Nitrogen Nutrition of Containerized Citrus Nursery Plants

B.E. Maust¹ and J.G. Williamson²

Department of Horticultural Sciences, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL 32611

Abstract. Experiments were conducted with ‘Hamlin’ orange [Citrus sinensis (L.) Osb.] budded on Cleopatra mandarin (Citrus reticulata Blanco) or Carrizo citrange [Citrus sinensis (L.) Osb. × Poncirus trifoliata (L.) Raf.], seeding rootstocks to determine minimum container solution N concentrations required for optimum growth and fertilizer uptake efficiency at various growth stages. Plants were fertigated daily with 1 liter of N solution at either 0, 12.5, 25, 50, 100, or 200 mg·liter⁻¹ from NH₄NO₃ or 0, 3.13, 6.25, 12.5, 25, or 50 mg·liter⁻¹ from NH₄NO₃ dissolved in a complete nutrient solution, respectively. Percentage of N in the mature plant tissues increased as N concentration in the solution medium increased. Shoot length and leaf area increased as N concentrations increased up to a critical concentration of 15 to 19 mg·liter⁻¹. The critical N concentration for root, shoot, and total plant dry weight was =18 mg·liter⁻¹ for ‘Hamlin’– Cleopatra mandarin nursery plants and 15 mg·liter⁻¹ for ‘Hamlin’–Carrizo nursery plants. The critical N concentration for relative total plant dry weight accumulation (percentage) for the two experiments was 16.8 mg·liter⁻¹. In a separate experiment, plants were given labeled fertilizer N (FN) (¹⁵NH₄¹⁰NO₃) at one of five growth stages: A) in the middle of rapid shoot extension of the third flush, B) immediately following the cessation of the third flush shoot extension but during leaf expansion, C) immediately following leaf expansion, D) before the fourth flush, or E) in the middle of rapid shoot extension of the fourth flush. Labeled FN recovery increased during rapid shoot extension of the fourth scion flush compared to the other labeling periods. FN uptake per gram of total plant dry weight was greatest during rapid shoot extension (A and E) and lowest during the intermediate labeling periods (B–D). FN supplied 21% to 22% of the N required for new growth during rapid shoot extension.

Fertilizer plays a major role in the production of citrus nursery plants. Nitrogen is the most important element in most fertilization programs and is especially critical in the nursery where high plant densities exist and rapid vegetative growth occurs. Improved fertilizer application efficiency is needed to reduce production costs and minimize groundwater contamination. In container-grown ‘Conica’ Alberta spruce [Picea glauca (Voss)] fertigated with N at 900 kg·ha⁻¹·year⁻¹, >34% of the applied fertilizer N (FN) was recovered in the leachate and runoff water (Rathier and Frink, 1989). Maintaining low but adequate concentrations in the soluble N pool, applying fertilizer during times of increased plant uptake capacity, or both would be possible means of improving uptake efficiency (Gilliam and Wright, 1978; Hershey and Paul, 1983; Ingstad, 1977, 1982).

Many studies have been conducted comparing the effect of various N rates on the yield and fruit quality of citrus trees (Chapman and Parker, 1942; Koo, 1979; Mungomery et al., 1978; Smith, 1970; Stewart et al., 1961). Several investigators have also studied N fertilizer practices in young citrus trees (Marler et al., 1987; Swietlik, 1992; Willis et al., 1991). However, very few reports have been published on N fertilization of citrus nursery plants. Chapman and Liebig (1937; 1940) found that sweet orange seedling growth with N at 0.14, 0.7, 1.4, or 840 mg·liter⁻¹ was markedly reduced compared to plants grown at 70 or 420 mg·liter⁻¹. Only slightly less growth was achieved at 7 mg N/liter, and the authors suggested that the optimal solution N concentration was =10 mg·liter⁻¹. However, no work has been reported on the intermediate N concentrations.

An estimated 12 to 14 million citrus nursery plants are produced annually in Florida (Jackson et al., 1989), with an increasing number being grown in containers. There are currently no published recommendations for fertilizer rates for containerized citrus in Florida. The recommended N field rate is 560 to 1120 kg·ha⁻¹·year⁻¹ (Tucker and Youtsy, 1980), although field rates of 2240 kg·ha⁻¹·year⁻¹ are more common (Castle and Ferguson, 1982; Castle and Rouse, 1990). Castle and Ferguson (1982) found that growers of containerized citrus nursery trees in Florida were applying FN at rates similar to those who operate field nurseries (2240 kg·ha⁻¹·year⁻¹). A more recent survey among citrus nurseries in Florida revealed wide variations in fertilizer rates and application frequencies depending on the nursery manager with N at 200 to 400 mg·liter⁻¹ being common among containerized-plant nurseries (Williamson and Castle, 1989). In South Africa, the current recommendation of 250 mg N/liter applied at every irrigation (Lee, 1988) seems high.

Citrus and many other evergreen subtropical and tropical trees manifest episodic growth rhythms, even when environmental factors are favorable and constant (Borchert, 1973; Greathouse et al., 1971; Niemiera and Wright, 1982). Shoot growth of cacao (Theobroma cacao L.) remained rhythmic under constant controlled environmental conditions (Greathouse et al., 1971). Although root growth of young ‘Valencia’ orange trees on rough lemon (Citrus limon (Burm.) and Carrizo citrange rootstocks was continuous, the rate of visible growth decreased with the onset of a shoot flush and an increase in shoot extension, even when soil temperatures and soil moisture content were nonlimiting (Bevington and Castle, 1985). Root growth increased again immediately after shoot elongation ceased, resulting in a definite alternating pattern of root and shoot growth.

Nitrogen uptake has been related to growth stages. Nitrate absorption by ‘Valencia’ orange trees grown outdoors in solution cultures was observed to be more related to periods of active root than to top growth (Chapman and Parker, 1942). Nitrate absorption
in *Euonymus japonica* Thunb. increased during root growth and decreased to near zero during shoot elongation (Hershey and Paul, 1983). FN applied to ‘Helleri’ holly (*Ilex crenata* Thunb.) after stem elongation ceased and before the next shoot flush resulted in greater total shoot growth (Gilliam and Wright, 1978). This result, coupled with the observation that root flushes preceded shoot flushes by 1 to 2 weeks in ‘Helleri’ holly (Mertens and Wright, 1978), indicates that N use efficiency could be improved by timing fertilizer applications to coincide with root growth.

The objectives of the present study were to determine the container solution N concentrations required to optimize citrus nursery plant growth. Additionally, uptake efficiency of FN at various plant growth stages was compared.

**Materials and Methods**

Citrus nursery plants were grown in 2-liter plastic containers using washed silica quartz sand. The water-filled pore space after saturation was ≈600 ml. The plants were grown in a fiberglass greenhouse under natural light averaging 1400 µmol·m−2·s−1 at the top of the shoot canopy on clear days and 165 µmol·m−2·s−1 on overcast days, as measured by a steady-state porometer (model LI-1600, LI-COR, Lincoln, Neb.). The average daily maxima were 29.2, 31.7, and 30.9°C and the average daily minima were 20.0, 23.2, and 21.9°C for Expts. 1, 2, and 3, respectively. The containers were covered with aluminum foil to prevent high root-zone temperatures and algal growth. Deionized water was used in all nutrient solutions, and NH₄NO₃ was the N source for all of the experiments. The pH of all nutrient solutions was adjusted to 6.3 with H₂SO₄.

**Response to N concentration (Expts. 1 and 2).** In Expt. 1, Cleopatra mandarin seedlings were budded with ‘Hamlin’ orange and the buds were forced on 13 Jan. 1991. In Expt. 2, Carrizo citrange seedlings were budded with ‘Hamlin’ orange and the buds forced on 18 May 1991. The buds were forced by cutting off the rootstock shoot 5 cm above the bud. The N treatments began the day that the buds were forced. Before beginning the experiment, the plants were maintained by applying fertilizer three times a week at 50 mg N/liter. At the beginning of the experiment, the containers were flushed with 1 liter of deionized water daily for 5 days to remove any pretreatment N. During Expt. 1, the plants were fertilized daily through drip rings with ≈1 liter of either 0, 12.5, 25, 50, 100, or 200 mg N/liter as NH₄NO₃ dissolved in a nutrient solution, while during Expt. 2, the plants were fertilized with ≈1 liter of either 0, 3.13, 6.25, 12.5, 25, or 50 mg N/liter as NH₄NO₃ dissolved in a nutrient solution. The nutrient solution contained (mg liter−1) 50 N as NH₄NO₃, 50 K and 10 P as KH₂PO₄ and K₂SO₄, 120 Ca as CaSO₄·2H₂O, 40 Mg as MgSO₄·7H₂O, 0.5 Mn as MnCl₂·4H₂O, 0.02 Mo as Na₂MoO₄·2H₂O, 0.02 Cu as CuSO₄·5H₂O, 0.05 Zn as ZnSO₄·7H₂O, 0.5 B as H₃BO₃, and 5 Fe as FeNaEDTA. For N analysis, samples were digested using a modification of the aluminum block-digestion procedure of Gallaher et al. (1975). Samples (0.25 g) were digested for 4 h at 400°C using 10 ml H₂SO₄ and 2 ml H₂O₂ and 3.2 g of 9 K₂SO₄; 1 CuSO₄ as a catalyst. Ammonia in the digestate was determined by semiautomated colorimetry (Hamilton, 1977).

Data were analyzed using the linear and quadratic regression models and the linear plateau procedure (SAS Institute, 1987). The linear plateau procedure was preferred over the linear and quadratic models because of smaller residual error and was used to determine critical N concentrations (Anderson and Nelson, 1975; Nelson and Anderson, 1977).

**Nitrogen uptake efficiency (Exp. 3).** ‘Hamlin’–Carrizo citrus nursery plants were greenhouse-grown in 2-liter plastic containers using washed silica quartz sand. The plants were fertigated every other day with a complete nutrient solution containing (mg liter−1) 50 N as NH₄NO₃, 50 K and 10 P as KH₂PO₄ and K₂SO₄, 120 Ca as CaSO₄·2H₂O, 40 Mg as MgSO₄·7H₂O, 0.5 Mn as MnCl₂·4H₂O, 0.02 Mo as Na₂MoO₄·2H₂O, 0.02 Cu as CuSO₄·5H₂O, 0.05 Zn as ZnSO₄·7H₂O, 0.5 B as H₃BO₃, and 5 Fe as NaFeEDTA. The plants were grown through two scion flushes under natural day light (average photoperiod of 12.2 h) supplemented with fluorescent and incandescent light (45 µmol·m−2·s−1 at top of plant canopy) to maintain daylength at 15 h. Twilight before sunrise and after sunset added ≈50 min to the natural light period.

Eight uniform plants were selected for the labeling experiments, based on overall shoot growth, from a population of plants during each of five growth stages: A) in the middle of rapid shoot extension of the third flush, B) immediately after the cessation of the third flush shoot extension but during leaf extension, C) immediately following leaf extension, D) before the fourth flush, and E) in the middle of rapid shoot extension of the fourth flush. The labeling periods for the different growth stages of each plant overlapped during September.

Labeling for the period of most rapid shoot extension of the third scion flush (A) and the fourth scion flush (E) began =10 days after flush initiation. The labeling for the leaf expansion period (B) began when the length of the shoot was the same for 2 consecutive days. Leaf expansion took ≈11 days. Labeling for the period following leaf expansion (C) began on day 12 after the end of shoot extension. Labeling for the period before the fourth scion flush (D)
began on day 19 after shoot extension of the third scion flush ceased. The time between the cessation of shoot extension of the third scion flush and the beginning of the fourth scion flush averaged 31 days. The medium was flushed first with deionized water and then with 1 liter of the nutrient solution minus the NH\textsubscript{4}NO\textsubscript{3} during the regular fertigation 2 days before beginning the treatment. Labeled FN (4.5 mmol per container as \textsuperscript{15}NH\textsubscript{4}NO\textsubscript{3}; 10.8 atom % abundance \textsuperscript{15}N; ISOTEC, Miamisburg, Ohio) was dissolved in the regular nutrient solution minus the standard NH\textsubscript{4}NO\textsubscript{3} and supplied to the plants in three doses during the labeling period. About 45% of the \textsuperscript{15}N was applied on day 0, and 55% was split and applied on days 3 and 5. Plants were given nutrient solution, without any NH\textsubscript{4}NO\textsubscript{3}, to bring them to container water holding capacity on days they did not receive the labeled fertilizer solution. Any leachate was collected and reapplied. Additional plants were maintained on the standard fertilization regime to monitor growth stage development and to provide control atom percentage \textsuperscript{15}N abundances. Plants were harvested on day 7, washed with deionized water, and divided into fine roots (≤1 mm in diameter), structural roots (>1 mm in diameter), rootstock trunk, first and second scion flush leaves, third scion flush stem, third scion flush leaves, fourth scion flush stem, and fourth scion flush leaves. All plant parts were dried to a constant weight at 70°C and dry weights were measured. The six most uniform plants, based on total plant dry weight, were selected and ground to pass a 60-mesh screen. Total N and \textsuperscript{15}N were determined by mass spectrometry. The following equation adapted from Cabrera and Kissel (1989) and Hauck and Bremner (1976) was used to determine the milligrams of FN absorbed:

\[
\text{Total mg FN absorbed} = \text{mg FN applied} \times \frac{p(a - c)}{f(b - c)}
\]

where,

- \(p\) = moles of N in the plant,
- \(f\) = moles of N in the fertilizer,
- \(a\) = atom % \textsuperscript{15}N abundance in the plant,
- \(b\) = atom % \textsuperscript{15}N abundance in the fertilizer, and
- \(c\) = atom % \textsuperscript{15}N abundance in control plants (0.368 atom % abundance).

**Results and Discussion**

**Response to N concentration.** Overall scion growth rates were higher in Expt. 2 than Expt. 1, probably because of higher average greenhouse temperatures. In general, dry weights of the various plant parts increased as N concentrations increased up to a critical concentration before plateauing (Figs. 1 and 2). In both experiments, an increase in FN concentration resulted in a greater increase in shoot dry weight than in root dry weight, resulting in a higher shoot : root ratio (Table 1). This result agrees with work done on barley (Hordeum vulgare L.), corn (Zea mays L.), rye...
(Lolium perenne L.), and clover (Trifolium repens L.), in which the shoot : root ratio increased as N concentrations increased (Brouwer, 1965; Davidson, 1969; Turner, 1922). Increases in the shoot : root ratio were attributable to less root growth with high FN concentrations, a proportionately greater increase in shoot growth, or both. Yeager and Wright (1981) found that shoot dry weight of ‘Helleri’ holly plants increased when fertilized weekly at 300 mg N/liter compared to plants fertilized with 50, 100, or 200 mg N/liter; however, plants fertilized with 50 mg N/liter had higher root dry weights than plants receiving 100, 200, or 300 mg N/liter. In Expt. 1, there was an 18% decrease in total dry weight (25% decrease in root dry weight, 14.5% decrease in shoot dry weight) at 200 mg N/liter compared to 100 mg N/liter (data not shown).

From this study, we conclude that the critical N concentration in the media solution for dry weight accumulation was 15 to 19 mg·liter⁻¹. In Expt. 1, the critical concentrations for root, shoot, and total dry weight were 18.5, 18.7, and 18.6 mg N/liter, respectively (Fig. 1). In Expt. 2, these concentrations were 15.9, 15.0, and 15.2 mg N/liter, respectively (Fig. 2). Relative total dry weight accumulation (percentage) for Expts. 1 and 2 were obtained by dividing each total dry weight treatment mean within a block by the maximum treatment mean within that block and multiplying by 100. Relative dry weight accumulation was then related to the N treatment concentration maintained in the medium solution resulting in a critical concentration of 16.0 mg N/liter (Table 1). Scion length followed a trend similar to leaf area. Total scion length in Expt. 1 increased as FN concentrations increased, plateauing at 16.2 mg·liter⁻¹, while in Expt. 2, the critical FN concentration was 8.6 mg·liter⁻¹ (Table 1).

In both experiments, the percentage of N in the roots and mature scion leaves at harvest increased as medium solution N concentrations in the container increased, with these critical N concentrations (Table 2) being much higher than for any of the other growth characteristics (Table 1). Data for flushes that included some immature growth (i.e., flush 3) were more variable. However, the increase in percentage of N in the tissue did not necessarily mean an increase in plant growth, especially at high FN concentrations, when luxury consumption may have occurred.

Container media solution N concentrations are related to but different from the application concentration. Media solution N concentrations increased from 0 to 12.5 mg·liter⁻¹, before reaching a plateau (Table 1). In Expt. 1, the critical concentration for total leaf area was 17.8 mg N/liter, while in Expt. 2, it was 13.8 mg N/liter (Table 1).

The critical N concentration varies with plant species. Rough lemon plant growth was not increased by FN concentrations above 25 mg·liter⁻¹ (Lea–Cox, 1989). No differences in plant dry weight were found above 50 mg N/liter for Cotoneaster dammeri C.K. Scheid., Pyracantha coccinea Roem., and Weigela florida Bunge plants grown in sand culture (Gilliam et al., 1980). ‘Helleri’ and ‘Burfordi’ holly (Ilex cornuta Lindl. et Paxt.) shoot growth was not significantly increased by weekly FN concentrations above 300 mg N/liter (Gilliam and Wright, 1977).

Total leaf area in Expt. 1 increased as FN concentrations increased from 0 to 25 mg·liter⁻¹ then plateaued before decreasing at 200 mg N/liter (Table 1). This trend was due to an increase in leaf area for scion flushes 2 and 3 as leaf area for scion flush 1 was similar for the various N concentrations (data not shown). In Expt. 2, leaf areas for all scion flushes and total leaf area increased as FN concentrations increased from 0 to 12.5 mg·liter⁻¹, before reaching a plateau (Table 1). In Expt. 2, the critical concentration for total leaf area was 17.8 mg N/liter, while in Expt. 2, it was 13.8 mg N/liter (Table 1).

<table>
<thead>
<tr>
<th>N concn (mg·liter⁻¹)</th>
<th>Total leaf area (cm²)</th>
<th>Total dry wt (g)</th>
<th>Shoot : root ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>204</td>
<td>0.82</td>
<td></td>
</tr>
<tr>
<td>3.13</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6.25</td>
<td>---</td>
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</tr>
<tr>
<td>12.5</td>
<td>1396</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1762</td>
<td>1.86</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>1930</td>
<td>1.92</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2081</td>
<td>2.05</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>1832</td>
<td>2.29</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1. Growth of 30-week-old ‘Hamlin’–Cleopatra (Expt. 1) and 17-week-old ‘Hamlin’–Carrizo (Expt. 2) citrus nursery plants as affected by solution N concentrations.**

**Fig. 3. Final relative total dry weight yield (percent) of containerized ‘Hamlin’–Cleopatra and ‘Hamlin’–Carrizo nursery plants as affected by container solution N concentrations (Expts. 1 and 2).** R² Value is based on all of the data and is for the entire model; CL = critical N concentration. Data points shown are the means of four plant replications per block.
concentrations will vary depending on the amount of fertilizer applied, the type of potting medium, irrigation, and leaching. Desired N concentrations can be maintained by varying the application concentration, the frequency of application, the amount applied, or by combining N from different sources such as soluble fertilizer, controlled release fertilizer, or granular fertilizer.

Low concentrations of N in the medium solution (i.e., 19 mg·liter⁻¹) were equally as effective in promoting growth as higher concentrations (i.e., 50 to 100 mg·liter⁻¹). Excessively high rates of N (i.e., 200 mg·liter⁻¹) reduced total growth, with the largest percentage of that reduction being in the roots. It is proposed that lower N fertilization concentrations in the nursery may increase transplant adaptation in the field while optimizing total plant growth. Further, lower fertilization concentrations will reduce the potential for groundwater contamination.

Nitrogen uptake efficiency. Whole-plant uptake of applied FN was higher during rapid shoot extension of the fourth scion flush (Table 3) than during the other labeling periods, when whole-plant uptake was similar. Recovery of applied FN was 48% to 70%, depending on the application period. The increased uptake at the latest sampling time may indicate that the potential for FN uptake increases with plant size (Ingestad, 1977, 1982) or with the specific growth stage. FN uptake per gram of total plant dry weight was higher and about equal during rapid shoot elongation (A and E) than during the intermediate labeling periods (B–D) (Fig. 4). These findings seem to contradict previous reports indicating that N uptake decreased during rapid shoot elongation (Chapman and Parker, 1942; Gilliam and Wright, 1978; Hershey and Paul, 1983).

Table 3. Distribution of applied fertilizer N in various organs of containerized ‘Hamlin’–Carrizo nursery plants during rapid shoot extension of the third scion flush (A), leaf expansion (B), after leaf expansion (C), before a shoot growth cycle of the fourth scion flush (D), and rapid shoot extension of the fourth scion flush (E) (Expt. 3).z

<table>
<thead>
<tr>
<th>Plant part</th>
<th>Fertilizer N (mg)</th>
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<th></th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td></td>
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<tr>
<td>Leaves</td>
<td></td>
<td></td>
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<tr>
<td>Fourth flush</td>
<td>20.2 a</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Third flush</td>
<td>9.0 a</td>
<td></td>
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<td></td>
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<tr>
<td>First and second flush</td>
<td>5.1 a</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Stem</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Fourth flush</td>
<td>5.1 a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third flush</td>
<td>3.6 a</td>
<td></td>
<td></td>
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<tr>
<td>First and second flush</td>
<td>3.0 a</td>
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<tr>
<td>Trunk</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Fine</td>
<td>24.6 c</td>
<td></td>
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<td></td>
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<tr>
<td>Structural</td>
<td>5.0 c</td>
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<td></td>
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<tr>
<td>Whole plant</td>
<td>70.4 b</td>
<td></td>
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</tbody>
</table>

zEach number represents the mean of six plants. Data were taken at the end of the 7-day labeling period.

Fig. 4. Fertilizer N (FN) uptake per gram of total plant dry weight in containerized ‘Hamlin’–Carrizo nursery plants during rapid shoot extension of the third scion flush (A), leaf expansion (B), after leaf expansion (C), before a shoot growth cycle of the fourth scion flush (D), and rapid shoot extension of the fourth scion flush (E). Each bar represents the mean of six plants. Mean separation by Ryan–Einot–Gabriel–Welsh’s multiple range test, P ≤ 0.05.
Examining the roots at harvest in our study indicated that root and shoot growth periods may overlap. Roots of plants harvested after labeling during rapid shoot extension of the third flush had many new, white roots. During leaf expansion, the roots were darker, indicating very little new growth. After the leaf expansion period, the roots were dark brown with very little new growth. In the period just before the fourth flush, most of the roots were brown, but white tips were emerging from the old roots and from the rootstock just below the soil line. During the fourth scion shoot flush, there were many new tan and white roots evident. Waynick and Walker (1930) noted that root growth of grapefruit (Citrus paradisi Macf.), lemon, and ‘Valencia’ orange trees of various ages preceded shoot growth early in the growing season, but overlapped in the fall growth cycle. Marloth (1949) observed a general trend toward alternation in periodicity of root growth and shoot growth in rough lemon and sweet orange seedlings and budlings in South Africa, but with large variations. In a study with 30-year-old ‘Valencia’—sweet orange trees, the two cycles of root growth that occurred during the growing season completely overlapped shoot extension cycles (Schneider, 1952).

Although root and shoot growth of citrus alternates at times (Bevington and Castle, 1985; Marloth, 1949), in our study, root growth apparently overlapped shoot growth. Therefore, it would be difficult to time fertilizer application according to shoot growth cycles in citrus nursery plants.

Most of the FN taken up by the plants remained in the fine roots during all of the labeling periods (P ≤ 0.05) (Table 3). The amount of labeled FN in the fine roots was higher during leaf expansion (B), after leaf expansion (C), and before the fourth scion flush (D) than during rapid shoot extension of the third scion flush (A). There was a shift in partitioning of absorbed FN as its percentage partitioned to the fine roots increased from 35% during rapid growth of the third scion flush to 54% during leaf expansion, 58% after leaf expansion, and 63.5% before the fourth scion flush (P ≤ 0.05). The portion of FN in the fine roots then decreased to 44% during rapid growth of the fourth scion flush. During rapid shoot extension, the rapidly growing flush received the second highest amounts of FN. The amount of FN partitioned to the first, second, and third scion flush leaves decreased during leaf expansion (A–B) (Table 3).

FN supplied only part of the N required for new growth during the labeling periods of rapid shoot extension (Table 4). Although 35.8% of the FN absorbed during rapid shoot extension of the third scion flush went to the new flush, it supplied only ~21% of the N required. While 21% of the FN absorbed during the fourth scion flush went to the new flush, FN supplied only 22% of the N required. Thus, ~78% of the N required in the rapidly growing shoot came from N reserves in other plant parts. This dependency on N reserves is similar to that exhibited by 22-year-old ‘Shamouti’ orange trees in which 79% of new spring growth N came from previously assimilated N (Feigenbaum et al., 1987). In 4-year-old calamondin (Citrus mitis Bl.) trees, recently absorbed N contributed less than 16% of the N required for new spring leaves (Legaz et al., 1982). Containerized citrus nursery plants absorb N during all stages of their growth cycles. The data from this experiment suggest that there are differences that may coincide with root or shoot growth cycles or both. FN uptake per gram of total plant dry weight was greatest during the periods of rapid shoot extension but since the root growth cycle overlapped the shoot growth cycle, it was unclear whether the root or shoot growth cycle was more influential.

FN uptake and plant growth of containerized citrus nursery plants are influenced by many factors. More work needs to be done with containerized citrus nursery plants to clarify the relationship between increased FN uptake and growth cycles. However, low N concentrations in the medium solution (i.e., 19 mg·liter–1) were effective in promoting optimum growth through three scion flushes and may reduce potential FN losses.

### Literature Cited


### Table 4. Contribution of labeled fertilizer N (FN) to the N demands of new growth of the third and fourth scion flush in containerized ‘Hamlin’–Carrizo nursery plants (Expt. 3).2

<table>
<thead>
<tr>
<th>Scion flush</th>
<th>N source</th>
<th>N content (mg)</th>
<th>Percentage in new growth a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third</td>
<td>FN</td>
<td>25.2 (21%)</td>
<td>70.4 (10%)</td>
</tr>
<tr>
<td></td>
<td>Reserve N</td>
<td>95.5 (79%)</td>
<td>641 (90%)</td>
</tr>
<tr>
<td></td>
<td>Total N</td>
<td>119.7</td>
<td>711.4</td>
</tr>
<tr>
<td>Fourth</td>
<td>FN</td>
<td>17.7 (22%)</td>
<td>85.7 (11%)</td>
</tr>
<tr>
<td></td>
<td>Reserve N</td>
<td>62.2 (78%)</td>
<td>678 (89%)</td>
</tr>
<tr>
<td></td>
<td>Total N</td>
<td>79.9</td>
<td>764.1</td>
</tr>
</tbody>
</table>

2Each value represents the mean of six plants.

1Includes stems and leaves.

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| Table 4. Contribution of labeled fertilizer N (FN) to the N demands of new growth of the third and fourth scion flush in containerized ‘Hamlin’–Carrizo nursery plants (Expt. 3).2

<table>
<thead>
<tr>
<th>Scion flush</th>
<th>N source</th>
<th>N content (mg)</th>
<th>Percentage in new growth a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Third</td>
<td>FN</td>
<td>25.2 (21%)</td>
<td>70.4 (10%)</td>
</tr>
<tr>
<td></td>
<td>Reserve N</td>
<td>95.5 (79%)</td>
<td>641 (90%)</td>
</tr>
<tr>
<td></td>
<td>Total N</td>
<td>119.7</td>
<td>711.4</td>
</tr>
<tr>
<td>Fourth</td>
<td>FN</td>
<td>17.7 (22%)</td>
<td>85.7 (11%)</td>
</tr>
<tr>
<td></td>
<td>Reserve N</td>
<td>62.2 (78%)</td>
<td>678 (89%)</td>
</tr>
<tr>
<td></td>
<td>Total N</td>
<td>79.9</td>
<td>764.1</td>
</tr>
</tbody>
</table>

2Each value represents the mean of six plants.

1Includes stems and leaves.
HortScience 13:300–301.


