Fertilizer Effects on Early Growth and Yield of 'Hamlin' Orange Trees

Thomas A. Obreza¹ and Robert E. Rouse²

Southwest Florida Research and Education Center, University of Florida,
P.O. Drawer 5127, Immokalee, FL 33934

Additional index words. *Citrus sinensis*, Carrizo citrange, trifoliolate hybrids, fruit quality

Abstract. The growth response of young 'Hamlin' orange (*Citrus sinensis* L. Osbeck) on Carrizo citrange (*C. sinensis* × *Poncirus trifoliatus* L. Raf.) trees to N-P-K fertilizer rates under field conditions in southwestern Florida was studied to determine the minimum fertilizer required to bring trees into maximum early production. The highest 8N-1.8P-6.6K fertilizer rate was 2.72, 5.45, and 8.17 kg/tree in 1989, 1990, and 1991, respectively. Additional fertilizer treatments equaled 50%, 25%, or 13% of the maximum rate. Fertilizer sources contained either all water-soluble N (applied more frequently) or 40% to 50% controlled-release N (applied less frequently), and they did not affect fruit yield or quality. The response of trunk cross-sectional area, tree canopy volume, and fruit yield to fertilizer rate was described by a linear plateau model. The model predicted a fruit yield of 22.6 kg/tree at the estimated critical fertilizer rate of 48% of maximum. Fruit yield at the 50% maximum rate averaged 21.2 kg/tree. As fertilizer rate increased, total soluble solids concentration (TSS) in juice and the TSS : acid ratio decreased, but weight per fruit and TSS per tree increased. A fruit yield >21 kg/31-month-old tree indicated vigorous growth.

More than 48,000 ha of new citrus groves has been established in Florida since 1988 (Florida Dept. of Agr. and Consumer Serv., 1990). Land used for citrus production in southwestern Florida increased from 21,000 ha in 1980 to 51,000 ha in 1990. New plantings are expected to continue through the 1990s, most in Florida's new citrus-producing region.

The effect of agricultural practices on the environment is a concern associated with this growth. The mobility of N fertilizer in sandy Florida soils presents the potential for groundwater contamination. Adopting management practices to increase fertilizer efficiency (defined as the proportion of applied fertilizer taken up by the plant) should minimize environmental effects and reduce production costs. An example of such practices is using fertilizer rates near the minimum required by the plant for maximum growth under an application strategy that decreases leaching.

Milder winter temperatures in southwestern Florida allow a longer growing season than in central Florida. To produce large trees quickly and accelerate fruit production, growers have fertilized young trees at rates exceeding current N-P-K recommendations (Koo et al., 1984). These recommendations do not differentiate between central and southern Florida with respect to fertilizer rates.

Most citrus fertilization studies in Florida have involved trees established in the field for

several years before the experiments were initiated. Research data illustrating the response of newly planted trees to N-P-K fertilizer rates are limited, especially for citrus planted on southern Florida Spodosols and Alfisols. Such data are necessary to make recommendations that maximize fertilizer efficiency.

Rasmussen and Smith (1961) conducted one of the earliest comprehensive fertilizer rate studies with newly planted citrus trees in Florida. Satisfactory growth of young 'Hamlin' orange trees was effected by 0.45, 0.91, and 1.82 kg/tree of an 8N-0.9P-6.6K fertilizer applied 1, 2, and 3 years after planting, respectively. Calvert (1969) determined that young 'Valencia' orange trees in the Indian River area responded most favorably when 2.72 to 3.63 kg/tree of an 8N-1.8P-6.6K fertilizer was applied for three consecutive years. The trees, however, were 2 years old when the experiment was initiated.

Recent studies with newly planted 'Hamlin' orange trees in several Florida locations have suggested that the current fertilizer recommendation for the first year (2.0 to 3.4 kg/tree of 8N-3.5P-6.6K fertilizer) may exceed that required for maximum growth. Ferguson et al.'s (1988) experiments with newly planted 'Hamlin' orange trees in central and east-coastal Florida showed that N fertilizer applied at 26% to 60% of the recommended rate failed to affect trunk diameter in the first year. Marler et al. (1987) studied first-year growth of newly planted trees on an acidic Ultisol in north-central Florida and found no trunk cross-sectional area (TCA) or canopy volume differences between 0.91, 1.82, or 2.72 kg/tree of an 8N-2.6P-6.6K fertilizer. However, Willis et al. (1990), working in the same area, observed a positive linear response of 'Hamlin' orange trunk diameter to 8N-0P-6.6K fertilizer rates of 0.75, 1.38, and 2.88 kg/tree applied 8 months after planting.

Research with young trees in more northern Florida locations has involved a series of single-year studies that could not be continued due to winter freezes. This study was designed to determine the minimum N-P-K fertilizer required to produce fruit on young 'Hamlin' orange trees in southwestern Florida. The objective was to determine the relationship between N-P-K fertilizer rates and young 'Hamlin' orange tree growth, leaf tissue nutrient concentration, early fruit yield, and fruit quality.

This experiment was conducted within a large, newly developed commercial Florida citrus grove. The site was similar to most new groves in the region in terms of soil type (Spodosols and Alfisols) and previous land use (range land for cattle). Land that had been in unimproved pasture for >25 years was disked, laser-leveled, and formed into two-row beds during Summer and Fall 1988. 'Hamlin' orange on Carrizo citrange trees were planted in Mar. 1989 at a 2.7-m (within rows) × 7.6-m (between rows) spacing. The trees were subirrigated, with water supplied through upward flux from a water table maintained ≈ 0.60 to 0.75 m below the soil surface.

Table 1. N-P-K fertilizer treatments applied to young 'Hamlin' orange on Carrizo citrange rootstock trees, 1989-91.

Relative fertilizer rate ² (%)	Source ²	Analysis (% N-P-K)	Fertilizer annual application rate (kg/tree)			3-yr total application (kg/tree)		
			1989	1990	1991	N	P	K
13	CONV	8-1.8-6.6	0.34	0.68	1.02	0.16	0.04	0.14
25			0.68	1.36	2.04	0.33	0.07	0.27
50			1.36	2.72	4.09	0.65	0.15	0.54
100			2.72	5.45	8.17	1.31	0.29	1.08
13	IBDU	8-1.8-6.6	0.34	0.68	1.02	0.16	0.04	0.14
25			0.68	1.36	2.04	0.33	0.07	0.27
50			1.36	2.72	4.09	0.65	0.15	0.54
100			2.72	5.45	8.17	1.31	0.29	1.08
13	MU	9-2.2-6.6	0.30	0.61	0.91	0.16	0.04	0.12
25			0.61	1.21	1.82	0.33	0.08	0.24
50			1.21	2.42	3.63	0.65	0.16	0.48
100			2.42	4.85	7.27	1.31	0.32	0.96

²Percentage of maximum rate applied.

²CONV = all water-soluble N; IBDU = controlled-release N as isobutylidene diurea; MU = controlled-release N as methylene urea.

Received for publication 17 Apr. 1992. Accepted for publication 24 Aug. 1992. Florida Agr. Expt. Sta. Journal Series no. R-02315. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked advertisement solely to indicate this fact.

¹Assistant Professor, Soil Scientist.

²Associate Professor, Citrus Horticulturist.

The experiment was conducted within four adjacent tree rows (two two-row beds). The soils were classified as Pople fine sand (loamy, siliceous, hyperthermic Arenic Ochraqulf) and Holopaw sand (loamy, siliceous, hyperthermic Grossarenic Ochraqulf). The area was divided into eight blocks (replications), and plots within each block consisted of four adjacent trees within a row. One replication of each fertilizer treatment was randomly assigned to a plot within each block. Treatments consisted of three N-P-K fertilizers—one containing all water-soluble N and the others containing a portion of the N in controlled-release form—applied at four rates (Table 1). A nonfertilized control was also included.

The maximum 8N-1.8P-6.6K fertilizer rate was 2.72, 5.45, and 8.17 kg/tree in 1989, 1990, and 1991, respectively. These rates are $\approx 10\%$ higher than the current average N-P-K recommendation for Florida citrus trees in each of the first 3 years after planting (Koo et al., 1984). Additional fertilizer treatments equaled 50%, 25%, or 13% of the maximum rate each year.

The conventional (CONV) fertilizer source contained all water-soluble N (as NH_4 and NO_3), 3.0% Mg, 0.3% Mn, and 0.05% Fe. In addition to 2.4% Mg, 0.3% Mn, and 0.06% Fe, the second source contained 50% water-soluble N (as NH_4 and NO_3) and 50% N as controlled-release isobutylidene diurea (IBDU). The third source contained 60% water-soluble N (as urea, NH_4 , and NO_3) and 40% controlled-release N, including methylene urea (MU), sulfur-coated urea, and activated sludge, with 3.0% Mg, 0.5% Mn, and 0.03% Fe. Phosphorus was applied as monocalcium phosphate, K as potassium sulfate, Mg as magnesium sulfate, Mn as manganese sulfate or manganese oxide, and Fe as iron-EDTA.

Following tree planting, soil samples were collected from each block and initial trunk diameter measured. The diameter of the two middle trees in each four-tree plot was measured 15 cm above the bud union in north-south and east-west directions. Assuming a circular trunk, the TCA was calculated from the mean radius.

Initial fertilizer applications were made in Apr. 1989. The fertilizer materials were applied by hand under the trees in a 1-m circle at first and later in a wider circle that matched tree canopy expansion as the trees grew. The CONV fertilizer was split equally into six applications in 1989 (April, June, July, September, October, December), five in 1990 (March, May, July, September, November), and four in 1991 (March, May, July, November). The IBDU fertilizer was split equally into three applications in 1989 (April, July, November), three in 1990 (March, June, September), and two in 1991 (March, August). The MU fertilizer was split equally into two applications each in 1989 (April, September), 1990, and 1991 (both years March, August).

TCA was calculated at 7, 12, and 24 months after planting. Mean canopy width (measured in north-south and east-west directions) and height were measured at 12 and 24 months after planting. The height was greater than the

width, so canopy volume was calculated based on the formula for a prolate spheroid shape: $(4/3)(\pi)(\text{tree height}/2)(\text{mean canopy radius})^2$.

Leaf tissue samples from 5- to 6-month-old autumn growth were taken from each plot in mid-Mar. 1990 and 1991, marking the conclusion of one fertilizer year and the beginning of the next. Samples were dried and ground to pass a 1-mm screen, and 1-g subsamples were ashed in a muffle furnace at 500°C. The residue was dissolved in concentrated HCl , and the resulting solution was analyzed for K, Ca, and Mg concentration using atomic emission/absorption spectrophotometry (Baker and Suhr, 1982), and for P concentration using the ascorbic acid method (Council on Soil Testing and Plant Analysis, 1980). A 0.4-g subsample of the ground tissue was digested in concentrated H_2SO_4 , and the resultant solution was analyzed for N concentration using the indophenol blue method (Hanlon and DeVore, 1989).

Soil core samples, 2 cm in diameter, were taken to a 15-cm depth at the tree drip line at planting. The soil was air-dried and passed through a 1-mm screen. A 5-g subsample was extracted with 20 ml of Mehlich 1 solution (0.05 M HCl + 0.0125 M H_2SO_4), and the P, K, Ca, and Mg concentrations were measured using the methods mentioned above. The soil was also analyzed for pH (2 water : 1 soil ratio) and Walkley-Black organic matter content (Hanlon and DeVore, 1989).

Fruit yield was determined in Oct. 1991 (31 months after planting). Fruit on the middle two trees in each plot was harvested and weighed. A random 40-fruit subsample from each plot was used to estimate size and analyze juice quality. The juice was extracted using a commercial juice extractor (FMC Corp., Jonesboro, Ark.). Juice quality characteristics included percent juice per fruit, total soluble

solids concentration (TSS), acid content, and TSS : acid ratio. Per-tree TSS was calculated from yield, percent juice, and juice TSS.

Analysis of variance and linear or nonlinear regression were used to determine main effects and fertilizer source $\times$ rate interaction on tree growth and yield variables and leaf nutrient concentrations. Relative fruit yield, canopy volume, and TCA values were calculated by: relative yield = $100 \times (\text{actual yield})/(\text{highest yield})$. A linear plateau function was fitted to the data (pooled across fertilizer sources due to lack of interaction) relating the relative growth or yield variables to fertilizer rate: yield = $A + B(X)$ (when X is below the critical rate); yield = $A + B(\text{CR})$ (when X is above the critical rate), where X = relative fertilizer rate and CR = critical fertilizer rate (the point at which maximum yield is reached). Duncan's multiple range test was used to evaluate the effect of fertilizer source at each rate. The response of leaf nutrient concentration was examined with respect to fertilizer rates across all sources.

The soil in which the trees were planted had not been previously fertilized and was very low in extractable P and K at planting (Table 2). The organic matter content was higher in the 15- to 30-cm soil depth than in the top 15 cm, because the original pasture surface layer was buried under the subsurface material used to form the planted beds. The pH of the bed surface soil was considerably higher than that of the original surface (Table 2); however, roots of the citrus trees were exposed to both soils during planting, since the plant holes were dug ≈ 30 cm deep.

During the second and third years of tree growth, fertilizer source had no effect on any growth, yield, or fruit quality response variables measured. There was no interaction between fertilizer source and rate. Rainfall in 1990 was 20% below normal (127 cm annually) but was 20% above normal in 1991. CONV source efficiency was likely increased through higher application frequency. The remaining discussion deals with the response of growth/yield/quality variables to fertilizer rate across sources.

There was no response of TCA to fertilizer rate at 7 months after planting (Table 3). About 60% of the total first-year trunk growth occurred between Oct. 1989 and Mar. 1990 (7

Table 2. Selected soil characteristics of the experimental site (data represent the mean of eight samples taken at planting in 1989).

Depth (cm)	Texture	pH	Organic matter (%)	Mehlich 1-extractable ($\text{mg}\cdot\text{kg}^{-1}$)			
				P	K	Ca	Mg
0-15	Sand	7.0	1.0	8	7	1160	20
15-30	Sand	5.3	1.4	5	5	570	14

Table 3. Growth and yield response of young 'Hamlin' orange on Carrizo citrange rootstock trees to fertilizer rates through the first 31 months after planting. Values in parentheses represent the percentage of the maximum value for the variable.

Relative fertilizer rate ^y	TCA ^z (cm ²)				Canopy vol (m ³)		Fruit yield (kg/tree)
	Months after planting						
	0	7	12	24	12	24	
0	1.4	3.4 (88)	6.2 (79)	28.1 (75)	0.8 (65)	5.8 (59)	2.0 (8)
13	1.4	3.5 (91)	6.6 (84)	31.6 (85)	1.0 (78)	7.8 (80)	6.1 (26)
25	1.4	3.7 (97)	7.3 (93)	34.4 (92)	1.1 (88)	8.4 (85)	12.7 (53)
50	1.4	3.8 (100)	7.8 (100)	37.2 (100)	1.3 (100)	9.8 (100)	21.2 (89)
100	1.4	3.6 (94)	6.9 (89)	33.8 (91)	1.2 (90)	8.9 (90)	23.9 (100)
Significance							
Linear-plateau	NS	NS	**	**	**	**	**

^aTCA = trunk cross-sectional area.

^yPercentage of maximum rate applied.

NS, **Nonsignificant or significant at $P = 0.01$, respectively.

to 12 months after planting). Above-normal temperatures were most likely a contributing factor to the substantial growth observed during fall and winter, traditionally a "dormant" period for citrus trees in Florida.

At 12 and 24 months, TCA and canopy volume response to fertilizer rate was described by a linear plateau model (Table 3, Fig. 1). The model estimated a critical fertilizer rate-at which maximum growth was reached-of 30% and 33% of maximum for TCA and canopy volume, respectively. Largest trunk and canopy size was observed at the 50% rate. The decrease in these variables at the 100% rate may have been due to applying the fertilizers by hand. The materials may have been too concentrated around the trees during the first year, and the high soil salt levels from the 100% rate could have retarded tree growth.

The response of fruit yield to fertilizer rate was described by a linear-plateau model (Table 3, Fig. 1). The model predicted a fruit yield of 22.6 kg/tree at an estimated critical rate of 48%-a value in good agreement with the observed yield of 21.2 kg/tree at the 50% rate.

Trees receiving the 100% rate yielded 11% more fruit, with 10% less canopy volume (at 24 months), than trees receiving the 50% rate. However, tree canopy volume at 24 months and fruit yield at 31 months were poorly correlated ($r = 0.45$). Nonfertilized tree canopy volume was 59% of observed maximum, but yield was only 8% of maximum. Tree canopy volume in the spring of the first bearing year was not a good predictor of yield in this experiment.

Weight per fruit increased linearly with fertilizer rate (Table 4). Mean fruit diameter was estimated from fruit weight of fruit subsamples by the regression equation: fruit

Fig. 1. Relative growth and yield response of young 'Hamlin' orange on Carrizo citrange rootstock trees to fertilizer rate.

Table 4. Fruit quality response of young 'Hamlin' orange on Carrizo citrange rootstock trees to fertilizer rate, 1991.

Relative fertilizer rate ² (%)	Wt/fruit (kg)	Juice concn (%)	TSS ¹ (%)	Acid (%)	TSS : acid ratio	TSS/tree (kg)
0	0.14	54.9	8.4	0.39	21.7	0.09
13	0.16	53.8	7.9	0.50	16.9	0.26
25	0.17	49.8	7.6	0.47	16.6	0.48
50	0.17	52.8	7.5	0.51	14.9	0.84
100	0.18	53.6	7.4	0.54	13.9	0.95
Significance						
Linear	**	NS	**	NS	**	
Exponential						**

¹TSS = total soluble solids concentration.

²Percentage of maximum rate applied.

NS, **Nonsignificant or significant at $P = 0.01$, respectively.

Table 5. Leaf tissue nutrient concentration response of young 'Hamlin' orange on Carrizo citrange rootstock trees to fertilizer rate.

Relative fertilizer rate ² (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
1990					
0	3.19	0.18	1.68	2.88	0.30
13	3.11	0.15	1.72	2.78	0.24
25	3.10	0.15	1.98	2.61	0.23
50	3.17	0.16	2.27	2.47	0.25
100	3.38	0.15	2.61	2.21	0.26
Significance					
Linear	*	NS	**	*	NS
1991					
0	2.78	0.16	1.61	4.65	0.32
13	2.61	0.16	1.51	4.76	0.30
25	2.74	0.16	1.83	4.35	0.30
50	2.90	0.16	2.29	4.27	0.33
100	2.89	0.16	2.62	4.01	0.34
Significance					
Linear	*	NS	**	**	NS

²Percentage of maximum rate applied.

NS, *, **Nonsignificant or significant at $P = 0.05$ or 0.01 , respectively.

diameter = $0.0145(\text{fruit weight}) + 4.51$, $r^2 = 0.97$. Fruit from nonfertilized trees averaged 6.48 cm in diameter and were classified as no. 125 commercial size for Florida oranges (fruit diameter range 6.35-6.99 cm). Fruit from fertilized trees averaged 6.97 cm in diameter and were classified as no. 100 commercial size (fruit diameter range 6.83-7.62 cm). Commercial sizes are based on the number of fruit that fit in a 92-liter carton; thus, the lower the commercial size number, the larger the fruit.

TSS and the TSS : acid ratio decreased linearly with increasing fertilizer rate. The decrease in ratio was due solely to decreasing TSS; acid concentration did not vary significantly with fertilizer rate. Juice concentration per fruit was also unaffected by fertilizer rate. TSS per tree increased exponentially with fertilizer rate.

Leaf tissue concentrations of N and K increased linearly with fertilizer rate in 1990 and 1991 (Table 5). Leaf Ca decreased linearly as fertilizer rate increased both years, which may have been due to the competitive effects of increasing the soil K level (Barber, 1984). Both leaf P and Mg levels were unaffected by fertilizer rate. This result was unexpected for P, considering the low extractable-P levels in the nonfertilized soil. Compared with leaf analysis standards for 4- to 6-month-old spring

growth (Koo et al., 1984), the N, P, and K concentrations of the 6-month-old fall leaves were optimum or high in both years, regardless of fertilizer rate. The Ca and Mg concentrations were low in 1990 but optimum in 1991.

Leaf N concentration was $\approx 0.4\%$ higher across all treatments in 1990 than in 1991 (Table 5). For citrus nursery trees in Florida, elevated levels of nutrients stored in tissues have been attributed to intensive fertilization in the nursery (Castleland Rouse, 1990). Higher leaf N levels in the 12-month-old trees may have been due to a carryover effect from high N levels in the trees at planting.

This experiment's results show that maximum growth and early yield of 'Hamlin' orange trees planted on a typical southwestern Florida flatwoods soil can be obtained by applying N-P-K fertilizer at 50% of the currently recommended rate. This agrees with the findings of Marler et al. (1987) and Ferguson et al. (1988). A yield of 21 to 24 kg fruit/tree for trees planted slightly >2.5 years indicates vigorous growth. Critical rates for TCA, canopy volume, and fruit yield as estimated by a linear-plateau model were $\leq 50\%$. Fertilizing to, but not in excess of, the critical rate is logical economically and should provide the highest fertilizer efficiency. Using higher rates

because of the longer growing season in southwestern Florida is not justified.

Using fertilizer rates below the critical rate may be advantageous if fruit is to be grown for the early fresh market. Even though yield decreased, 'Hamlin' orange maturity based on TSS and TSS : acid ratio was more advanced at lower fertilization rates. Fruit size decreased only slightly at lower fertilizer rates.

Measuring canopy volume may not be meaningful for young citrus trees, because canopy density can vary among trees with similar canopy volume. Measuring canopy density could possibly produce a higher correlation with fruit yield of young trees.

Leaftissue analysis data (from fall growth) were compared with leaf analysis standards as defined by Koo et al. (1984). These standards are based on established criteria derived from spring growth and are directly related to productivity. Leaf N, P, K, Ca, and Mg concentrations from trees receiving fertilizer rates that limited yield were optimum or high in the first bearing year. These results were not indicative of tree size or early fruit yield. Willis et al.

(1990) also observed this phenomenon. Acceptable ranges for leaf nutrient concentrations have been developed from data obtained from mature trees and apparently should not be used to evaluate the nutritional status of vigorously growing young trees.

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