Carolina orchard caught 70% of the adult FRB emerging from the soil whereas only 28% were trapped at the dripline. This trend was not apparent in the current study because the extensive root system radiating out from the base of the tree prohibited digging close to the tree trunk. Dickson (4) reported larvae at depths from 7.62 cm to 60.96 cm in citrus groves, both between and beneath trees. Pupation occurred usually within 10 cm of the soil surface.

While influence of pH on distribution of several turf pests has been investigated (12, 13, 16, 17, 18), the presence of FRB larvae + pupae in soils with such a wide range of pH suggests that its management by adjusting acidity of flatwood soils with lime or sulfur applications might be ineffective.

The proximity of immature FRB to the soil surface from Feb. through May in the flatwoods soils of the Indian River area of Florida (Fig. 1) may make shallow digging in soil beneath the tree canopy a practical method of confirming the presence of active FRB infestations in groves where foliar feeding damage has been found.

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FERTILIZATION, NITROGEN LEACHING AND GROWTH OF YOUNG 'HAMLIN' ORANGE TREES ON TWO ROOTSTOCKS

LEAH E. WILLIS AND FREDERICK S. DAVIES
Fruit Crops Department
University of Florida
Gainesville, FL 32611
DONALD A. GRAETZ
Soil Science Department
University of Florida
Gainesville, FL 32611

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Abstract. **Five experiments were conducted with newly planted 'Hamlin' orange trees (*Citrus sinensis* [L] Obs.), 1 in 1987 and 2 in 1988 using sour orange rootstock (*C. aurantium* L.) and 2 in 1989 using Carrizo citrange rootstock (*C. sinensis* x *Poncirus trifoliata* [L.] Raf.) to determine optimum fertigation rate and application frequency, to compare fertigation with granular fertilizer, and to monitor N leaching in the soil. Experiments were conducted on a Ridge- or flatwoods-type soil. Irrigation was maintained at optimum levels (20% soil moisture depletion) and all treatments were irrigated equally. Soil samples were taken at 0-15, 16-46 and 47-76 cm depths the day before the third major fertilization date and thereafter at weekly intervals the day after each fertigation. No difference in growth occurred in 1987 or 1988 on sour orange rootstock in response to fertilizer type (granular vs. liquid) or application frequency (granular 3 and 5, or liquid 3, 5, 10 and 30 times/year). However, during 1989 'Hamlin'/Carrizo growth was greatest on the Ridge-type soil using the 30 time/year treatment. There was a positive linear correlation between fertilization rate and trunk diameter for both Ridge- and flatwoods-type soils in 1989, with maximum growth occurring at the 0.23 kg rate. Nitrate and ammonium concentrations fluctuated seasonally and increased significantly at the 15 and 46 cm depths after fertilization and rainfall. There was considerably more nitrate leaching at the 0.23 kg granular rate applied 5 times/year compared with the 10 or 30 time/year liquid treatments.**

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Since 1988 over 48,000 ha of citrus have been planted in Florida (7), most of which are irrigated using microirrigation systems. Consequently, fertigation is also becoming increasingly popular for newly planted groves (18). The increased use of fertigation has led to many questions concerning optimum fertilizer rate and frequency of application for liquid materials. Reuther et al.(16) found a positive correlation between growth of mature citrus trees and number of fertilizations in an 8-year study. Conversely, Rasmussen and Smith (15) found no effect of application frequency on growth of newly planted orange trees using granular fertilizer. Similarly, Bester et al. (1) compared application frequency for broadcasted urea and liquid fertilizer on newly planted 'Valencia' orange trees and found no difference in growth. However, the fertigated treatment had higher leaf N concentrations. Willis et al. (20) also found that there was no difference in growth in response to granular or liquid fertilizers or frequency of application when using newly planted 'Hamlin' orange trees on sour orange rootstock.

While considerable information is known about chemical and physical behaviors of N in the soil (19), most fertilizer studies on young citrus trees are conducted to determine the optimum rate or application frequency needed for maximum growth with little consideration given to the effects of groundwater quality. However, nitrate movement into groundwater is of concern particularly in areas of the southeastern United States that have sandy soils, high rainfall which maximizes potential leaching past the root zone, and an increasing use of irrigation (9).

Several experiments have been conducted with citrus to determine the amount of NO_3^- losses due to leaching. A positive correlation was found between NO_3^- concentration in a sandy loam soil and the rate of N applied in Israel (5, 6). In contrast, Rible and Pratt (17) did not find a significant correlation between amount of N applied and NO_3^- accumulated or leached when comparing 40 agricultural sites in California. Similarly, in preliminary studies Willis et al. (20) did not find a correlation between N rate applied and NO_3–N concentrations in the soil in Florida.

Our objectives were to compare growth and development of newly planted 'Hamlin' orange trees on sour orange and Carrizo citrange rootstocks related to fertigation rate and application frequency and type of fertilizer (liquid vs granular). In addition, seasonal NO_3–N and NH_4–N movement through and accumulation in the root zone were monitored. The overall objective of this research was to determine the optimum fertigation rate and application frequency needed to attain maximum growth with minimal nitrogen losses.

Materials and Methods

Fertigation on a Kanapaha fine sand, sour orange rootstock (Expt.1). Container-grown 'Hamlin' orange trees on sour orange rootstock (about 1.5 years in the nursery) were obtained from Southern Citrus Nurseries (Dundee, FL) and planted in Apr. 1987 on double beds 16.8 m width x 0.60-0.50 m height x 85 m length at the Horticultural Research Unit near Gainesville, FL. Soil type was a Kanapaha fine sand (loamy, siliceous, hyperthermic, Grossarenic, Paleudults) with a loamy or clayey layer starting about 1.2 m below the soil surface and a water table fluctuating between 0.45 to 1.5 m from the crest of the bed (13). Trees were watered 2 to 4 hrs every other day for 2 weeks until they became established using 38 liter*hr^{-1} 90° microsprinklers located 1 m northwest of the trunk. Treatments included granular fertilizer applied 5 times/year (every 6 weeks) as currently recommended (11), or liquid fertilizer applied 30 (weekly), 10 (every 3 weeks), or 5 times/year (every 6 weeks). In-line 2% fixed Dosatron injectors (Dosatron International, Inc., Clearwater, FL) were used to apply liquid fertilizer. The liquid formulation (8 N [4.85% NH_4^+, 3.15% NO_3^-] - 0 P - 6.6 K - 0.26 Mg - 0.14 Mn - 0.008 Cu - 0.005 B) was representative of that commonly used by commercial growers and as currently recommended (11). Total dissolved salts ranged from 300 (well water) to 12,000 (fertigation 5 times/year) ppm, and no damage to trees was observed. Since P precipitates in irrigation lines, the fertigated treatments received 213 g of granular P/tree/year in five applications that were broadcast by hand within the dripline of each tree. The granular fertilizer was formulated to match the soluble source as closely as possible (8 N [4.0% NH_4^+, 4.0% NO_3^-] - 3.5 P - 6.6 K - 0.40 Mg - 0.29 Mn - 0.008 Cu - 0.006 B). All trees received 0.23 kg N/tree/year. Trees were arranged in a randomized complete block design consisting of 24 individual tree samples/block (treatment). Therefore each block constituted a single replicate for each treatment. Trees were spaced 3.4 m within rows and 7.6 m between rows on each double bed.

All trees received the same amount of water applied either during fertigation or at 20% soil moisture depletion (SMD) as determined using a Troxler 2601 neutron probe (Troxler, Inc., Raleigh, NC) (13). Liquid fertilizer was injected at the end of an irrigation cycle with all treatments finishing at the same time to reduce nutrient leaching after application. Measurements included preplant soil analysis, tree height and trunk diameter at planting and after each growth flush (3/year) for all trees, leaf nutrient analysis, and shoot length and number after each growth flush for 10 trees/treatment. Whole plant fresh and dry weights were taken in Dec. 1987.

Fertigation on an Arredondo fine sand, sour orange rootstock (Expt. 2). Barerooted 'Hamlin' orange trees on sour orange rootstock (about 2 years in the nursery) were obtained from Southern Citrus Nurseries (Dundee, FL) and planted in Apr. 1988 at the Fifield Farm in Gainesville, FL. Soil type was an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic, Paleudults). Treatments included granular fertilizer broadcasted within the dripline 3 or 5 times/year, or liquid fertilizer applied 3, 5, 10, or 30 times/year. Fertilizer analysis and rate were the same as in Expt. 1. Trees were arranged in a randomized complete block design with 4 blocks of 5 single tree replicates/block and spaced 4.6 m within rows and 6.1 m between rows.

All trees received the same amount of water during fertigation and irrigation using a 38 liter*hr^{-1} 90° microsprinklers located 1 m northwest of each trunk. Trees were irrigated every 2 days during the first 2 weeks of establishment, every 2-4 days the next 6 weeks, and at 20% SMD for 1.25 hr the remainder of the year based on neutron probe readings from four randomly placed access tubes. Fertilizer injection times ranged from 7 min to 67 min. When irrigating and fertigating simultaneously, trees were irrigated first followed by fertilizer injection, after which the system was flushed for 10 min. Tree trunks were wrapped with R-11 fiberglass tree wraps to reducing sprouting.

Measurements included trunk diameter at 2-4 cm above the graft union and height taken at planting and after each growth flush, and leaf nutrient analysis after each growth flush on all trees. Leaf samples were taken from each matured growth flush from the mid-shoot and included 2 to 3 leaves per tree from all trees. Shoot number and length were measured after each flush on eight trees per treatment.

Fertigation at 2 rates on Kanapaha fine sand, sour orange rootstock (Expt. 3). Baretooted 'Hamlin' orange trees on sour orange rootstock (about 2 years in the nursery) were obtained from Southern Citrus Nurseries (Dundee, FL) and planted in Apr. 1988 on double beds at the Horticultural Research Unit near Gainesville, FL. Site characteristics were the same as those in Expt. 1. Treatments were applied in a 2x4 factorial arrangement with 2 fertilizer rates 0.06 kg or 0.11 kg N/tree/year, and four fertilizer application frequencies that included a granular treatment applied 5 times/year, or liquid fertilizer applied 5, 10, or 30 times/year. Injection times for the liquid fertilizer ranged from 4.5 to 8 min. Fertilizer analysis, application procedures, irrigation levels, and tree wraps were the same as those in Expt. 2. The same measurements were made as in Expt. 2 except that shoot number and length were measured on 10 trees per treatment. Trees were arranged in a completely randomized design with 12 single tree replications per treatment. Complete randomization was achieved by placing 7 irrigation lines down each row and using individual injectors for each treatment (13).

Fertigation at 3 rates on Arredondo fine sand, Carrizo citrange rootstock (Expt. 4). Barerooted 'Hamlin' orange trees on Carrizo citrange rootstock (about 2 years in the nursery) were obtained from Hilltop Nursery (Tavares, FL) and planted in March 1989 at the Fifield Farm in Gainesville, FL. Trees were planted 6.1 m between rows and 4.6 m within rows with a 2.1 m wide herbicide strip in the row. The experiment consisted of a 3x3 factorial arrangement which included three N rates 0.06, 0.11, or 0.23 kg N/tree/year and three application types (granular five times/year, or liquid 10 or 30 times/year). Treatments were arranged in a completely randomized design with 10 single tree replications/treatment. The liquid fertilizer formulation consisted of an 8 N (3.5% NH_4^+, 4.5% NO_3^-) - 0 P - 6.6 K - 0.32 Mg analysis, while the granular formulation was similar except Mg was present at 0.40% and NO_3^- and NH_4^+ were 4.0% each. Fertilizer application procedures, site characteristics, irrigation levels and tree wraps were the same as in Expt. 2. Injection time for liquid material ranged from, 11 to 19 min. All treatments received granular P to avoid precipitation in irrigation lines with Mg and Ca at 213, 106, and 53 g for the high, medium, and low N/year rates, respectively, split into five applications.

Measurements included trunk diamater taken 2-4 cm above the graft union and height taken at planting and after each of three growth flushes. Leaf samples were taken at the end of the growing season for nutrient analysis. Leaf samples (3-4 leaves/tree) were collected from mid-shoot on the last matured growth flush.

Fertigation at 3 rates on Kanapaha fine sand, Carrizo citrange rootstock (Expt. 5). Barerooted 'Hamlin' orange trees on Carrizo citrange rootstock (about 2 years in the nursery) were obtained from Hilltop Nursery (Tavares, FL) and planted in March 1989 at the Horticultural Research Unit near Gainesville, FL. Trees were planted 6.7 m apart and 3.4 m within rows in double beds with a 2.1 m herbicide strip within rows. Site characteristics were the same as in Expts. 1 and 3. Experimental design, treatments, fertilizer formulations and application procedures, tree wraps, irrigation levels, and plant measurements were the same as those in Expt. 4. Injection times ranged from 9 to 19 min.

In addition, soil samples were taken during the last two-thirds of the growing season (10 July to 15 Nov.). Soil samples were taken using a 2.5 cm diameter soil sampling tool at three depths 0-15, 16-46 and 47-76 cm with 4 single tree replications per treatment. Soil cores were taken one day before and after the third major fertilization date (11 July) and continued throughout the season at weekly intervals the day after each fertigation. Fertilizer was applied every 6 weeks (5 times/year), 3 weeks (10 times/year), and weekly (30 times/year). Therefore, on 3 soil sample dates, samples were taken the day after all treatments received fertilizer. The last sample was taken 8 days after the last fertigation application (15 Nov.).

Soil sample cores were taken about 30 cm from the tree trunk at 5-7.5 cm apart around the tree to reduce sampling variability (2). Samples were not taken on the southeast side of the tree where the wrap prevented uniform placement of water and fertilizer from the emitter located on the northwest side. Each sample hole was refilled with soil from between trees to prevent free movement of water and fertilizer. Halfway through the sampling period (13 Sep.), a new set of trees was randomly chosen to prevent sampling in old sites. After samples were collected, they were air dried and stored until extraction.

Nitrate-N and NH_4-N were extracted using 7 g of soil mixed with 70 ml 1 N KCl and stirred 3 times in 1 hr. The Rapid Flow Analyzer (RFA 300, Alpkem Corp., Clackamas, OR) was used for all samples except those with high concentrations of NO_3-N and NH_4-N, which were run on a Technicon AutoAnalyzer II (Technicon Industrial Systems, Tarrytown, NY).

Data from Expts. 1, 2 and 3 were analyzed individually using a general linear model with contrast statements. Data from Expts. 4 and 5 were analyzed collectively to take into account site characteristics, again using a general linear model with contrast statements.

Results and Discussion

Growth and leaf nutrient concentrations, Expts. 1-3, sour orange rootstock. No significant difference in trunk diameter and tree height occurred in response to fertilizer frequency or type (granular vs liquid) at the 0.23 kg/tree/year N rate for Expt. 1 (1.5-1.8 cm and 1.2-1.4 m, respectively) and Expt. 2 (1.8-2.0 cm and 1.1-1.2 m). Trunk diameter and tree height were also similar in response to fertilizer type and application frequency for the 0.11 kg or 0.06 kg N/tree/year rates in Expt. 3 (Table 1). The 0.06 kg N/tree/year rate resulted in significantly less growth than the 0.11 kg N/tree/year rate, however. There were also no differences in timing of growth flushes, amount of shoot growth, or leaf nutrient concentrations as related to treatments (data not shown). For Expt. 2, leaf nutrient concentrations within acceptable levels included N, P, K, Mg, Fe, Mn, and B, while those that were low included Ca, Zn, and Cu. In Expt. 3, leaf nutrients within acceptable levels were P, K, Mg, and B, while those at low levels included N, Ca, Fe, Mn, Zn, and Cu. Acceptable levels, however, were based on mature tree standards (11).

Growth and leaf nutrient concentrations, Expts. 4 and 5, Carrizo citrange rootstock. Tree height was similar for all treatments at both sites ranging from 1.2-1.4 m (data not shown). However, there were significant differences in trunk diameter among treatments (Table 2). Trunk diameter was similar for the 5 and 10 time/year treatments, but significantly larger for Expt. 4 on the Arredondo fine sand

Table 1. Effect of fertilizer rate, type, and application frequency on growth of young 'Hamlin' orange trees on sour orange rootstock 8 months after planting on a Kanapaha fine sand (Expt. 3, 1988).[z]

Fertilizer type	Frequency (No/yr.)	Trunk diameter[y] (cm)	Height[y] (cm)
	0.11 kg N/tree/year		
Granular	5	2.4	113
Liquid	5	2.0	94
Liquid	10	2.3	111
Liquid	30	2.2	109
Mean		2.2	107
	0.06 kg N/tree/year		
Granular	5	2.0	98
Liquid	5	2.0	99
Liquid	10	2.0	97
Liquid	30	2.1	103
Mean		2.0	99
Frequency		NS	NS
Rate		*	*
Frequency*Rate		NS	NS

NS, *, nonsignificant or significant, P = 0.05.
[z]Data adapted from Willis et al., 1991. HortScience 26:106-109.
[y]Means of 12 individual tree replicates per treatment.

when fertilizer was applied 30 times/year (Fig. 1). In contrast, there were no differences in trunk diameter in response to application frequency in Expt. 5 on the Kanapaha soil. Trunk diameter also showed a significant linear response to fertilizer rate for both experiments, where maximum growth was obtained at the 0.23 kg N/tree/yr rate (Fig. 2). Marler et al. (14) have shown with newly planted 'Hamlin' trees that using granular fertilizer at rates higher than 0.23 kg N/tree/year does not significantly increase growth. Similarly, Obreza (unpublished) observed this same trend for 'Hamlin' oranges growing in the flatwoods of southwest Florida.

Table 2. Trunk diameter of young 'Hamlin' orange trees on Carrizo citrange rootstock 8 months after planting in response to fertilizer type, freqeuency of application, and rate at two different sites, 1989 (Expt. 4 and 5, 1989).

Fertilizer type	Frequency (No./yr)	Trunk diameter[z] (cm) Expt. 4	Expt. 5
	0.23 kg N/tree/yr		
Granular	5	3.0	2.9
Liquid	10	3.2	3.1
Liquid	30	3.3	3.0
	0.11 kg N/tree/yr		
Granular	5	2.8	2.8
Liquid	10	3.0	3.0
Liquid	30	3.2	2.8
	0.06 kg N/tree/yr		
Granular	5	3.0	2.8
Liquid	10	2.7	2.6
Liquid	30	3.0	2.7
Rate		**	**
Freq		**	NS
Rate*Freq		NS	NS
Freq*Site		*	*

NS, *, **, nonsignificant, significant P = 0.05, significant P = 0.01.
[z]Means of 10 single tree replications/treatment. Expt. 4 was conducted on an Arredondo fine sand; Expt. 5 on a Kanapaha fine sand.

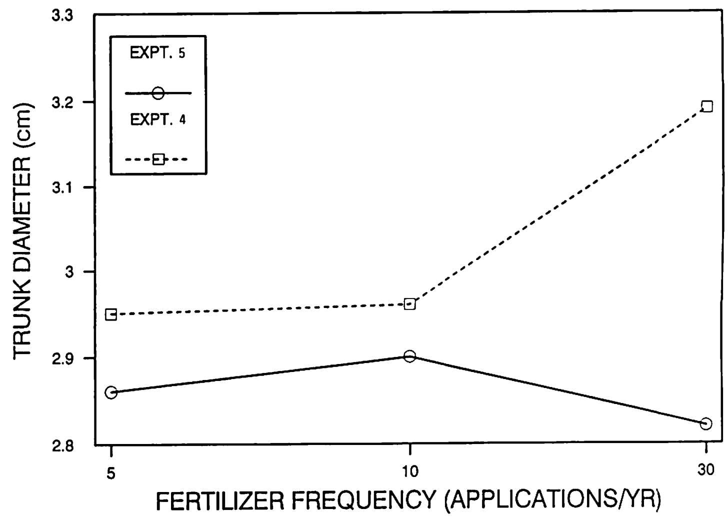

Fig. 1. Trunk diameter and fertilizer application frequencies for young 'Hamlin' orange/Carrizo citrange trees 8 months after planting at 2 experimental sites (Expt. 4, Arredondo fine sand; Expt. 5 Kanapaha fine sand). Data points are the means of 3 treatments with 10 single tree replicates/treatment.

Leaf nutrient concentrations varied among treatments within each experiment (data not shown). For Expt. 4 (Arredondo fine sand), N concentrations for all treatments ranged from 2.1 to 3.0%, with no apparent pattern related to nutrient treatment (Table 3). For all treatments, leaf P and K concentrations were within acceptable ranges for mature leaves, while Mn and Zn concentrations were below optimum. Calcium, Fe, Mg and Cu were within acceptable ranges for most treatments. In Expt. 5 (Kanapaha fine sand), leaf N concentrations ranged from 2.7 to 3.6% with levels being greater for liquid treatments at the 0.11 and

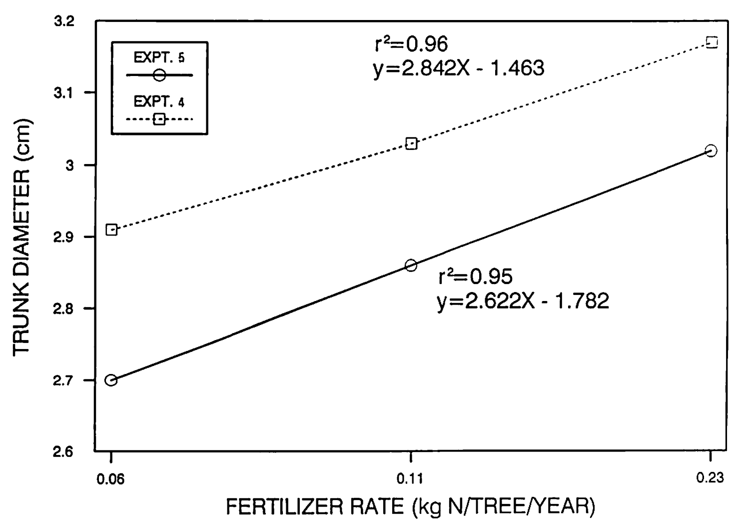

Fig. 2. Trunk diameter and fertilizer rates for young 'Hamlin' orange/Carrizo citrange trees 8 months after planting at 2 experimental sites as described in Fig. 1. Data points are means of 3 treatments with 10 single tree replicates/treatment.

Table 3. Leaf nutrient concentrations of young 'Hamlin' orange trees on Carrizo citrange rootstock 8 months after planting on Arredondo fine sand (Expt. 4, 1989).

Fertilizer type	Frequency (No./yr)	N[z]	P	K (%)	Ca	Mg	Fe	Mn (ppm)	Zn	Cu
				0.23 kg N/tree/yr						
Granular	5	–[y]	0.29	2.8	2.5	0.39	77	23	17	6
Liquid	10	2.9	0.23	2.8	3.3	0.33	82	19	20	6
Liquid	30	2.8	0.30	2.4	3.2	0.35	66	16	16	6
				0.11 kg N/tree/yr						
Granular	5	3.1	0.29	2.4	3.2	0.34	67	15	15	6
Liquid	10	2.1	0.26	2.2	3.2	0.33	57	11	16	6
Liquid	30	3.0	0.35	2.6	3.5	0.36	75	12	15	6
				0.06 kg N/tree/yr						
Granular	5	2.5	0.30	2.1	3.1	0.36	62	13	15	7
Liquid	10	2.0	0.34	2.3	4.2	0.43	68	10	17	9
Liquid	30	2.9	0.33	2.0	3.8	0.34	74	10	13	8

[z]Each number represents the mean of 3-4 leaves per tree from 10 trees/treatment. Leaf samples were taken at mid-shoot from the last matured growth flush on 18 Nov. 1989.
[y]Data are missing.

0.06 kg rates than for the granular treatment. However, at the 0.23 kg rate, all concentrations were greater than 3.0% with the granular application being the greatest (Table 4). Levels of other nutrients were variable and inconsistent. However, acceptable ranges for leaf nutrient concentrations as defined by Koo et al. (11) are for mature citrus and a vigorously growing young tree may have different nutrient requirements.

Optimum application frequency, however, may be affected by rootstock or soil type. 'Hamlin' orange trees on Carrizo citrange rootstock are more vigorous and precocious than those on sour orange (4). Therefore, the difference in response to frequency of application may also be related to tree vigor. Carrizo will tolerate a wide variety of soils, growing best in well drained sandy soils and poorest in highly saline or calcareous soils. Although both sites used in these experiments are well drained sandy soils, water movement through the soil profile in Expt. 5 (Kanapaha) was slowed by a hardpan resulting in a perched water table which was present between 0.45 and 1.5 m from the crest of the double bed (13). In contrast, Expt. 4 (Arredondo sand) was conducted on a deep, well-drained sandy soil where trees were also irrigated more frequently to maintain an optimum SMD of 20%. Therefore, when using a vigorous rootstock/scion combination like 'Hamlin'/Carrizo on soils with poor water and nutrient holding capacity, frequent application of small amounts of fertilizer may result in optimum growth. Reuther et al. (16) in California also observed that an increase in fertilizer

Table 4. Leaf nutrient concentrations of young 'Hamlin' orange trees on Carrizo citrange rootstock 8 months after planting on Kanapaha fine sand (Expt. 5, 1989).

Fertilizer type	Frequency (No./yr)	N[z]	P	K (%)	Ca	Mg	Fe	Mn	Zn (ppm)	Cu	B
				0.23 kg N/tree/yr							
Granular	5	3.6	0.07	–[y]	3.5	0.70	52	57	21	5.9	39
Liquid	10	3.4	0.08	–[y]	4.7	0.60	100	22	25	6.7	40
Liquid	30	3.2	0.28	2.6	3.4	0.40	108	16	16	6	52
				0.11 kg N/tree/yr							
Granular	5	3.0	0.08	–[y]	3.6	0.60	110	14	19	5.7	24
Liquid	10	3.6	0.07	–[y]	4.6	0.60	100	–[y]	15	4.0	26
Liquid	3)	3.1	0.30	2.5	2.8	0.40	69	22	14	4	69
				0.06 kg N/tree/yr							
Granular	5	2.7	0.30	2.9	3.0	0.44	80	27	16	4	56
Liquid	10	3.3	0.08	4.2	5.0	0.60	70	–[y]	18	5.6	28
Liquid	30	3.0	0.38	2.2	2.8	0.38	78	18	12	5	62

[z]Each number represents the mean of 3-4 leaves per tree from 10 trees/treatment. Leaf samples were taken at mid-shoot from the last matured growth flush on 18 Nov. 1989.
[y]Data are missing.

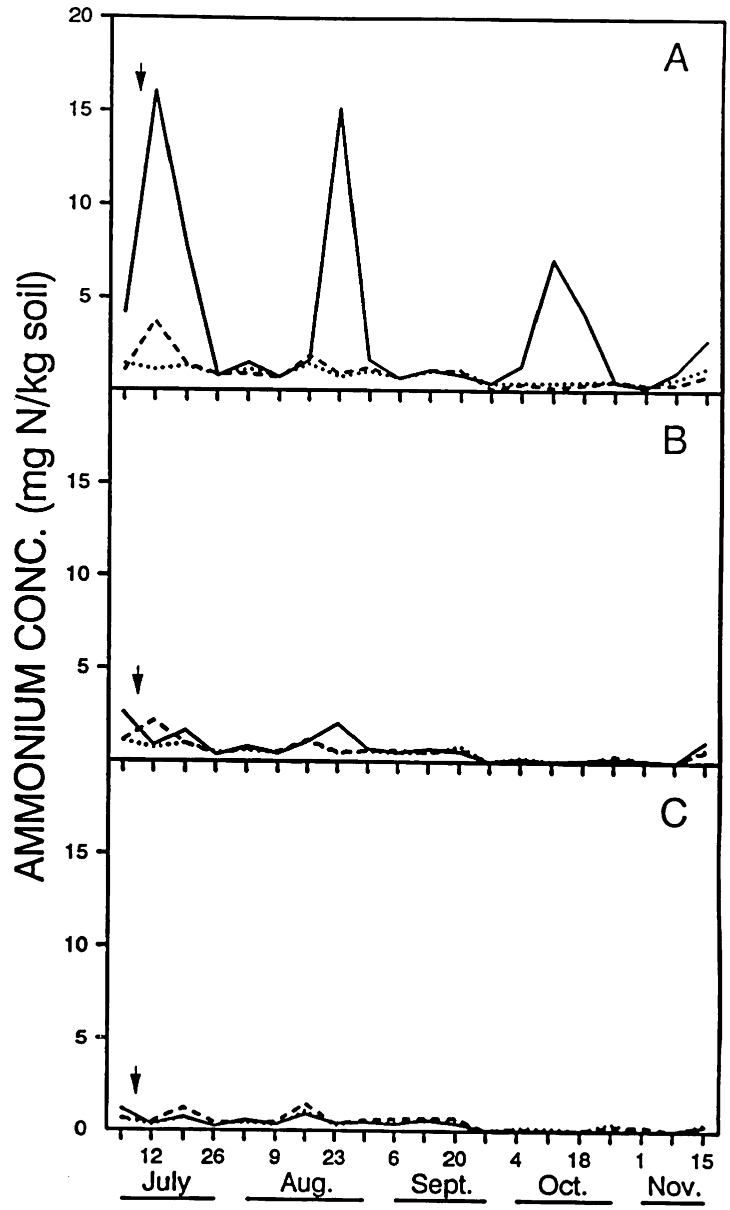

Fig. 3. Seasonal soil NH_4-N concentration at 3 depths under young 'Hamlin' orange/Carrizo citrange trees in response to fertilization frequency. All trees received received 0.06 kg N/tree/year A) 0-15 cm; B) 16-46 cm; C) 47-76 cm. The arrow represents fertilization of all treatments, 11 July (—5,---10, or ···30 fertilizer appl/yr).

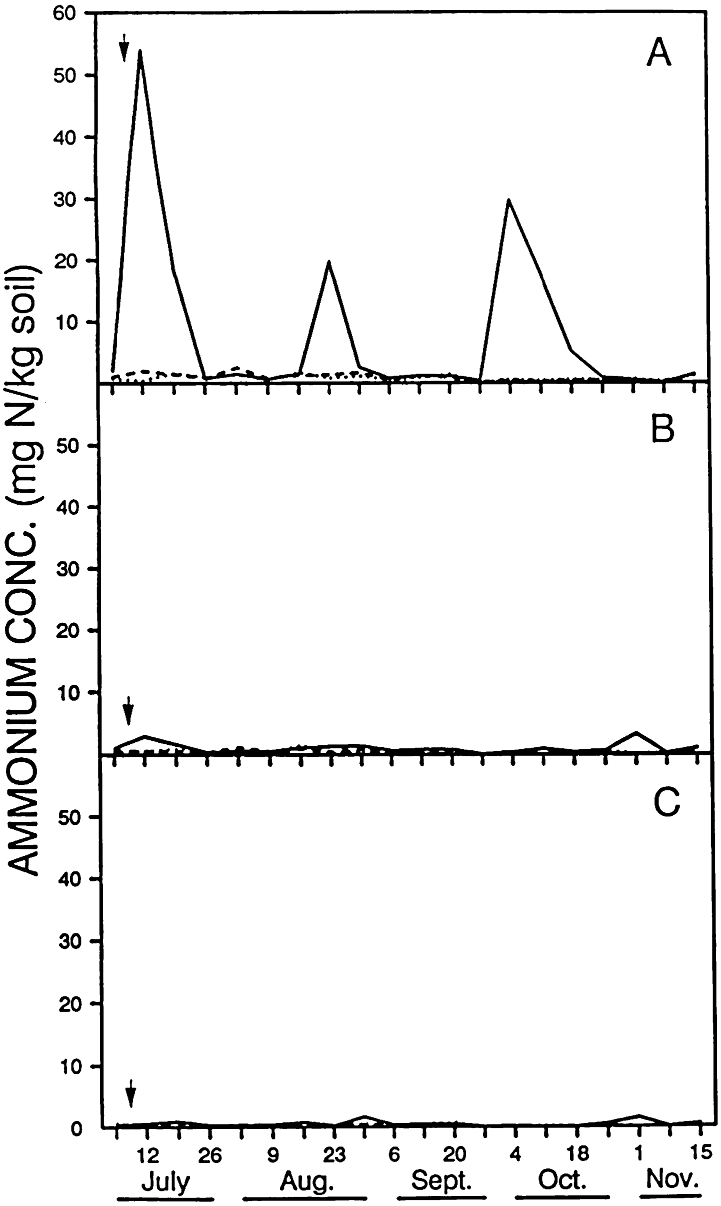

Fig. 4. Seasonal soil NH_4-N concentration at 3 depths under young 'Hamlin' orange/Carrizo citrange trees in response to fertilization frequency. All trees received 0.11 kg N/tree/year. A) 0-15 cm; B) 16-46 cm; C) 47-76 cm. The arrow represents fertilization of all treatments, 11 July (—5, ---10, or ···30 fertilizer appl/yr).

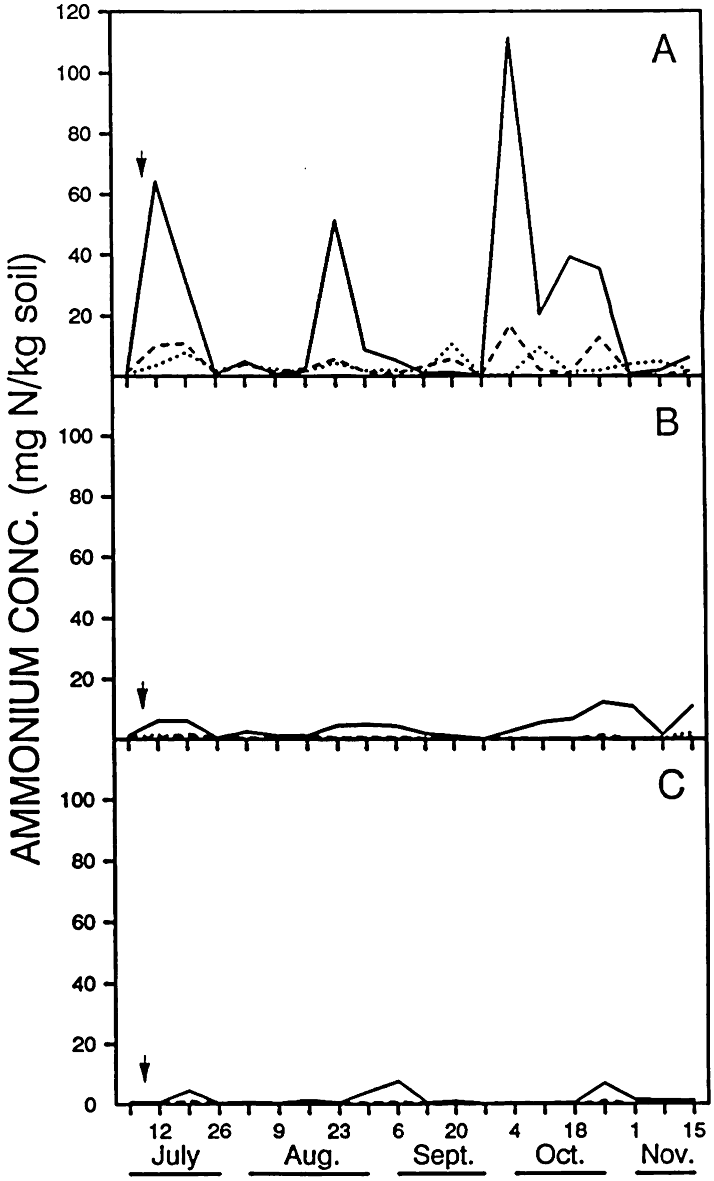

Fig. 5. Seasonal soil NH_4-N concentration at 3 depths under young 'Hamlin' orange/Carrizo citrange trees in response to fertilization frequency. All trees received 0.23 kg N/tree/year. A) 0-15 cm; B) 16-46 cm; C) 47-76 cm. The arrow represents fertilization of all treatments, July 11 (—5, ---10, or ···30).

application frequency resulted in increased growth when using granular materials. However, Rasmussen and Smith (15) observed no effect of fertilizer frequency on tree growth in central Florida. Fertigation (N) rates for newly planted citrus trees as determined here are within currently recommended rates for granular fertilization (11).

Soil nitrogen concentrations. Ammonium-N for the 0.06 kg N/tree/year (Fig. 3) and 0.11 kg N/tree/year (Fig. 4) treatments did not move or accumulate in the 2 lower depths. However, concentrations increased in the lower depths for the treatment applied 5 times/year for the 0.23 kg N/tree/year rate (Fig. 5). This increase in NH_4-N in the lower depths may have resulted from leaching. Soil NH_4-N concentrations were significantly affected by fertilizer rate, application frequency, and soil depth ($P = 0.0001$). There was also a significant interaction between fertilizer rate and frequency ($P = 0.0001$). In addition, NH_4-N concentrations increased linearly in response to fertilizer rate within the rates tested ($P = 0.0001$). There was no difference in NH_4-N concentrations between liquid treatments (10 or 30 times/year), but a highly significant difference occurred among treatments applied 5 vs 10 or 30 times/year ($P = 0.0001$). Ammonium-N concentrations increased sharply 2 to 4 weeks after fertilization for treatments applied 5 times/year for all rates at the 0-15 cm depth.

Nitrate-N for the 0.06 kg N/tree/year rate accumulated in the lower soil depths only for the treatment applied 5 times/year (Fig. 6). Nitrate-N levels for the 0.11 kg N/tree/year rate were somewhat higher for all application frequencies and all depths compared to the lower rate, especially for treatments applied 5 times/year (Fig. 7). Nitrate-N for the 0.23 kg N/tree/year rate moved and accumulated into the lower soil depths for the treatment applied 5 times/

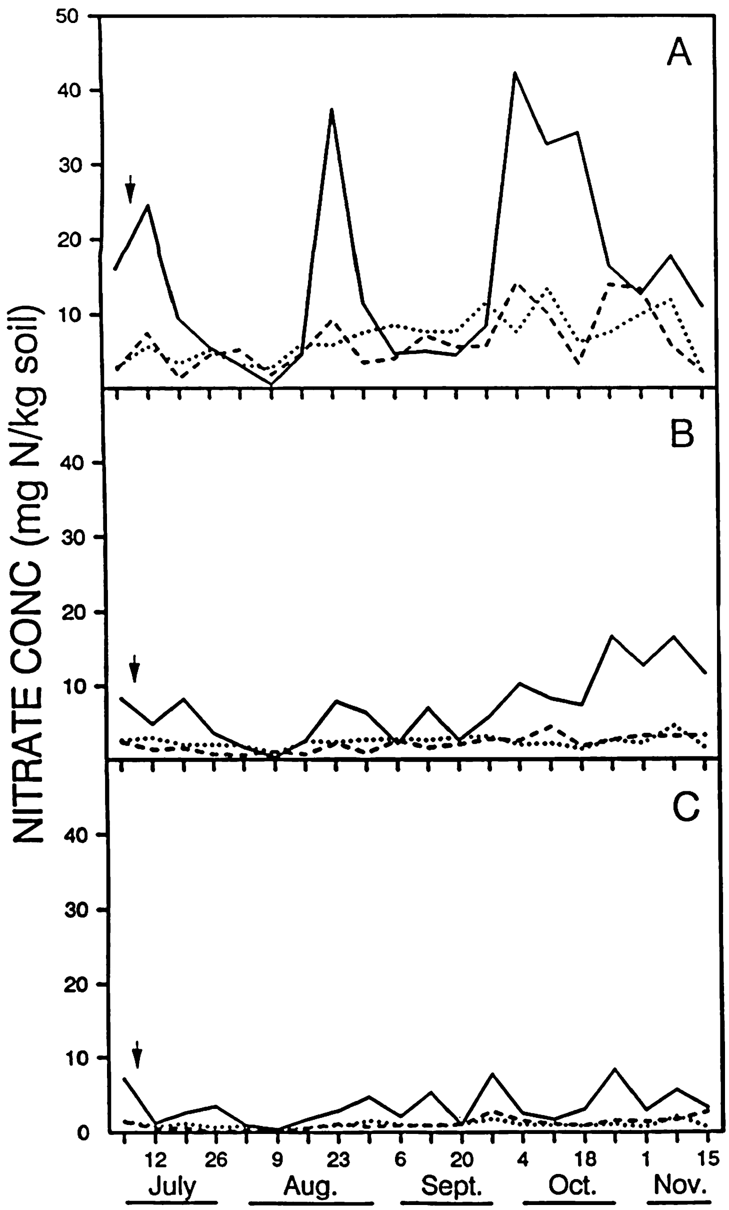

Fig. 6. Seasonal soil NO_3-N concentration at 3 depths under young 'Hamlin' orange/Carrizo citrange trees in response to fertilization frequency. All trees received 0.06 kg N/tree/year. A) 0-15 cm; B) 16-46 cm; C) 47-76 cm. The arrow represents fertilization of all treatments, 11 July (—5, ---10, or ···30 fertilizer appl/yr).

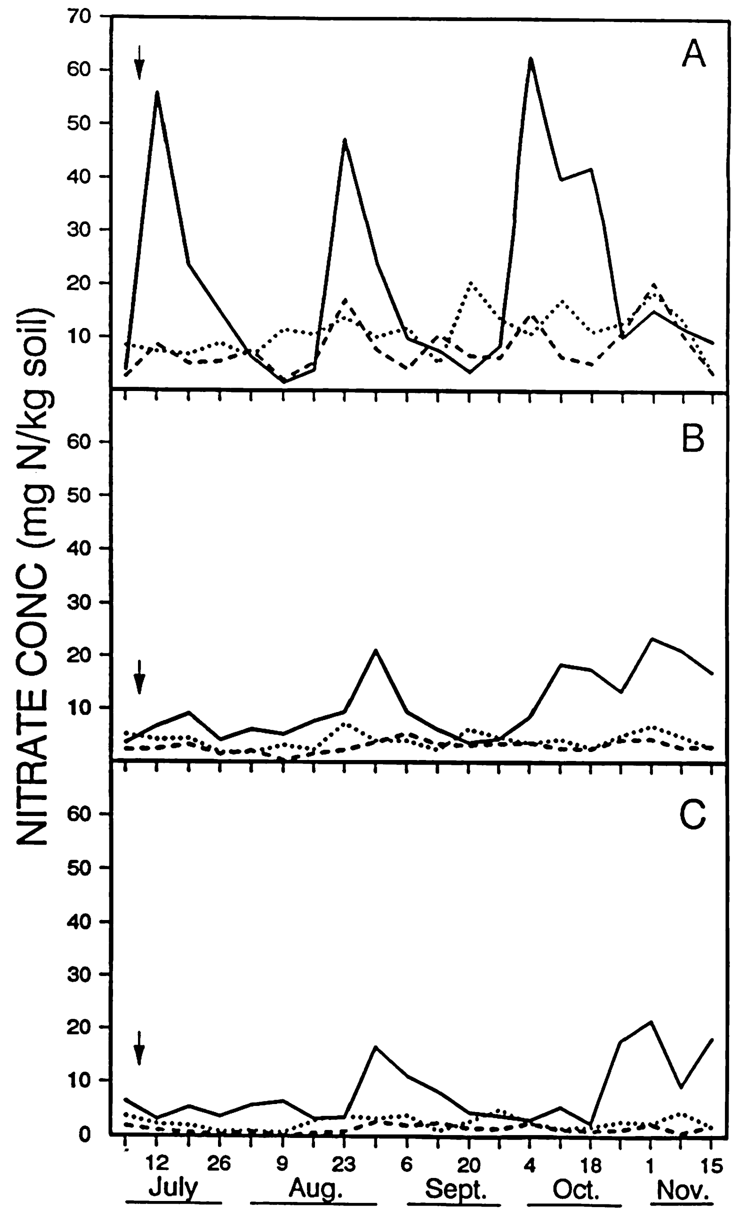

Fig. 7. Seasonal soil NO_3-N concentration at 3 depths under young 'Hamlin' orange/Carrizo citrange trees in response to fertilization frequency. All trees receoved 0.11 kg N/tree/year. A) 0-15 cm; B) 16-46 cm; C) 47-76 cm. The arrow represents fertilization of all treatments, 11 July (—5, ---10, or ···30 fertilizer appl/yr).

year, while other application frequencies showed less leaching (Fig. 8). Nitrate-N levels in the soil were significantly affected by fertilizer rate, application frequency, and soil depth (P = 0.0001). There were also significant interactions between soil depth and fertilizer rate (P = 0.0001), soil depth and fertilizer application frequency (P = 0.0001), and fertilizer rate and application frequency (P = 00159). In addition, NO_3-N concentration increased linearly in response to fertilizer rate (P = 0.0001), which is similar to the findings of Dasberg et al. (5, 6) for citrus. Nitrate-N levels were significantly higher for the 0).23 kg N/tree/year rate in the 0-15 cm depth than for the other fertilizer rates. Unlike NH_4-N, NO_3-N in the lower 2 depths for all rates moved and accumulated particularly for the 5 time/year treatment. While soil NO_3-N levels increased for all treatments within 1 week after fertilization, levels for treatments applied 5 times/year remained high for 2 to 3 weeks after application. Soil NO_3-N concentrations for the liquid treatments (10 and 30 times/year) showed less seasonal fluctuations than the granular application (5 times/year).

Nitrate leaches readily through the soil with excessive irrigation or heavy rainfall (3, 8, 10, 12). Our experiments also showed movement and accumulation of NO_3-N into the 46-76 cm depth after heavy rains. For all rates, treatments applied 10 and 30 times/year showed very little change in soil NO_3-N concentrations at the lowest depth. However, treatments applied 5 times/year fluctuated considerably in response to rainfall.

Leaf N concentrations for young citrus in Florida tended to be higher than those currently recommended for bearing citrus (11); however, there was no consistent

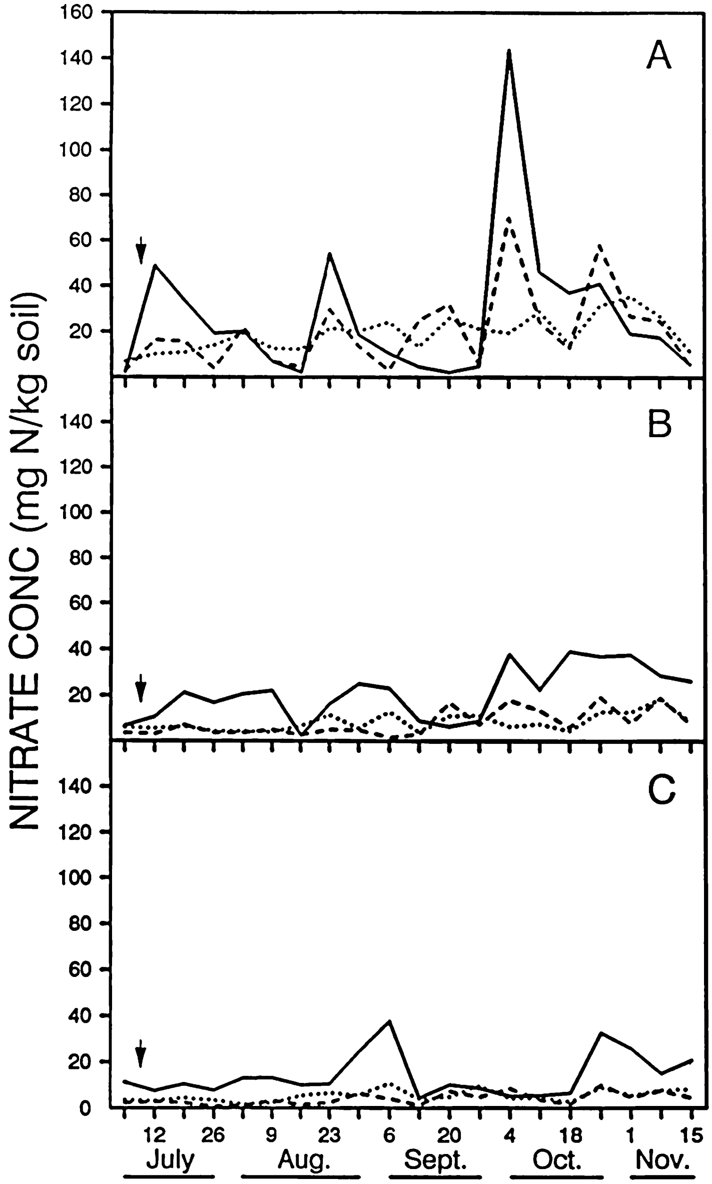

Fig. 8. Seasonal soil NO_3-N concentration at 3 depths under young 'Hamlin' orange/Carrizo citrange trees in response to fertilization frequency. All trees received 0.23 kg N/tree/year. A) 0-15 cm; B) 16-46 cm; C) 47-76 cm. The arrow represents fertilization of all treatments, 11 July (—5, ---10, or ···30 fertilizer appl/yr).

difference among treatments. Our optimum fertigation rates for newly planted citrus are similar to those currently recommended for granular materials by Koo et al. (11). However, the most N leaching occurred at recommended levels when fertilizer was applied 5 times/year, particularly during times of high rainfall. Soil type and rootstock also affected tree responses to fertigation. 'Hamlin' orange trees on less vigorous rootstocks like sour orange and in better soil types are less affected by fertigation frequency or fertilizer type than trees on Carrizo citrange rootstock growing on soils with low water and nutrient holding capacities. This concept may also be applicable when comparing fertigation growth responses in more southerly locales in Florida where the growing season is longer than in more northerly regions. Growers have flexibility in choosing their fertilizer programs in the first season after planting, allowing them to adjust fertilizer rates and frequencies according to leaf analyses, water quality, and cultural practices. However, to reduce nutrient leaching, growers should consider fertigating on a weekly or biweekly basis.

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