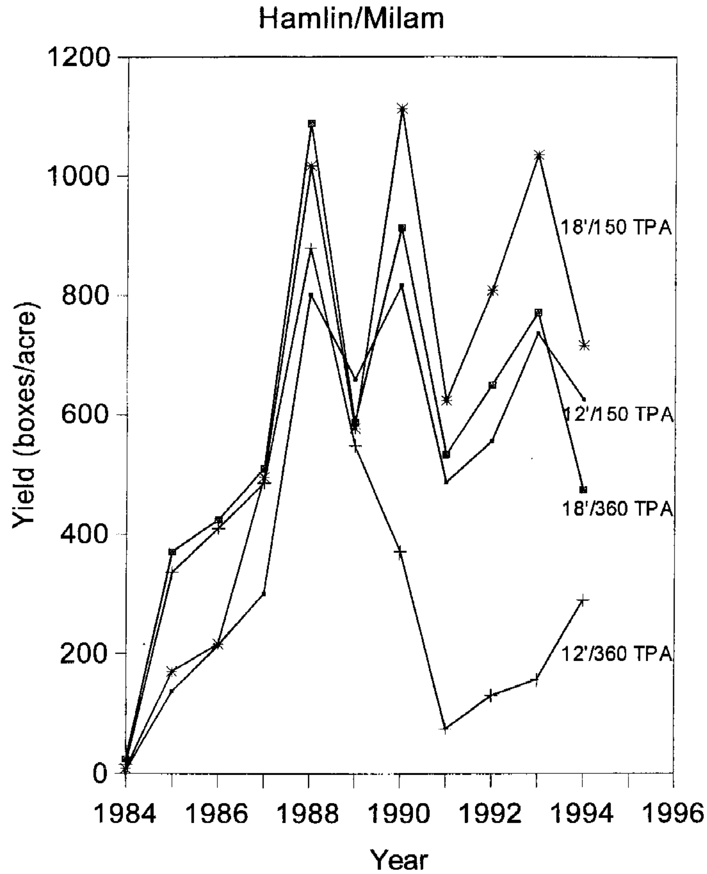

Figure 6. Annual production of 'Hamlin' orange trees on Milam rootstock at topping heights of 12 or 18 ft and tree densities of 150 or 360 TPA. For 1990 through 1994, yield of trees topped at 12 ft and planted at 360 TPA was significantly lower ($P < 0.05$) than for the other treatments.

Yield of trees on Milam topped at 12 ft declined rapidly after topping began and the yield reduction was greatest at 360 TPA (Fig. 6). Production of these trees improved somewhat after topping twice each year during 1991 to 1993 and reducing fertilizer rates. The yield of trees on Milam topped at 18 ft was excellent, however, and declined only slightly as density increased.

For mature trees on Milam, the relationship between yield loss, topping height, and tree density is shown more completely in Fig. 7. At the 12 ft topping height, yield reduction increased with increasing tree density. At the 18 ft height, tree density was less important and production remained satisfactory. For mature trees on Milam planted at 360 TPA, topping at 18 ft instead of 12 ft improved annual yield by approximately 400 boxes per acre. For trees topped at 12 ft, planting 150 instead of 360 TPA improved yield by an equal amount.

Trees on Rusk continued good production as the grove matured (data not shown). Average yield of Hamlin/Rusk and Valencia/Rusk for trees 9 to 14 yr was 814 and 597 boxes per acre, respectively. Topping height was not a factor because trees never grew higher than 13 ft. Yield tended to be greater at the higher density for these trees, probably because trees at the wider spacings never completely filled their allocated space.

Fruit size and quality. Fruit size and quality of each variety were affected by rootstock, topping height, and tree density

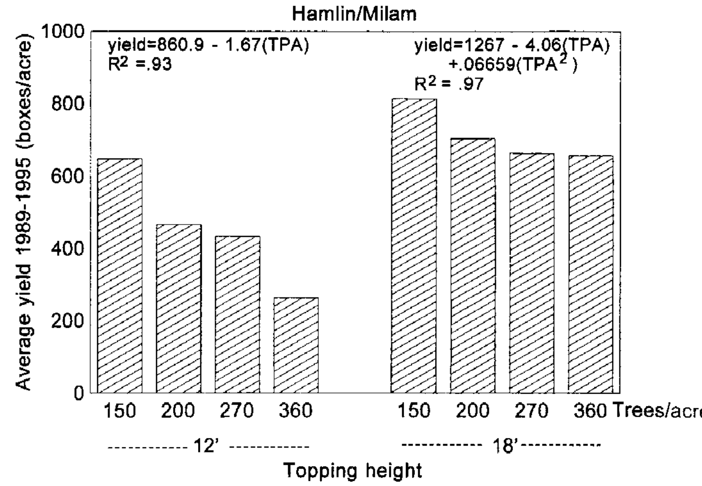

Figure 7. Average annual production of 'Hamlin' oranges for trees 9 to 14 yr old, topped at 12 or 18 ft heights, and planted at tree densities of 150, 200, 270, or 360 TPA. The regression equations are for the 12 and 18 ft topping heights.

(Table 2). Several fruit quality factors were adversely affected by increasing density at the 12 ft topping height of 'Hamlin' on Milam stock. Fruit size increased, but brix, juice, solids per box, and external color decreased with increasing tree density. Fruit quality of 'Valencia' on Milam was less seriously affected.

Fruit from trees on Rusk rootstock were smaller but had better juice content, brix, pounds solids per box, and juice color than trees on Milam. Tree density had only a minor effect on fruit quality of trees on Rusk. Topping height was not a factor as trees on Rusk grew little beyond the 12 ft height. The 12 and 18 ft topping height plots were combined in the analysis.

Nutrition, diseases, pests, and tree loss. The nutritional status of trees determined by leaf analysis was generally in the optimal range (data not shown). However, leaf K of trees on Rusk with heavy crops was in the deficient range several times, and the ratio of N:K2O in the fertilizer was increased from 1:1 to 1:1.25 for several years. Leaf K remained adequate for trees on Milam.

Excellent pest control was maintained by the commercial grove operator and little effect of tree density or topping height on pest populations was observed. Less freeze damage occurred at higher tree densities during the 1983 and 1985 freezes, but differences after the severe 1989 freeze were not apparent. Tree loss of less than 5% was caused by blight. No relationship between tree loss and any experimental treatment was observed.

Financial analysis. The financial analyses included discounted costs and returns for each year since the beginning of the experiment. Assumptions used in the analysis were described previously (Wheaton et al., 1995). The IRRs after the grove was 13 yr old varied from less than 0 to over 20%. Poor production for trees on Milam topped at 12 ft and planted at higher tree densities resulted in a low or negative IRR (Fig. 8).

Trees on Rusk provided the best IRRs with little effect of tree density. A small trend toward better IRRs at the wider (20 ft) between-row spacing may reflect lower costs of establishing and maintaining trees at this wider row spacing. The relative insensitivity of IRR to tree densities ranging from 150 to 360

Table 2. The effect of rootstock, topping height, and tree density on fruit quality of Hamlin and Valencia oranges. Values are average for 1991 to 1993.

Variety	Stock	Topping height	Tree density	Fruit size	Juice	Soluble solids	Solids per box	Ext. color
		ft	trees/acre	lb/fruit	%	%	lb	a/b
Hamlin	Milam	12	150	0.43*	51.6	8.92***	4.15*	0.01+
Hamlin	Milam	12	200	0.44	48.5	8.41	3.67	-0.05
Hamlin	Milam	12	270	0.45	49.0	8.65	3.82	-0.02
Hamlin	Milam	12	360	0.46	45.6	8.16	3.34	-0.10
Hamlin	Milam	18	150	0.42	52.7	9.14	4.34	0.05
Hamlin	Milam	18	200	0.43	54.6	9.04	4.45	0.11
Hamlin	Milam	18	270	0.41	54.4	9.49	4.66	0.07
Hamlin	Milam	18	360	0.44	54.9	9.26	4.58	0.09
Valencia	Milam	12	150	0.46+	59.8	11.67**	6.28***	0.39**
Valencia	Milam	12	200	0.51	57.7	10.85	5.64	0.31
Valencia	Milam	12	270	0.47	60.0	11.43	6.17	0.33
Valencia	Milam	12	360	0.52	58.3	10.57	5.55	0.24
Valencia	Milam	18	150	0.45	59.5	11.68	6.24	0.44+
Valencia	Milam	18	200	0.48	58.9	11.28	5.97	0.36
Valencia	Milam	18	270	0.46	60.4	11.67	6.35	0.34
Valencia	Milam	18	360	0.48	59.8	11.13	6.00	0.32
Hamlin	Rusk	ᶻ	150	0.39	57.9	10.85	5.66	0.13
Hamlin	Rusk		200	0.42	58.5	10.51	5.54	0.12
Hamlin	Rusk		270	0.39	58.4	11.15	5.86	0.17
Hamlin	Rusk		360	0.40	58.1	10.88	5.69	0.19
Valencia	Rusk		150	0.41	60.8	13.06	7.15	0.47
Valencia	Rusk		200	0.43	61.1	12.90	7.09	0.47
Valencia	Rusk		270	0.40	61.0	13.51	7.42	0.48
Valencia	Rusk		360	0.42	61.7	13.06	7.25	0.47

[z]Trees on Rusk were approximately 12 ft high in plots designated for both 12 and 18 ft topping heights. Because tree heights were similar, the means for both topping heights were used.
***, **, *, +Significant linear regression within each group at P ≤ 0.001, 0.01, 0.05, or 0.10, respectively.

TPA for trees on Rusk indicates that all tree densities in this range were satisfactory. These trees were well matched to their allocated spaces and provided good financial returns. Trees on Milam were too vigorous to be contained at 12 ft. Milam trees topped at 18 ft provided a satisfactory IRR, but trees on Milam topped at 12 ft and at higher densities gave very poor returns.

Discussion

The ability of citrus to adapt to a wide range of spacings is demonstrated by the good growth and production of many trees in this experiment. Limits to this ability to adapt were encountered, however. Trees may be either too small or too large (vigor too low or too high) for the allocated space. In this experiment, the trees on Rusk of moderate vigor performed well at all spacings. A trend, however, for slightly lower yield of mature 'Valencia' trees on Rusk at the lowest density (150 TPA) indicates the vigor of this combination may be inadequate at wider spacings. Rusk would be unacceptable at tree densities commonly used 30 yr ago because of its small size. This experiment clearly demonstrated the problem with trees too vigorous becoming too large for their allocated space. The decline in yield of 'Hamlin' on Milam planted at 360 TPA and topped at 12 ft is an example of the result of excessive vigor. Production and fruit quality were poor and vegetative regrowth after topping and hedging was excessive.

Changes in tree spacing and topping heights make big differences in the space allocated for canopy development per tree. The range of allocated canopy volume per tree varied from 603 cubic ft to 2757 cubic feet (Fig. 9). The difference between the lowest and highest canopy volume allocation is over 400%. Production varied from unsatisfactory to very good over this range (Fig. 7). The plots planted at 360 TPA and topped at 12 ft provided a relatively small space for canopy development. Production of 'Hamlin' on Milam under those conditions declined substantially after trees filled the available space. Increasing the space by either planting fewer trees per acre or by allowing trees to grow taller greatly improved the production of these trees. Although yield per acre increased with canopy volume per tree at both 12 and 18 ft, both curves indicated that allocated canopy volume must exceed 2000 cubic ft per tree for maximum production of 'Hamlin' on Milam under central Florida conditions (Fig. 10). 'Valencia' on Milam was less vigorous and was less affected by the space allocation.

We previously suggested the number of trees (number of trunks) per acre was not important in plantings that became solid hedge rows (Wheaton et al., 1978 and 1995). This appears to be true when operating at densities where trees adapt to the allocated space. The decrease in yield with increasing density of 'Hamlin' on Milam in this experiment, however, suggests that outside this range of adaptability, the number of trees per acre is important. In such cases, removal of every other tree may be justified.

A number of factors influence tree vigor including soil, climate, nutrition, irrigation, nematodes, diseases, and source of budwood. Partial correction of excessive vigor may be possible by reducing irrigation and nutrition inputs, and by hedging and topping more frequently. These were not included as treatments in this study, but the decline in yield of 'Hamlin' on Milam at higher densities was reversed when fer-

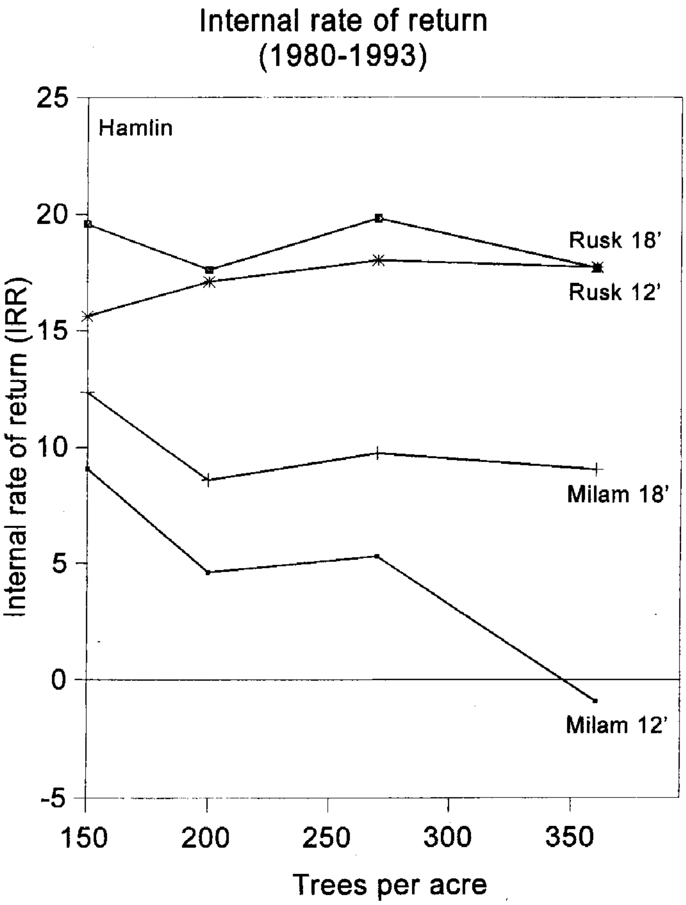

Figure 8. The effect of variety, rootstock, topping height, and tree density on the internal rate of return (IRR) at tree age 13.

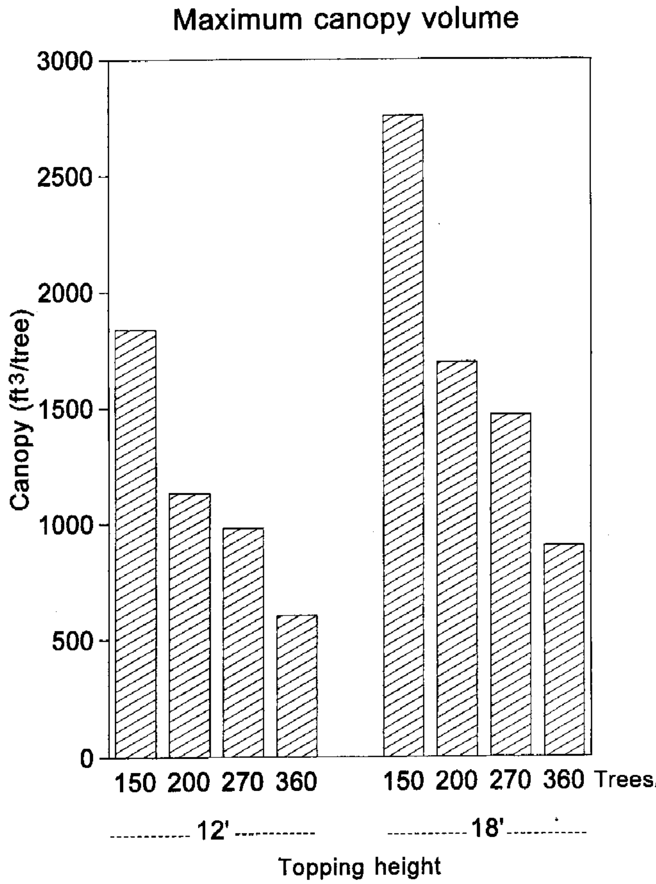

Figure 9. Maximum canopy volume available per tree (containment for trees topped at 12 or 18 ft and planted at 150, 200, 270, or 360 tree acre.

tilizer was reduced and trees were topped 2 times each year. Testing such a program in established groves of vigorous trees is warranted.

Conclusion

Tree vigor is of fundamental importance in determining the tree spacing, density, topping, and hedging in new citrus groves. Citrus trees are flexible and adapt to a range of space allocations. Adaptability is limited, however, and maximum economic returns are generated only when trees perform well within their allocated space. Trees of low vigor never fill their allocated space and thus never generate maximum economic returns if planted at wide spacings. On the other hand, confining vigorous trees to a small space results in difficult tree size control, excessive vegetative growth, and poor production. A minimum tree spacing of 10 by 20 ft and a maximum spacing of 15 by 25 ft appears to be appropriate for the vigor of most trees in commercial use today. These spacings range in densities from 120 to 220 trees per acre. Within this range, tree spacing must reflect the tree vigor of a particular variety and rootstock combination as well as site, environment, and management.

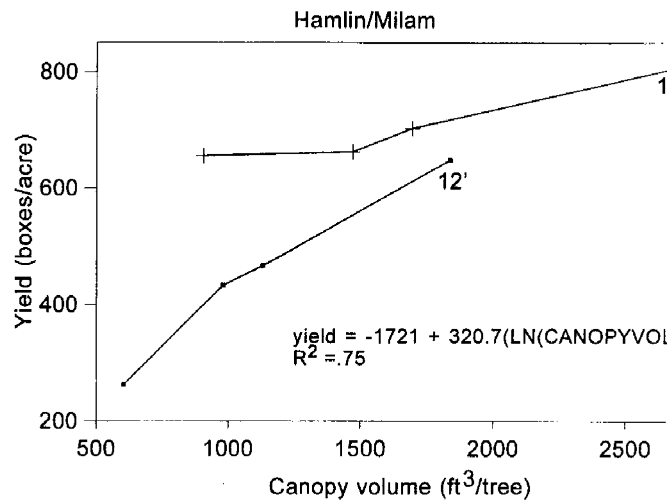

Figure 10. Average annual production of 'Hamlin' on Milam trees, 14 yr old, topped at 12 or 18 ft as a function of maximum canopy volume regression equation combines average yield for 12 and 18 ft topping hei

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"A 6-YEAR COMPARISON BETWEEN 16 ROOTSTOCKS BUDDED WITH 'HAMLIN' SWEET ORANGE"

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Abstract. **Yields, juice quality, and tree size were recorded from one Hamlin orange (*C. sinensis* (L.) Osbeck) clone on 10 unnamed citrumelo (*Citrus paradisi* Macf. × *Poncirus trifoliata*) and 3 unnamed citrange (*C. sinensis* × *P. trifoliata*) rootstocks, Sour orange (*Citrus aurantium*), Swingle citrumelo and Norton citrange. Trees were planted in November 1986, spaced 14 × 22 feet in 6 replications of 3 tree plots. Cumulative yields were highest for trees on citrumelos F/80-3, F/81-18, W-2, F/80-2, and sour orange, and lowest for citrange F/81-10, citrumelo F/80-19 and F/80-7. Cumulative pounds soluble solids per acre were highest for citrumelo F/80-3, F/81-18, F/80-2, F/80-8, and sour orange. They were lowest for citrange F/81-10, citrumelo F/80-19, and F/80-7. Tree size was calculated by measuring the effective height of fruiting. Citrumelo F/80-2,W-2, F/81-18, sour orange, F/80-3 and F/80-6 were the largest trees.**
When Swingle was assigned an index of 100, there were trees on seven rootstocks that produced fruit higher in the tree than Swingle. Using Swingle as an index for production of pounds soluble solids per tree in seasons 1992-93 & 1993-94, only trees on F/80-2, F/81-18, sour orange, and F/80-3 rootstocks out produced trees on Swingle. Tests for Citrus Tristeza Virus (CTV) in December 1992 on all trees on sour orange rootstock showed that 27.7% of these trees were identified with severe isolates of CTV. By August 1993, five trees on sour orange rootstock were declining.

[1]Retired

Introduction

In 1955, Dr. Mortimer Cohen, then a pathologist with the State Plant Board in Gainesville, made controlled pollinations among selected trees in the University of Florida horticultural grove on Archer Road as part of his interest in horticultural characteristics of nucellar citrus seedlings. Fruits from these pollinations were harvested in January and March of 1956 and seed was planted. Many of these nucellar and zygotic seedlings were subsequently planted in 1960 at the Division of Plant Industry Budwood Foundation Grove located near U.S. 27 and I-4 in Polk County.

After extensive evaluation by personnel from the Citrus Budwood Registration Office, nucellar selections of 'Pineapple', navel, 'Valencia' and 'Redblush' grapefruit were released as budwood for use by the Florida Industry beginning in 1972 and have become popular scions commonly used in the Florida industry. (Bridges 1973) (Bridges & Youtsey 1974) (Norman 1964) (Pieringer et al. 1978).

Certain of the zygotic seedlings from Cohen's work were fruited and from 1968 through 1973, many seedling stands were established for evaluation of uniformity, vigor, germination, and disease susceptibility. Several of the more uniform and vigorous selections were identified for trial as rootstocks in 1973 when the Budwood Foundation Grove was moved to a new location near Dundee, Florida, and in other trials by USDA and IFAS research scientists. (Wutscher et al. 1988) (Youtsey and Bridges 1979).

Because of increased interest in the potential for use of citranges and citrumelos, this study was undertaken to determine the performance of these controlled pollination seedlings used as rootstocks for Hamlin sweet orange in comparison with standard commercial rootstocks.

Materials and Methods

In the fall of 1983, seeds were harvested and sown for 10 citrumelo, (*C. paradisi* cv. 'Duncan' grapefruit × *P. trifoliata*) and 3 citrange (c.sinensis cv. 'Parson Brown' × *P. trifoliata* and