Proc. Fla. State Hort. Soc. 101:13-17. 1988.

GROUND SPEED AND SPRAY VOLUME OF AIRBLAST SPRAYERS AFFECT COPPER DEPOSITION AND GREASY SPOT CONTROL

J. D. Whitney, M. Salyani, D. B. Churchill
USDA-ARS, NFSPRC
3450 SW Campus Way
Corvallis, OR 97331

J. O. Whiteside, J. L. Knapp
Florida Cooperative Extension Service
Citrus Research and Education Center
Lake Alfred, FL 33850

R. C. Littell
Department of Statistics
University of Florida
Gainesville, FL 32611

Abstract. **Two types of airblast sprayers were used to apply a copper fungicide to 20-ft high grapefruit trees at 4 lb-metallic copper equivalent/acre. The sprayers were operated at 3 ground speeds (1, 1.75, 2.5 mph) and 3 spray volumes (125, 250, 500 gal/acre).**

On the lower leaf surfaces, mean copper deposition was not affected by sprayer type, spray volume, or ground speed. On the upper surfaces, however, mean copper was affected by all of the factors. Copper deposition on both leaf surfaces was affected by location of the leaves in the tree. All spraying treatments significantly reduced greasy spot severity and the level of disease control achieved was not affected by sprayer type, spray volume, or ground speed.

Airblast sprayers are used in Florida to apply pesticides to most of the 615,000 acres of citrus. Muraro (1) has estimated that the total cost of operating these sprayers plus the pesticides applied constituted 25% of the citrus production costs.

The cost of applying pesticides includes the investment cost in equipment and its operating cost in a total spraying system. Whitney (4, 5) estimated the costs of operating a spraying system consisting of an airblast sprayer, tractor, spray supply unit, and labor. Fixed costs are a function of the total purchase price, while variable or operating costs are functions of labor requirements, fuel usage, and repairs and maintenance costs. Fixed and variable costs per hr generally increase as the volume of water applied increases because more equipment and personnel are required. The time required per acre is directly related to the volume of water applied and inversely related to ground speed. Therefore, the application costs can be decreased by reducing spray volume and/or increasing ground speed.

Greasy spot is an important disease in Florida citrus groves caused by *Mycosphaerella citri* Whiteside. Grapefruit leaves are particularly susceptible to the disease. The more serious aspect of greasy spot is the defoliation it causes. Whiteside (3) has shown that successful control of greasy spot requires that the spray material be deposited on the lower leaf surface.

Many tests (6) have been conducted in Florida citrus to assess the effectiveness of various sprayers for controlling pests; however, pesticide deposition was not quantified. The objectives of this experiment were (1) to quantify the copper deposition on the upper and lower leaf surfaces of grapefruit leaves as a function of sprayer type, ground speed, spray volume, and location in the tree and (2) to measure the efficacy of the copper deposits for greasy spot control.

Materials and Methods

Experimental design. The experiment was conducted on 20-ft high 'Duncan' grapefruit (*Citrus paradisi* Macf.) trees and consisted of 17 spraying treatments plus an unsprayed control replicated 4 times in a randomized complete block design. The trees were spaced 30 x 30 ft and were recently hedged on 4 sides. Each plot consisted of 4 rows of 4 trees with 12 outside trees used as buffers against spray drift. One of the 4 inside trees was used for both copper deposition measurements and greasy spot severity assessment.

Spraying treatments. Sprayer A (FMC Model 987) was an engine-driven airblast sprayer with oscillator discs in the air discharge. The measured air volume flow rate at the discharge and power requirement at operating speed were 88,000 cfm (without oscillator discs in the discharge) and 130 hp, respectively. This sprayer was operated at all combinations of 3 ground speeds (1.0, 1.75, and 2.5 mph) and 3 spray volume rates (125, 250, and 500 gal/acre).

Sprayer B (Southwind Model 836) was a pto-driven airblast sprayer. The measured air volume flow rate at the discharge and power requirement at operating speed were 30,000 cfm and 50 hp, respectively. Sprayer B was operated at all combinations of ground speeds and spray volume rates except for the 2.5 mph and 500 gal/acre combination because it was not designed to deliver the high quantity (76 gal/min) of spray volume required.

Each sprayer was calibrated to deliver two-thirds of the total spray from the top half of the nozzle discharge and one-third from the bottom half. Bean ceramic disc-core nozzles were used on both sprayers at a pressure of 200 psi. Spray nozzle output ranged from 7.6 gal/min at 1 mph and 125 gal/acre to 76 gal/min at 2.5 mph and 500 gal/acre. Generally, disc numbers 2-1/2 and 3 were used with 2 hole whirlplates at the lower outputs, and disc numbers 5 through 8 with 2 or 3 hole whirlplates were used at the higher outputs. Sprayer A used 8 nozzles per side at the lower outputs and 18 per side at the higher outputs, whereas Sprayer B used 9 nozzles per side for all outputs.

Field procedure with copper deposition. Cupric hydroxide (50% metallic copper) was applied at 4 lb-metallic copper equivalent/acre in July 1987. After the copper compound was added to the spray tank, the copper concentration of

Florida Agricultural Experiment Station Journal Series No. 9521. The authors are grateful to Agtrol Chemical for providing the cupric hydroxide, to FMC Corporation and Citrus Systems for providing the sprayers, and to Coca-Cola Foods and Alcoma Packing Co. for providing the groves used in this experiment. Trade names and company names are used in this publication solely for the purpose of providing specific information. Their mention does not constitute a guarantee or warranty or an endorsement of the product by the University of Florida or the U.S. Department of Agriculture.

the tank mix was checked with a Hach Model DR 100 colorimeter to insure the concentration was within ± 10% of the correct concentration. All treatments of 1 replication were applied before starting another replication. Leaf samples for the copper deposit determination were picked immediately after the spray had dried on the leaves. After picking the leaf, the lower leaf surface was placed on a section of paper towel and an adhesive vinyl tape was firmly applied to the upper leaf surface. The sample leaf with towel and vinyl tape was placed in a Ziploc vinyl bag and refrigerated until the copper deposit was measured in the laboratory.

In each plot, one leaf was picked from each of 18 locations in one quadrant of the sample tree (Fig. 1). The 18 locations were combinations of 3 heights (5, 10.5, and 16 ft), 2 radii (outer canopy and about 30 inches inside canopy), and 3 azimuths (0, 45, and 90° to tree row line). The weather conditions during the application of the spray treatments were fairly constant. Wind speeds were less than 5 mph, dry bulb temperatures ranged from 80°F in the mornings to 96°F in the afternoons, and relative humidities of 90% in the mornings to 50% in the afternoons.

Laboratory procedure for measuring copper deposits. The leaf samples were analyzed for copper deposits within 1 week of sampling in the field. Each taped leaf was washed in 50 ml of 0.05 normal nitric acid solution to remove the copper from the lower leaf surface and paper towel. After the first wash, the tape and towel were separated from the leaf and both the leaf and tape were washed in another nitric acid solution to remove the copper that had been deposited on the upper leaf surface. The copper on each leaf surface was quantified by measuring the copper concentration of the wash solution in a Hach Model DR 100 colorimeter. The area of each leaf was measured in a LI-COR Model LI-3000 area meter. Deposition was then calculated for each leaf surface as oz./inch².

The data were analyzed with sprayer, ground speed, and volume rate as main plot treatments and leaf locations (azimuth, radius, and height) as subplot treatments. In the analysis of variance, the subplot treatments were analyzed as repeated measures in space (2).

Procedure for greasy spot assessment. Before applying the spraying treatments, shoots of the 1987 spring flush were tagged at about a 5-ft height on the sample tree in each plot. The leaves on 10 shoots per quadrant (Fig. 1) were counted and the total number of leaves per quadrant ranged from 50 to 100. In late November 1987 and mid-February 1988, the remaining leaves were counted. At the latter date, the leaves were also examined for greasy spot symptoms.

All defoliation was assumed to be caused by greasy spot infection. The percent defoliation in each plot quadrant was the ratio of the number of missing leaves to the initial count. The percent diseased leaves for each plot quadrant was the ratio of the number of missing leaves plus the remaining diseased leaves to the initial count. Leaves that contained only a single greasy spot lesion were considered as being diseased.

The data were analyzed with sprayer, ground speed, and volume rate as main plot effects and quadrants as subplot effects.

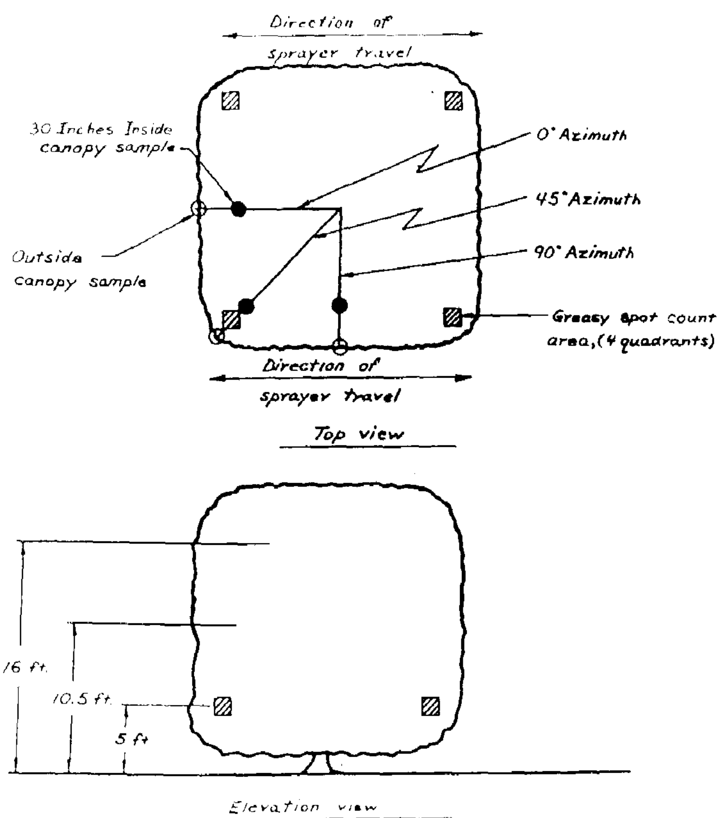

Fig. 1. Schematic views of tree showing 3 azimuths, 2 radii (outside canopy, 30 inches inside canopy), and 3 heights or 18 locations where leaf samples were taken for copper deposition and locations of greasy spot count areas.

Results

Although copper deposition in this experiment will be discussed in this paper, a more detailed discussion has been reported by Whitney et al. (7). The mean copper depositions on the leaves of the check trees were significantly less (5% level) than the depositions on the leaves from the trees of all the spraying treatments. The mean values for the upper and lower leaf surfaces were 0.41×10^{-7} and 0.37×10^{-7} oz/inch², respectively.

Main plot treatment effects on copper deposit. Neither sprayer, volume, nor ground speed had a significant effect on lower leaf surface deposit (Table 1). Also, their interactions were not significant.

In contrast, sprayer, volume, and ground speed had a significant effect on copper deposits on the upper leaf surfaces (Table 1). Sprayer B deposits were significantly higher than those of Sprayer A. The 250 gal/acre volume deposits were significantly higher than those at the 125 or 500 gal/acre volumes. Mean deposits at 1.75 and 2.5 mph were significantly higher than at 1 mph.

Some interactions were significant on the deposits of the upper leaf surface. The sprayer x volume interaction was significant because the mean deposits of Sprayer B were more uniform with respect to volume than those of Sprayer A. The ground speed x volume interaction was significant because the deposits increased with volume at 1 mph, were relatively constant with volume at 1.75 mph, and decreased with volume at 2.5 mph. It should be remembered that Sprayer B did not operate at 500 gal/acre and 2.5 mph and therefore this treatment combination is not included in the 500 gal/acre or 2.5 mph means.

Table 1. Main plot treatment effects on mean[z] copper deposit in oz/inch² x 10^{+7} and the standard error of the mean (SE).

Attribute	Sprayer A	Sprayer B	Volume, gal/acre 125	250	500	Ground speed, mph 1.0	1.75	2.5
Lower leaf surface mean	5.88[y] a	5.66 a	5.88 a	5.79 a	5.63 a	5.87 a	5.72 a	5.74 a
SE	0.25	0.27	0.31	0.31	0.34	0.31	0.31	0.34
Upper leaf surface mean	6.42 b	7.46 a	6.38 b	7.84 a	6.41 b	6.03 b	7.06 a	7.78 a
SE	0.28	0.29	0.34	0.34	0.37	0.34	0.34	0.37

[z]Means in table must h multiplied x 10^{-7} to obtain oz/inch².
[y]Mean separation in rows within sprayer, volume, and ground speed by Fisher's protected LSD at the 5% level.

Subplot treatment or tree location effects on copper deposit. The lower leaf surface deposits were significantly affected by all subplot treatments or tree locations (Table 2). Deposits at the 90° azimuth (nearest sprayer) were significantly higher than those of the other 2 azimuths. Deposits at the 5-ft height were significantly less than those of the 2 upper heights, and the outside canopy deposit was significantly higher than the inside canopy deposit. The height x radius interaction was significant because deposits were more uniform with height on the inside of the canopy than on the outside.

Upper leaf surface deposits were also affected by the subplot treatments (Table 2). Deposits were significantly higher at the 90° azimuth than at the 0° azimuth. Deposits at the 16 ft height were significantly less than the lower heights and the outside canopy deposit was significantly higher than the inside deposit. A significant height x azimuth interaction resulted because deposits generally increased with height at the 0° azimuth and decreased with height at the 90° azimuth. A significant height x radius interaction was caused by the deposits being relatively uniform with height on the outside, but decreased with height on the inside.

Main plot and subplot interactions. For the lower leaf surface deposits, there were 2 significant interactions (means not tabulated). The sprayer x height interaction was significant because the deposits of Sprayer B were relatively uniform with height while Sprayer A deposited approximately 50% more at the 10.5 and 16 ft heights than at the 5 ft height. A volume x azimuth interaction resulted from deposits being relatively uniform at 500 gal/acre, but increasing with azimuth at 125 and 250 gal/acre.

There were 5 significant interactions with the upper leaf surface deposits. A sprayer x height interaction resulted because Sprayer A deposited the most at 10.5 ft height, while the deposits of Sprayer B decreased with increased height. Deposits decreased with height at 125 gal/acre and increased with height at 500 gal/acre, causing a volume x height interaction. There was an inconsistent relationship between volume and azimuth. A volume x radius interaction resulted because the increase in deposit from inside to outside the canopy was much greater at 250 gal/acre than at 125 or 500 gal/acre. Deposits increased with ground speed both inside and outside the canopy, but increased more rapidly on the outside, causing a speed x radius interaction.

Greasy spot assessment. Table 3 summarizes the greasy spot results. Severe greasy spot infection pressure existed as evidenced by the heavy defoliation and the large percentages of diseased leaves in the check plots. All spraying treatments provided a significant reduction in defoliation and diseased leaves when compared with the check (no spray) plots. Among the main treatment effects, neither sprayer, volume, nor ground speed had a significant effect on defoliation for either of the assessment dates. The percentage diseased leaves were significantly less with Sprayer B than with Sprayer A. Also, the 500 gal/acre volume had significantly less diseased leaves than the 125 and 250 gal/acre volumes.

The only significant interaction (means not tabulated) of main treatment factors was that of ground speed and volume for the diseased leaves. The percentage diseased leaves decreased with increasing volume at 1.75 mph, whereas at 1 and 2.5 mph, no definite trends existed.

Table 2. Subplot treatment or tree location effects on mean[z] copper deposit in oz/inch² x 10^{+7} and the standard error of the mean (SE).

Attribute	Azimuth, degrees 0	45	90	Height, ft 5	10.5	16	Radius 30 inches inside canopy	Outside canopy
Lower leaf surface mean	4.42[y] c	6.09 b	6.82 a	4.93 b	6.47 a	5.90 a	3.91 b	7.64 a
SE	0.22	0.22	0.22	0.22	0.22	0.22	0.18	0.18
Upper leaf surface mean	6.46 b	7.01 ab	7.25 a	7.41 a	7.05 a	6.27 b	4.89 b	8.91 a
SE	0.24	0.24	0.24	0.24	0.24	0.24	0.20	0.20

[z]Means in table must be multiplied x 10^{-7} to obtain oz/inch².
[y]Mean separation in rows within azimuth, height, and radius by Fisher's protected LSD at the 5% level.

Table 3. Main treatment effects on mean percentage defoliation and diseased grapefruit leaves and standard error (SE) following copper application in July, 1987.

Greasy spot assessment date	Criterion	Sprayer		Volume, gal/acre			Ground speed, mph			Check[y]
		A	B	125	250	500	1.0	1.75	2.5	
30 Nov. 1987	% defoliation	5.0a[z]	3.7a	4.5a	4.8a	3.6a	5.1a	3.7a	4.4a	33.2
	SE	0.7	0.7	0.8	0.8	0.9	0.8	0.8	0.9	—
15 Feb. 1988	% defoliation	10.2a	8.7a	10.3a	10.0a	7.9a	9.3a	9.3a	10.0a	48.6
	SE	0.9	0.9	1.1	1.1	1.2	1.1	1.2	1.2	—
	% disease	57.5a	46.7b	54.5a	55.8a	45.9b	53.8a	48.1a	56.0a	94.2
	SE	2.3	2.4	2.8	2.8	3.2	2.8	2.8	3.1	—

[z]Mean separation in rows within sprayer, volume, and ground speed by Fisher's protected LSD at the 5% level.
[y]Check means were sigfnificantly greater than the spraying treatment means at the 5% level.

Greasy spot-copper deposit correlation. The greasy spot and copper deposit data from the same proximity of each sample tree were analyzed. On the quadrant of the sample trees from which the copper deposit leaf samples were collected, the average defoliation and diseased leaves data were correlated with the average copper deposit data on the lower leaf surfaces at 2 locations—inside and outside radius at 45° azimuth and 5 ft height.

The correlations between percentage defoliation or diseased leaves and copper deposit on the lower leaf surface were very weak and not significant (1st column, Table 4). The highest correlations were with ground speed, and the only significant correlation was 0.26 between ground speed and percentage defoliation on November 30.

Discussion

Some may have found it hard to believe that the sprayers, volumes, and ground speeds used in this experiment had no significant effect on the lower leaf surface copper deposits. These deposition results, however, were supported for the most part by the assessments on greasy spot control in that no significant differences were found in defoliation. Only the percentage diseased leaves were significantly affected by sprayer type and volume. Sprayer B deposited an average of 29% more copper at the 5 ft height than did Sprayer A, and the percentage diseased leaves were significantly higher with Sprayer A. With volume, however, average copper deposits on the lower leaf surfaces at the 5 ft height decreased with increasing volume, and 500 gal/acre resulted in the lowest percentage diseased leaves. The negative correlation between volume and percentage diseased leaves, however, was weak. This decrease in diseased leaves with decreasing deposits may suggest that distribution of the copper on the leaf surface, which may have been affected by volume, could play an important role in greasy spot control. The correlation of percentage defoliation with ground speed was stronger, but ground speed did not result in significant differences in defoliation.

Table 4. Pearson correlation coefficients between lower leaf surface copper deposits, volume spray rate, ground speed, percentage defoliation, and diseased leaves.[z]

Greasy spot assessment date		Lower leaf surface copper deposit	Volume spray rate	Ground speed
30 Nov. 1987	% defoliation	0.03	0.16	0.26
15 Feb. 1988	% defoliation	–0.07	–0.01	0.23
	% diseased leaves	–0.16	–0.16	0.13

[z]The probability of a correlation coefficient which is numerically equal to 0.24 being zero is 5%.

Copper deposits were highest at the 90° azimuth (nearest the sprayer) and lowest at the 0° azimuth (farthest from the sprayer). Deposits on the outside of the canopy were approximately double those 30 inches inside the canopy. With respect to height, the lowest deposits on the lower and upper leaf surfaces were at 5 and 16 ft, respectively. The orientation of the leaves with respect to the sprayer discharges at the 5 ft height may have caused the leaves to shingle, which could have made deposition more difficult on the lower leaf surfaces. In contrast, this condition probably maximized deposits on the upper leaf surfaces. Leaf orientation at the 16 ft height may have caused them to be deflected upward by the spray, thus minimizing the deposit on the upper leaf surface. Recent hedging prior to the copper application had thinned the foliage at the lower heights of the tree and probably allowed better spray penetration into the canopy than would be expected on a nonhedged tree. Such hedging could improve spray deposits on the lower leaf surfaces on the opposite side of the tree from the sprayer.

It was not clear why Sprayer B deposited more copper on the upper leaf surfaces than Sprayer A. Sprayer B did deposit 50% more than Sprayer A at the 5 ft height and may have been due to the differences in discharge nozzling of the 2 sprayers with respect to tree height. The dividing line between the upper and lower halves of the spray nozzle setup (2/3 in upper, 1/3 in lower) entered the canopy at least 2 ft higher for Sprayer A than for Sprayer B (Fig. 2). This dividing line entered the canopy above and below the 5 ft height for Sprayers A and B, respectively. In addition, this setup was probably the reason Sprayer A deposited the most copper at the 10.5 ft height for both upper and lower leaf surfaces. The maximum heights of the nozzle discharge for Sprayer A and Sprayer B were approximately 104 and 64 inches, respectively.

The upper leaf surface deposits were higher at 250 gal/acre than the 2 other volumes. The two highest ground speeds also gave higher upper leaf surface deposits than 1 mph for both sprayers. There may have been some runoff at 500 gal/acre to reduce the deposit on the upper leaf surfaces, although little runoff was observed during the test. The 250 gal/acre appeared to be the optimum. As for

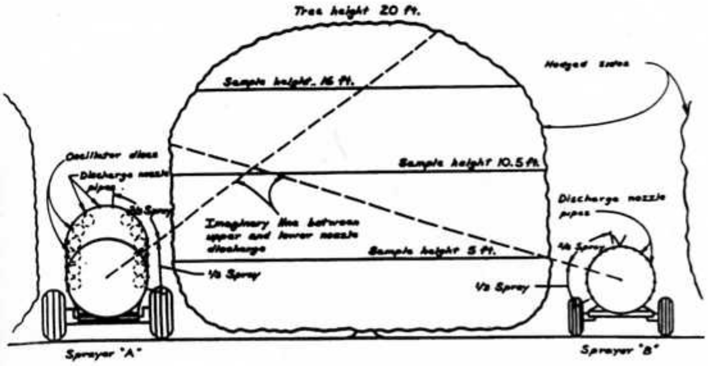

Fig. 2. Schematic elevation view of tree and sprayers.

the ground speed effect, the 1.75 and 2.5 mph speeds apparently improved spray penetration of the canopy for these sprayers and the types of grapefruit trees mentioned.

Conclusions

The following conclusions are supported by the results of this experiment:

1. Copper deposits on the lower leaf surface were not significantly affected by sprayer type, spray volume, or ground speed.
2. A significant and similar reduction in greasy spot infection was provided by all spraying treatments, irrespective of sprayer type, spray volume, or ground speed.
3. Mean copper deposits on the upper leaf surface were significantly affected by sprayer type, spray volume, and ground speed.
4. Mean copper deposits on the upper and lower leaf surfaces were significantly affected by their locations in the tree.

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Proc. Fla. State Hort. Soc. 101:17-20. 1988.

CONTROLLED-RELEASE FERTILIZERS AND GROWTH OF YOUNG 'HAMLIN' ORANGE TREES

J. J. FERGUSON AND F. S. DAVIES
Fruit Crops Department, IFAS
University of Florida
Gainesville, FL 32611

C. H. MATTHEWS
Southwest Florida Research and Education Center
Rt. 1, Box 2G
Immokalee, FL 33934-9716

R. M. DAVIS
Citrus Research and Education Center
700 Experiment Station Road
Lake Alfred, FL 33850-2299

Additional index words. nutrition, *Citrus sinensis.*

Abstract. **Various types of controlled-release fertilizers were applied at different rates and frequencies to young 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] trees on sour orange (*C. aurantium* L.) rootstock. Experiments were conducted in commercial groves on the Ridge and coastal and interior flatwoods. When comparable rates were used, tree diameter and tree height were similar for controlled-release fertilizers applied 2-3X/yr and standard materials applied 6X/yr. Moreover, a single application of some controlled release materials was as effective in promoting growth of young trees as 5-6 applications of standard granular materials applied at higher rates. The use of controlled-release materials can reduce fertilizer application rates and frequencies. However, single broadcast applications may not suffice when high rainfall and associated soil erosion move fertilizer away from the root zone.**

Florida Agricultural Experiment Station Journal Series No. 9483. This research was supported by the Barron Collier Company, the R. D. Keene Trust, Sun Ag. Inc./Fellsmere Farms, Turner/Harrison Farms, Estech, Inc., Melamine Chemicals, Inc., Sierra Chemicals, Inc., W. R. Grace and Co., and the Tennessee Valley Authority. We acknowledge the support of John Jackson and Steve Futch, citrus agents in Lake and Indian River Counties, respectively.

Accumulating evidence suggests that reduced fertilizer application rates and frequencies compare favorably with traditionally used higher rates and frequencies in stimulating growth of young citrus trees, especially when controlled-release fertilizers are used (1, 2, 3, 4). Controlled-release materials may be especially useful in reducing fertilizer application costs for a small number of resets per acre. More general issues like the impact of fertilization practices on the quality of ground and surface waters and the development of more economical production programs that minimize energy and capital inputs have stimu-