Nitrogen, Rootstocks, and Growth of Young ‘Rhode Red’ Valencia Orange Trees

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Abstract. Several studies suggest that optimum N rate and application frequency differ among citrus rootstocks. ‘Rhode Red’ valencia orange trees [*Citrus sinensis* (L.) Osb.] on three rootstocks, *C. volkameriana* Ten. and Pasq., ‘Carrizo’ citrange [*C. sinensis* (L.) Osb. × *Poncirus trifoliata* (L.) Raf.], and ‘Swingle’ citrumelo [*C. paradisi* Macf. × *P. trifoliata* (L.) Raf.], were used to determine if N rate and application frequency should be adjusted, based on rootstock, during the first 3 years in the field. Treatments were arranged in a 3×3×3 (rootstock, N rates, N application frequency, respectively) factorial experiment. Annual N application rates ranged from 68 to 272 g/tree depending on tree age, and N was applied biweekly, weekly or monthly. Application frequency had no effect on trunk diameter or leaf N concentration in any year. Rootstock had a significant effect on growth in all 3 years, with trees on *C. volkameriana* being largest and having the greatest yields, followed by those on ‘Carrizo’ and ‘Swingle’, respectively. Trees on *C. volkameriana* were larger than those on the other rootstocks because they were larger at planting, grew over a longer period during the year, and often grew at a faster rate. Nitrogen rate had no effect on growth during the first 2 years in the field, but the highest N rate increased yields in year 3 for trees on *C. volkameriana* and ‘Swingle’ rootstocks. Interaction between rootstock and N rate was nonsignificant for trunk diameter, but it was significant for yield, suggesting that trees on *C. volkameriana* responded more to increased N than did those on the other rootstocks.

Several studies have been conducted in Florida to determine optimum N rates and application frequencies for 1- to 3-year old citrus trees. Rasmussen and Smith (1961) found an optimum annual N rate/tree of 36 g for 1-year-old trees growing on deep, sandy soils. Calvert (1969) observed a broader range of optimum annual rates (109 to 327 g/tree, depending on soil characteristics) for 2-year-old trees growing in coastal areas. Willis et al. (1990) found a slightly lower optimum annual rate (104 g/tree) for ‘Hamlin’ orange during the first year in the field. In contrast, Guazzelli et al. (1996) observed no effect of N rate on growth the first year in the field, but found that of 168 g/tree was optimum in the second year.

The effect of application frequency on growth of young citrus trees varies with growing region, soil type, and tree age. Application frequency generally had no effect on growth of ‘Hamlin’ orange trees the first year in the field in Florida (Willis et al., 1990). In contrast, more frequent fertilizer application in-

creased growth of mature orange trees in Israel (Dasberg et al., 1988), and for young trees on ‘Carrizo’ citrange rootstock growing in sandy soils in Florida (Willis et al., 1990).

Rootstock has a significant effect on growth (Castle, 1987) and nutrition of citrus trees as summarized by Wutscher (1989). For example, scions on rough lemon (*C. jambhiri* Lush.) or sweet orange [*C. sinensis* (L.) Osb.] rootstocks had higher leaf N concentrations than did those on sour orange (*C. aurantium* L.) or ‘Cleopatra’ mandarin (*C. reticulata* Blanco) rootstocks under the same fertilizer regime. In contrast, Willis et al. (1990) observed that the growth and leaf mineral concentration of ‘Hamlin’ orange trees on ‘Carrizo’ citrange and sour orange were not differentially affected by N application rate or frequency in spodosols of the Florida flatwoods. However, in Arredondo fine sand soils, trees on ‘Carrizo’ grew more than did those on sour orange as application frequency increased from 5 or 10 to 30 times/year. Similarly, Syvertsen and Smith (1996) observed that trees on *C. volkameriana* rootstock required higher N rates for optimum growth than did those on sour orange rootstock. They suggested that N rate and application frequency should be adjusted based on rootstock.

The objective of this study was to determine if N rate and application frequency should be adjusted based on rootstock for ‘Rhode Red’ valencia orange trees during the first 3 years in the field. Currently, most young citrus trees in Florida are fertilized based on tree age

or size without regard to rootstock (Davies and Albrigo, 1994; Tucker et al., 1995).

Materials and Methods

Plant material. Bare-root ‘Rhode Red’ valencia orange trees were obtained from a commercial field nursery (Roland Dille, Avon Park, Fla.) and planted in Gainesville, Fla., on 19 May 1995 at 6 m between rows and 2.4 m within rows. Trees had been in the nursery ≈2 years before digging. Soil type was an Arredondo fine sand (loamy, siliceous, hyperthermic, Grossarenic Paleudults). Trees were irrigated every other day for the first 2 weeks after planting using 38 L·h⁻¹, 90° pattern microsprinklers located 1 m northwest of the tree. Soil water deficit was maintained at <30% throughout the study, which is the optimum level for citrus trees in this soil type (Marler and Davies, 1990).

The irrigation system was designed so that each tree served as an individual replication that was randomly assigned a treatment within each block as described previously (Marler and Davies, 1990). Treatments consisted of three rootstocks, *C. volkameriana*, ‘Carrizo’ citrange, and ‘Swingle’ citrumelo; three annual fertilizer rates (years 1 and 2, 68, 136, and 204 g/tree; year 3, 136, 204, and 272 g/tree); and three application frequencies (years 1 and 2; 28, 14, and 7×/yr; year 3; 60, 15, and 8×/yr). Application frequencies and N rates were chosen based on ranges observed in previous studies (Tucker et al., 1995; Willis et al., 1990). Fertilizer treatments were begun in May 1995, and continued until mid-November. Fertilizer was applied beginning in Apr. 1996 and Mar. 1997 and continued until December of each year. Liquid fertilizer with an 8N (4% NH₄⁺, 4% NO₃⁻)–0.9P–6.6K analysis was applied using Dosatron 2% fixed injectors (Dosatron Int., Clearwater, Fla.). This fertilizer analysis is typically used for young trees in Florida, although the P rate was reduced based on relatively high levels of P in the soil (Tucker et al., 1995). The irrigation system was run for 30 min, after which the fertilizer was injected for 20 to 40 min, depending on the treatment. The system was then flushed for 30 min after fertilizer injection.

Measurements. Trunk diameters were measured about monthly from May 1995 until Dec. 1998 except during January and February when trees were not growing. Leaf tissue nutrient concentrations were measured in three of the six blocks in September of each year using five spring flush leaves/tree for each of the 27 trees/block (81 trees). Not all of the trees were sampled because of the large number (162 trees). Leaves were prepared and analyzed as described previously (Maurer and Davies, 1993). Fruit were harvested, counted, and weighed 8–12 Mar. 1998.

Experimental design and statistical analysis. Treatments were arranged into a 3×3×3 factorial experiment in a randomized complete-block design consisting of six blocks of 27 trees/block, and six individual trees/treatment (162 trees total). Trunk diameter data were analyzed within each year using repeated

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measures analysis for time, frequency, rate and interactions. Regression analysis was used to determine the correlation and best-fit equations for trunk growth over time. Treatment effects on yield were determined in year 3 using analysis of variance (ANOVA) and Duncan's multiple range test within rootstocks, where rootstock and N rate interactions were present. The correlation between N rate and yields was initially evaluated using regression analysis. However, best-fit equations are not very descriptive when using only three rates. Thus, means were separated using Duncan's multiple range test even though these are quantitative variables. Use of Duncan's multiple range test in this instance is statistically and practically warranted (R. Littell, Dept. of Statistics, Univ. of Florida).

Results and Discussion

In the first year (1995), there was no effect of N rate or application frequency on trunk diameter. Repeated measures analysis showed highly significant ($P \geq 0.0001$) time and rootstock effects (data not shown). Trunk diameter growth followed a sigmoid pattern that was best defined by a cubic function for all three rootstocks (Fig. 1). Trees on *C. volkameriana* started out largest and grew at a faster rate during much of the season than did those on 'Carrizo' or 'Swingle', which had similar growth patterns. Mean trunk diameter at the end of the year was 24.7 mm for trees on *C. volkameriana* vs. 20.1 mm for trees on both 'Carrizo' or 'Swingle'. Trees on *C. volkameriana* are known to be more vigorous than those on 'Swingle' (Castle, 1987). Trees on 'Carrizo' are usually more vigorous than those on 'Swingle', but this was not the case in the first year in this study. There were also no significant differences in leaf N concentration among rootstocks, N rates or application frequencies, averaging 2.29%, 2.32%, and 2.34% for *C. volkameriana*, 'Carrizo', and 'Swingle', respectively.

In the second year (1996), there was again no significant effect of N rate or application frequency on trunk diameter, nor was there an interaction between factors (data not shown). Time and rootstock again had highly significant ($P \geq 0.0001$) effects on trunk growth, and there was no time by rootstock interaction. Trees on *C. volkameriana* began the year larger than those on the other rootstocks and the trend continued through 1996 (Fig. 2). Trunk diameter growth again followed a sigmoid (cubic) growth curve, but the shape of the curve was similar for all three rootstocks. Trunk diameters in December averaged 40.4, 33.2, and 31.6 mm for trees on *C. volkameriana*, 'Carrizo', and 'Swingle', respectively. Leaf N concentration was statistically similar among rates, application frequencies, and rootstocks averaging 2.19%, 2.37%, and 2.19% for trees on *C. volkameriana*, 'Carrizo', and 'Swingle', respectively.

In the third year (1997) repeated measures analysis again suggested that rootstock had a highly significant overall effect on trunk diameter ($P \geq 0.0001$). Application frequency

Fig. 1. Main effects of rootstock, on trunk diameter of 1-year-old 'Rhode Red' valencia orange trees in Gainesville, Fla., 1995. There was no significant effect of N rate or application frequency, only rootstock effects are shown. Predicted equations, ($n = 54$ measurements per measurement date): Swingle, $y = 17.04 - 1.07x + 0.49x^2 - 0.03x^3$, $r^2 = 0.94$; Carrizo, $y = 17.49 - 0.67x + 0.32x^2 - 0.02x^3$, $r^2 = 0.96$; *C. volkameriana*, $y = 18.10 - 0.13x + 0.16x^2 - 0.01x^3$, $r^2 = 0.93$.

and N rate did not affect trunk diameter, nor was there an interaction with rootstock. Time again had a highly significant effect ($P \geq 0.0001$) and there was a highly significant interaction of time and rootstock on trunk diameter. In contrast, no time by rootstock interaction had occurred in years 1 and 2.

Trees on *C. volkameriana* were larger initially, grew at a faster rate, and continued growing later into the year than those on 'Carrizo' or 'Swingle', respectively. The shape of the growth curves for *C. volkameriana* and 'Carrizo' differed from that for 'Swingle', whose growth reached a plateau earlier in the year. Trunk diameters in December averaged 68.7, 62.1, and 54.6 mm for trees on *C. volkameriana*, 'Carrizo', and 'Swingle', respectively. Leaf N concentration did not differ significantly with rate, application frequency or rootstock, averaging 2.36%, 2.28%, and 2.25% for trees on 'Carrizo', *C. volkameriana*, and 'Swingle', respectively.

Both rootstock and N rate affected fruit number and weight in 1998 (Table 1) and a significant interaction between the two factors affected yields. Trees on *C. volkameriana* had considerably greater yields overall (number and weight) than those on 'Carrizo' or

'Swingle', which had similar yields. Mean fruit number and weight across rootstocks also increased significantly at the highest N rate for *C. volkameriana* and 'Swingle' rootstocks. However, trees on *C. volkameriana* showed a much greater response to increasing N rates than those on 'Swingle'; and 'Carrizo' showed no response. Yields were similar at all application frequencies.

The overall dominant effect of rootstock on trunk diameter and yield was expected and has been documented in several studies as summarized by Castle (1987). Note that the shape of the growth curves differed among rootstocks in 1995, with the linear portion of the growth curve having a much greater slope for trees on *C. volkameriana* than those on 'Carrizo' or 'Swingle'. Trees on all three rootstocks had very low growth rates by 2 Dec. In 1996, growth rate in the linear portion of the curve was similar for all rootstocks, but trees on *C. volkameriana* began growing earlier and continued growing later than those on the other two rootstocks. During 1997, trees on *C. volkameriana* had the highest growth rate over the linear portion of the curve, followed by those on 'Carrizo' and 'Swingle', respectively. However, trees on *C. volkameriana* again began

Fig. 2. Effects of rootstock, on trunk diameter of 2-year-old 'Rhode Red' valencia orange trees in Gainesville, Fla., 1996. There was no significant effect of N rate or application frequency, only rootstock effects are shown. Predicted equations, $n = 54$ measurements per measurement date: Swingle, $y = 19.75 - 0.60x + 0.85x^2 - 0.07x^3$, $r^2 = 0.96$; Carrizo, $y = 20.61 - 1.27x + 0.98x^2 - 0.81x^3$, $r^2 = 0.97$; *C. volkameriana*, $y = 23.92 - 0.63x + 1.00x^2 - 0.84x^3$, $r^2 = 0.94$.

Fig. 3. Effects of rootstock, N rate and application frequency on trunk diameter of 3-year-old 'Rhode Red' valencia orange trees in Gainesville, Fla., 1997. There was no significant effect of N rate or application frequency, only rootstock effects are shown. Predicted equation, $n = 54$ measurements per measurement date: Swingle, $y = 30.30 + 2.54x + 0.51x^2 - 0.044x^3$, $r^2 = 0.97$; Carrizo, $y = 28.80 + 2.59x + 0.36x^2 - 0.036x^3$, $r^2 = 0.97$; *C. volkameriana*, $y = 36.19 + 4.46x + 0.091x^2 - 0.020x^3$, $r^2 = 0.98$.

growing earlier in the year and continued to grow into January (data not shown), whereas growth of trees on 'Carrizo' and especially 'Swingle' had greatly declined by November. Therefore, trees on *C. volkameriana* were inherently more vigorous than those on the trifoliate hybrids, 'Carrizo' and 'Swingle', and also had the capacity to grow at lower average soil temperatures. Similarly, Young (1970) found that scions of rough lemon rootstock continued to grow at lower soil temperatures than did those on citrange rootstocks. Wilcox et al. (1981) also observed that root hydraulic conductivity was greater for rough lemon than for 'Carrizo' at a 10 °C root temperature. Rough lemon and *C. volkameriana* have similar characteristics as rootstocks; thus, the response to soil temperature may also be similar.

Seasonal rates of growth in trunk diameter were similar to those reported by Davies et al. (1996) for young 'Hamlin' orange trees on sour orange rootstock growing in Florida and tended to increase from year 1 to 3 in the field. For example, growth rates for *C. volkameriana* averaged 44 $\mu\text{m}\cdot\text{d}^{-1}$ in year 1; 78 $\mu\text{m}\cdot\text{d}^{-1}$ in year 2; and 140 $\mu\text{m}\cdot\text{d}^{-1}$ in year 3. Coefficient of determination (r^2) values were very high for all growth equations because of the large number of replications per measurement date.

The lack of N application frequency effect on growth is partially in agreement with previous studies in Florida by Willis et al. (1990). They generally found no effect of application frequency on growth of 'Hamlin' trees on sour orange rootstock, but did observe more growth with 30 than 10 with five applications/year for 'Hamlin' on 'Carrizo' citrange rootstock in sandy, well-drained soils. In this study, fertilizer (N) was applied as many as 60 times/year in 1997 without affecting growth or yield. These results differ from those of Maurer et al. (1995) who found that frequent application of reclaimed wastewater to mature grapefruit trees increased yields. Similarly, Legaz et al. (1981) in Spain found that yields of mature citrus trees were greater with frequent fertilization than with infrequent broadcast applications.

The lack of effect of N rate on trunk growth in the first year, 1995, is not surprising and is in agreement with several other studies (Obreza and Rouse, 1993; Rasmussen and Smith, 1961; Willis et al., 1990). In the second year, N rate again had no effect on trunk growth regardless of rootstock. In contrast, Guazzelli et al. (1996) found an optimum annual N rate of 168 g/tree, which is within the range of rates (68 to 204 g) used in this study. The N rate also had no effect on trunk diameter in 1997, but fruit number and weight increased with increasing N rate for trees on *C. volkameriana* and 'Swingle'. Similarly, Obreza (1994) observed only a slight effect of N rate on canopy volume of 'Hamlin' orange on 'Carrizo' rootstock during the first 3 years in the field. However, he found a linear increase in yields as annual N rate increased from 96 to 382 g/tree for years 4 and 5. The highest yields (fruit weight) for *C. volkameriana* and 'Swingle' in this study occurred at an annual N rate of 272 g/tree in year 3, but we could not determine the precise optimum N rate from this study based on only three N

Table 1. Effect of rootstock and N rate on yield per tree of 3-year-old 'Rhode Red' valencia orange trees in Gainesville, Fla., 1998.^z

Rootstock	Annual N rate (g/tree) ^y							
	136		204		272		Mean ^x	
	Fruit yield/tree							
	(No.)	(kg)	(No.)	(kg)	(No.)	(kg)	(No.)	(kg)
Swingle	2.8 b ^y	1.0 b	5.1 b	1.2 b	12.3 a	2.7 a	6.7 B	1.6 B
Carrizo	8.3 a	2.1 a	10.5 a	2.4 a	15.5 a	3.7 a	11.4 B	2.7 B
<i>C. volkameriana</i>	26.8 b	6.5 b	39.2 b	9.5 b	59.7 a	15.2 a	41.9 A	10.4 A
Mean ^x	12.6 B	3.2 B	18.3 B	4.4 B	29.2 A	7.2 A		

^zFruit were harvested 8–12 Mar. 1998.

^yMean separation within rows (abc) by DMRT, $P \leq 0.05$, $n = 18$. Regression analysis was not used to separate N rates because only three rates were used.

^xMain effects of N rates and rootstocks (means) were analyzed separately by DMRT, $P \leq 0.001$, $n = 54$. Interaction was significant at $P \leq 0.001$.

levels. Our data are in support of studies by Syvertsen and Smith (1996) and suggest that N rates should be adjusted based on rootstock, but only in the third year after planting.

A cumulative, indirect effect on yields of the highest N rate may have occurred over the entire 3 years of the study as has been suggested by Obreza (1994). However, there were no differences in leaf N concentrations, trunk diameters or tree appearance related to N rate that would support this suggestion.

In summary, during the first 3 years in the field, rootstock had a much more pronounced effect on tree growth (trunk diameter) of 'Rhode Red' valencia orange trees than did frequency or rate of N application. Moreover, there was no interaction between rootstock and N rate, or rootstock and application frequency related to trunk diameter as suggested by Willis et al. (1990). Nevertheless, the highest annual N rate, (272 g/tree) did increase fruit weight and number for trees on *C. volkameriana* and increased fruit number in year 3 for trees on 'Swingle' rootstock. There appears to be no advantage to adjusting N rates based on root-

stock during the first 2 years in the field. Nitrogen rates, however, should be increased in the third year, especially for vigorous rootstocks such as *C. volkameriana*, to increase fruit number and weight.

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