Date of Potting and Fertilization Affects Plant Growth, Mineral Nutrient Content, and Substrate Electrical Conductivity[1]

R. Lee Ivy[2], Ted E. Bilderback[3], and Stuart L. Warren[3]
Department of Horticultural Science
North Carolina State University, Raleigh, NC 2769-7609

Abstract

The landscape industry uses containerized plant material throughout the year. Thus, traditional spring potting at many nurseries has changed to potting throughout the year. The objective of this study was to determine the effect of potting date and rate of fertilization on plant growth and mineral nutrient content, substrate electrical conductivity (EC) and pH, and winter injury. To complete this objective, rooted stem cuttings of *Ilex crenata* Thunb. 'Compacta' and *Viburnum awabuki* K. Koch. 'Chindo' were potted in Raleigh, NC, July 17, 1998; September 7, 1998; October 29, 1998; March 25, 1999; and May 13, 1999. Two controlled-release fertilizers [Wilbro/Polyon 15N–1.8P–7.5K (15N–4P_2O_5–9K_2O) and Scotts 23N–1.8P–6.6K (23N–4P_2O_5–8K_2O)] were applied at four rates: a split application with 0.5X incorporated at potting and surface application of the remaining 0.5X six months after potting date [X = manufacturers' recommended rate per 3.8 liter (4 qt) container], and 1X, 1.5X, and 2X incorporated at potting. Plant growth and mineral nutrient content were determined one year after initial potting date. Substrate EC and pH were measured monthly. 'Compacta' holly and 'Chindo' viburnum potted in September or October were larger than plants potted in March regardless of fertilizer and rates of fertilization. In general, holly and viburnum were smaller when fertilized with 0.5/0.5X compared to 1X regardless of fertilizer and date of potting. Within each rate of fertilization, viburnum potted in September had significantly greater N and P content compared to viburnum potted in March or May. Nitrogen and P content were highly correlated to plant dry weight ($r > 0.79$, $P = 0.0001$). Mineral nutrient content of holly responded similarly. No plants were injured by winter temperatures regardless of potting date or rate of fertilization throughout the study period. Plants potted in July, September, or October had the highest substrate EC values in March, whereas plants potted in March or May had highest EC values in August regardless of species, fertilizer or rate of fertilization. Substrate pH was unaffected by date of potting, but pH decreased with increasing rates of fertilization.

Index words: *Ilex crenata*, *Viburnum awabuki*, pH, mineral nutrition, container culture, controlled-release fertilizer, containerized plant production.

Significance to the Nursery Industry

Nursery managers desire to produce a high quality plant throughout the year. Information concerning rates of fertilization and their interaction with potting date can aid in achieving this goal. Growers have been cautioned about applying fertilizer in the fall. However, concerns over winter injury to 'Compacta' holly and 'Chindo' viburnum fertilized with typical rates of fertilization and grown in Raleigh, NC, may be unfounded regardless of time of potting. If this applies to many other woody species is not known. Furthermore, based on our growth data, growers should apply the full rate of fertilizer at potting regardless of time of potting. Plants potted in the late summer/fall outperformed all other potting times. Therefore, growers may want to incorporate more fall potting in lieu of traditional spring potting.

Introduction

In a recent survey of containerized nurseries in the southeastern United States, 100% used controlled-release fertilizers (CRFs) as their primary source of fertilizer (7). While CRFs offer some advantages compared to liquid fertilization, there are problems associated with use of CRFs, e.g., nutrient release from CRF may not match plant mineral nutrient demand. Relatively high rates of nutrient release may occur at the beginning of the growing season when recently potted plants are small and their nutrient demands are low (26). In addition, at this time woody plants absorb few nutrients due to a very limited root system. Later in the season when the CRF may be nearing depletion, the reverse is true; larger plants need more N and absorb it more efficiently with a root system that has exploited much of the container volume. Thus, with traditional spring potting, it is difficult to match CRF release rate and woody plant nutrient needs.

The most common approach to improve plant growth when using CRFs is to change the CRF release rate so it meets plant nutrient needs (4, 11,19). Traditional CRF research has been conducted on plants potted in spring for fall evaluation (3, 11, 15, 20, 28). An alternative approach to improve effectiveness of CRFs would be to match woody plant nutrient needs to current CRF release patterns. This might be done by varying the date of potting.

Most woody plants exhibit cyclical patterns of top and root growth. However, it may not be as simplistic as proposed previously, i.e., root growth is biphasic, with peaks in spring or early summer and fall. Bevington and Castle (1) reported that root growth of 'Valencia' orange [*Citrus sinensis* (L.) Osb.] trees was cyclic when soil temperature and water were not limiting, i.e., it consistently alternated with periods of top growth. Research by Harris et al. (10), working with four trees in New York, reported root growth occurred throughout the growing season. Patterns of root growth are highly dependent upon species and environment. Container-grown

[1]Received for publication November 7, 2001; in revised form February 8, 2002. This research was funded, in part, by Wilbro Inc., Norway, SC 29113. Special thanks to William H. Swallow for statistical guidance and Mary Lorscheider and William Reece for technical assistance. From a thesis submitted by R.L.I. in partial fulfillment of the requirements for the M.S. degree.

[2]Former Graduate Teaching Assistant.

[3]Professor.

plants may produce fewer roots during the growing season due to high container temperatures. Martin and Ingram (12) reported that root growth of southern magnolia (*Magnolia grandiflora* Hort.'St. Mary') was reduced by 46% after being exposed to 42C (108F) for 6 hr daily for 6 weeks compared to 34C (93F). Since substrate temperatures can exceed 42C for many hours each day during the summer (22), root growth of containerized plants may predominate in spring and late summer/early fall. Rose and Biernacka (17) reported that container-grown Freeman maple (*Acer* x *freemanii*) nearly doubled their root dry weight between early September and October. In addition, Rose et al. (18) found notable gains in root biomass and a corresponding decrease in top:root ratios in the fall with 'Jefferred' maple (*Acer* x *freemanii* E. Murray 'Jefferred') and 'Calocarpa' crabapple [*Malus* x *zumi* (Rehd.) 'Calocarpa']. Bilderback et al. (2) reported that root dry weight of containerized *Cotoneaster dammeri* 'Skogholm' increased 391% from August to October. Yeager et al. (28) proposed that the plant's nutrient needs were highest during periods of active root growth. In addition, Rose and Biernacka (17) suggested an application of fertilizer in late summer or early fall may be utilized by the plant more efficiently than an application earlier in the season. Therefore, potting plants in late summer through fall when growth of roots may be high and CRF release rate is reduced due to lower temperatures may be a better match for CRF and woody plants.

Another approach to increasing CRF efficiency may be to split the fertilizer into two applications. Ruter (19) suggested using split applications to improve fertilizer longevity and subsequent nutrient availability.

Applying fertilizer other than during spring/early summer raises concerns about the effect of late season fertilization on woody plant susceptibility to winter injury. The supposition that high fertility levels, especially N, induce plants to continue growth into the fall and delays natural maturity development is well entrenched in the literature. This delayed maturity is believed to predispose plants to greater risk of winter injury. Wright and Niemiera (26) suggested reducing fertilizer applications in late summer and fall to about one-half that of summer applications to support cold acclimation. However, the influence of supplemental or untimely inputs of N on cold tolerance of woody plants has not been established conclusively (6). After critically reviewing the literature, Pellet and Carter (14) stated that most plants fertilized at levels that promote optimum growth will cold acclimate at a similar rate and to the same degree as plants grown under a lower fertility regime regardless of location. This suggests that concerns with lack of cold acclimation due to fall fertilization may be unfounded.

With growth of the landscape industry, containerized plant material is in demand throughout the year. Traditional spring potting at many nurseries has been replaced with potting throughout the year. More information is needed on how time of potting affects growth of woody plants in conjunction with differing rates of fertilization and subsequent cold acclimation. Therefore, the objective of this study was to determine the effect of potting date and rates of fertilization on plant growth and mineral nutrient content, substrate EC and pH, and winter injury.

Materials and Methods

A split-split plot experiment, in a randomized complete block design with 5 replications and two species, *Ilex crenata* 'Compacta' and *Viburnum awabuki* 'Chindo', was conducted at Horticulture Field Laboratory, North Carolina State University, Raleigh, from July 1998 to May 2000. The plant production area was a gravel pad. Potting dates of main plots were July 17, 1998; September 3, 1998; October 29, 1998; March 25, 1999; and May 13, 1999. Within each main plot were two subplots consisting of one of two CRFs: 15N–1.8P–7.5K (Wilbro/Polyon 15N–4P_2O_5–9K_2O, 12 month, Wilbro, Inc., Norway, SC, and Pursell Technologies, Sylacauga, AL) supplied by polymer-coated ammonium nitrate, ammonium phosphate, and potassium sulfate; and 23N–1.8P–6.6K (Scotts 23N–4P_2O_5–8K_2O Southern formulation, 12 month, The Scotts Co., Marysville, OH) containing polymer-coated urea, ammonium nitrate, ammonium phosphate, calcium phosphate, and potassium sulfate. Within each subplot were four sub-subplots with one of four rates of fertilization: a split application with 0.5X incorporated at potting and surface application of the remaining 0.5X six months after potting date [X = manufacturers' recommended rate per 3.8 liter (4 qt) container, Wilbro 15–4–9 X = 27 g (0.95 oz), Scotts 23–4–8 X = 22 g (0.78 oz)], 1X, 1.5X and 2X. Fertilizers were weighed for each container and incorporated into the substrate before transplanting. Rates above 1X (1.5X and 2X) were included to test effects of increased rates of fertilization on winter injury and not an attempt to increase growth.

Rooted stem cuttings were potted into 3.8 liter (# 1) containers in a pine bark :sand (8:1 by vol) substrate amended with 2.3 kg/m^3 (5 lbs/yd^3) dolomitic limestone. To assure that rooted stem cuttings were similar age and size at each potting date, cuttings were taken and rooted at the appropriate time for each potting date. Plants fertilized with Wilbro 15–4–9 were amended with Booster micronutrient fertilizer (Wilbro/Polyon, Inc.) at 2.2 g (0.078 oz)/container. Plants fertilized with Scotts 23–4–8 were amended with MicroMax micronutrient fertilizer (The Scotts Co.) at 3.3 g (0.12 oz)/container. Rates were based on two hundred seventy-five 3.8 liter containers/m^3 (two hundred ten 4 qt containers/yd^3).

Each plant was irrigated with a cyclic application from individual spray stakes {Acu-Spray Stick; Wade Mfg. Co., Fresno, CA [200 ml/min (0.3 in/min)]} and leaching fraction was monitored biweekly to maintain levels between 0.2 and 0.4. From November through February, plants were irrigated as needed. Plants were overwintered from December to February under white row covers (Pak Unlimited, Inc., Cornelia, GA).

One year after potting, tops of both species were removed and roots were placed over a screen and washed with a high pressure water stream to remove substrate. Plant tissues of each species were dried at 65C (150F) for 7 days and weighed. After drying, roots and tops were ground separately in a Wiley mill to pass a 40-mesh (0.425-mm) screen. Tissue samples (1.25 g) were combusted at 490C (914F) for 6 hr. The resulting ash was dissolved in 10 mL (0.03 oz) 6 N HCl and diluted to 50 mL (1.5 oz) with deionized water. Phosphorus and K concentrations were determined by inductively coupled plasma emission spectrophotometer (P–2000 Perkin-Elmer, Norwalk, CT). Nitrogen was determined using 10 mg (0.03 oz) samples in a CHN elemental analyzer (PE 2400, Perkin-Elmer). Mineral nutrient content was determined by multiplying plant part dry weight by nutrient concentration expressing each nutrient in grams. Top mineral nutrient content and root mineral nutrient content were combined for total plant mineral nutrient content. Total plant mineral nutri-

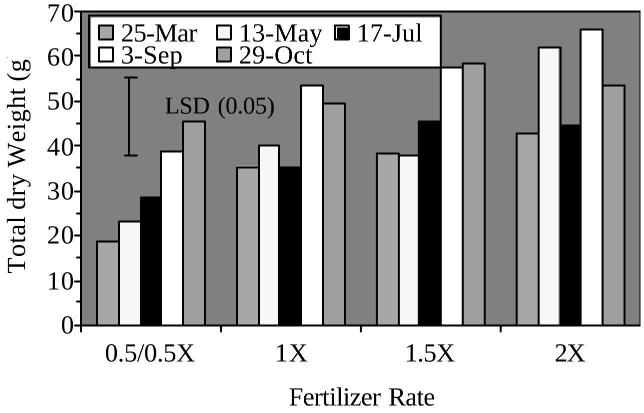

Fig. 1. Effect of fertilizer rate and potting date on total dry weight of *Ilex crenata* 'Compacta'. LSD can be used to separate potting dates within rates of fertilization or rates of fertilization within potting date.

ent content was used to calculate percentage nutrient recovery [(plant nutrient content ÷ nutrient applied) × 100].

At each potting date, 10 representative plants were harvested, dried, weighed, and ground for N, P, and K analysis as described previously. These initial weights and mineral nutrient contents were subtracted from the final dry weight and nutrient content of each species for each potting date prior to statistical analysis.

Substrate solution was collected from containers of holly and viburnum via the pour-through nutrient extraction method (25) every 30 days after potting until harvest. The solution sample was obtained by pouring 120 mL (4.1 oz) of distilled water on the substrate surface 2 h after irrigation and collecting the leachate. Solution EC and pH were measured with an Accumet meter (Fisher Scientific Co., Fairlawn, NJ). Irrigation water was also collected monthly. EC of irrigation water averaged 0.18 dS/m with a pH of 6.8.

Data were subjected to analysis of variance procedures (ANOVA). Mean separations were performed via least significant difference (LSD) procedures at $P = 0.05$. Regression analysis was not conducted on fertilizer rates since the split application (0.5X at potting with 0.5X applied 6 months later) was not a quantitative factor (personal communication, William H. Swallow, Dept. of Statistics, NC State University).

Results and Discussion

Plant growth. Top, root, and total (top + root) dry weight of 'Compacta' holly responded similarly to potting date, fertilizer, and rates of fertilization so only total plant dry weight is presented. The potting date X rate of fertilization interaction was significant. Fertilizer and all other interactions did not significantly affect total dry weight of holly. Maximum growth for plants fertilized with 0.5X/0.5X occurred when potted in September and October (Fig. 1). Hollies potted in October were 59% and 49% larger than hollies potted during the spring months of March and May, respectively, supporting the hypothesis that plant growth may be improved by matching date of potting with CRF release characteristics. Hollies grown with the split application of fertilizer (0.5X/0.5X) performed poorly compared to hollies grown with the 1X rate of fertilization when potted in March and May. Colangelo and Brand (5) also reported no growth benefits from a split application of fertilizer.

With the 1X and 1.5X rates of fertilization, hollies potted in September and October outperformed all other potting dates excluding July with 1.5X (Fig. 1). With the 2X rate of fertilization, plants potted in September were significantly larger than all other potting dates except May.

Increasing rates of fertilization did not necessarily increase plant growth. Within each date of potting, hollies fertilized with 1.5X and 2X were never significantly larger than 1X except for plants potted in May and fertilized with 2X which were 35% larger than 1X. However, the economic and environment impact must be considered.

No plants were injured by winter temperatures regardless of potting date or rate of fertilization throughout the study period (data not presented). Air temperatures during the period of research had lowest values of –8.3C (17F) in January 1999 and –10C (14F) in January 2000. These are average lows for the Raleigh, NC, area. This supports Pellet and Carter's (14) recommendation that rates of fertilization do not need to be reduced in the fall due to concerns with winter injury. DeHayes et al. (6) reported that field-grown red spruce (*Picea rubens* Sarg.) trees receiving late summer/early fall N applications acclimated to cold more rapidly in autumn and deacclimated more slowly in spring compared to nonfertilized trees. Goatley et al. (8) also reported that late growing season N applications to bermudagrass (*Cynodon dactylon*) did not increase winterkill potential.

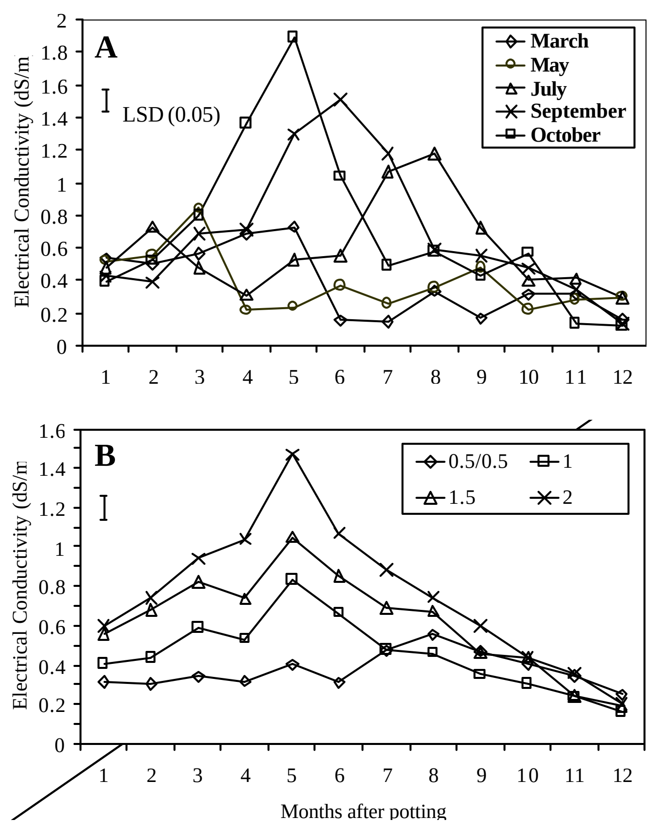

Fig. 2. A. Effect of months after potting and potting date on EC substrate values for *Viburnum awabuki* 'Chindo'. B. Effect of months after potting and rate of fertilization on EC substrate values for *Viburnum awabuki* 'Chindo'.

Table 1. Effect of fertilizer and fertilizer rate on total dry weight of *Viburnum awabuki* 'Chindo'.

Fertilizer rate	Fertilizers	
	Scotts 23–4–8	Wilbro 15–4–9
	g	
0.5/0.5X	44.9b	21.4b
1.0X	57.0a	30.4a
1.5X	53.1ab	33.1a
2.0X	55.6ab	37.8a

[z]Means within each fertilizer followed by the same letter or letters are not significantly different as determined by LSD, $P = 0.05$.

Top, root, and total (top + root) dry weight of 'Chindo' viburnum also responded similarly to potting date, fertilizers, and rates of fertilization, so only total plant dry weight is presented. The fertilizer × rate of fertilization and fertilizer × date of potting interactions were significant. All other interactions were nonsignificant. The 1X rate of 23–4–8 and 15–4–9 fertilizer resulted in a 27% and 42% increase, respectively, in total dry weight compared to the split application (0.5X/0.5X) (Table 1). There were no differences between the 1X, 1.5X, and 2X rates of fertilization for 23–4–8 or 15–4–9. Thus, for viburnum a split fertilizer application reduced growth and there were no growth advantages to increasing rates of fertilization above the 1X rate. Viburnums fertilized with 23–4–8 were larger than plants fertilized with 15–4–9 regardless of fertilizer rate. However, since the manufacturers' recommended rate was selected to determine our 1X rate, this resulted in 5.1 g N and 4.0 g N applied to each container for 23–4–8 and 15–4–9, respectively. The difference in growth may be attributed to the higher N input from 23–4–8.

'Chindo' viburnum potted in September produced the largest total dry weight compared to all other potting dates when fertilized with 15–4–9, whereas plants potted in March were the smallest (Table 2). Viburnum potted in July, September, and October and grown with 23–4–8 dramatically outperformed those potted in March or May. Even though viburnum potted in September and October did not produce new top growth prior to dormancy, based on previous research (1, 9, 10) it can be assumed that root weight increased substantially. Previous work (13, 24) demonstrated that most N used in new top growth is mobilized from storage and/or absorbed prior to the growth flush. Utilization of stored N in the spring after fall potting may produce a much bigger growth flush compared to plants that are potted in spring with minimal stored N and limited ability to absorb N prior to the spring growth flush (23). This is supported by Robinson and Hamilton (116) who suggested spring vegetative growth may be increased by fall fertilization but the impact on winter injury was unknown. In this study, viburnum was not injured by winter temperatures regardless of potting date or rate of fertilization throughout the study period (data not presented). This also supports the conclusions reached by Pellet and Carter (14) that late summer/fall fertilization will not interfere with cold acclimation and promote subsequent winter injury.

Table 2. Effect of fertilizer and date of potting on total dry weight of *Viburnum awabuki* 'Chindo'.

Potting date	Fertilizers	
	Scotts 23–4–8	Wilbro 15–4–9
	g	
March 25	27.9b	16.0c
May 13	35.2b	35.0ab
July 17	64.3a	31.4b
September 3	72.4a	46.8a
October 29	63.3a	24.1b

[z]Means within each fertilizer followed by the same letter or letters are not significantly different as determined by LSD, $P = 0.05$.

Plant mineral nutrient content. Nitrogen, P, and K content of 'Compacta' holly and 'Chindo' viburnum were unaffected by fertilizer and all interactions except potting date × rate of fertilization. In addition, N, P, and K content of both species fertilized with 1X and 1.5X had few differences between potting dates. Therefore, only 0.5/0.5X, 1X, and 2X of 'Chindo' viburnum are presented (Table 3). With the split application of fertilizer, viburnum potted in September and October had significantly greater N, P, and K content compared to viburnum potted in March and May. This is also reflected in the percentage nutrient recovery as N increased from 11% to 21%, P from 10% to 24%, and K from 21% to 42% for March and September potting dates, respectively. Struve (21), working with red oak (*Quercus rubra*), reported N, P, and K recovery rates of 4% to 9%, 5% to 9%, and 4% to 17%, respectively depending upon treatments. Yeager (27), working with yaupon holly (*Ilex vomitoria*), reported recovery rates of 33% to 55%, 20% to 42%, and 35% to 75% for N, P, and K, respectively. Differences in species, fertilizer, substrate, and irrigation management would affect nutrient recovery. Nitrogen, P, and K content were highly correlated to plant dry weight ($r > 0.79$, $P = 0.0001$).

When fertilized with 1X, viburnum potted in September had significantly greater N, P, and K content compared to all other potting dates. Nitrogen and P content were highly correlated to plant dry weight ($r > 0.85$, $P = 0.0001$). Struve (21) also reported that tree growth was highly correlated to N content. Even though there were differences in plant dry weight between the split application and 1X, N and K content between the split application and 1X were similar regardless of potting date. Percentage nutrient recovery was also similar for plants potted in July, September, and October.

When fertilized with 2X, viburnum potted in September had significantly greater N and P compared to viburnum potted in March and May. Viburnum fertilized with 2X had significantly lower N, P, and K percentage recovery compared to 1X regardless of potting date (excluding March).

Electrical conductivity. EC was significantly affected by potting date and rate of fertilization, however fertilizer and all interactions were nonsignificant. Substrate EC values averaged over the year for viburnum potted in March, May, July, September, and October were 0.38, 0.38, 0.60, 0.69, and 0.69 dS/m, respectively. Substrate EC values for holly produced similar results (data not presented). To facilitate comparisons among potting dates and monthly EC values, EC values were plotted by months after potting (MAP) for each potting date for viburnum (Fig. 2A). Viburnum substrate EC values peaked 5 MAP, 3 MAP, 8 MAP, 6 MAP, and 5 MAP for March, May, July, September, and October pot-

Table 3. Effect of date of potting and rate of fertilization on N, P, and K content of *Viburnum awabuki* 'Chindo' and percentage nutrient recovery.

	Rates of fertilization					
	0.5/0.5X		1.0X		2.0X	
Potting date	Content (mg)	Recovery[z] (%)	Content (mg)	Recovery (%)	Content (mg)	Recovery (%)
			Nitrogen			
March	462[y]	11	440	10	757	8
May	432	10	655	14	718	8
July	590	13	761	16	1048	12
September	965	21	1018	22	1038	11
October	743	16	718	16	800	9
			Phosphorous			
March	45	10	58	13	90	10
May	48	11	78	18	92	10
July	60	14	80	18	115	13
September	107	24	121	27	127	14
October	85	19	87	20	108	12
			Potassium			
March	362	21	470	27	558	16
May	375	22	559	32	617	18
July	572	33	617	35	810	23
September	722	42	801	47	670	19
October	617	35	628	36	632	18

[z]Percentage recovery = (mg plant nutrient content ÷ total mg nutrient applied) × 100.

[y]Mineral nutrient content across potting dates within rates of fertilization or mineral nutrient content across rates of fertilization within potting date with a difference > 256, 33, or 171 mg are statistically significant, LSD, $P = 0.05$ for N, P, and K, respectively. Similar comparisons for nutrient recovery use 3%, 4% or 5% for N, P, and K, respectively.

ting dates, respectively. This resulted in the highest EC values occurring in March for hollies potted in July, September, and October. High EC values in March may reflect increasing temperatures and reduced irrigation frequency. Since container substrates were irrigated as needed from November through February this could result in increased EC values. In contrast, viburnum potted in March and May reached their highest EC values in August and decreased for the remaining MAP. As nutrient release from many polymer-coated CRFs is temperature dependent, EC values of plants fertilized in the spring would be expected to increase during the summer. Plants potted and fertilized in summer and fall produced their EC peak in March. Cabrera (4) reported most CRFs exhibited N release patterns that were highly responsive to temperature changes between 20C (68F) and 25C (77F). The CRF release in March should be well timed for plants potted in late summer/fall as plant nutrient demand should be increasing at that time. In addition, there should be an adequate root system to absorb the released nutrients. The CRFs applied to spring potted plants would have released much of their nutrients during the growing season thus minimizing their peaks in March.

In general, EC values increased with increasing rates of fertilization regardless of potting date (Fig. 2B). The effect of the split application is evident with the lowest EC values from 1 to 6 MAP. From 7 to 12 MAP, application of the remaining 0.5X increased EC value above the 1X level. However, low EC values in the first 6 MAP may be responsible for the reduced holly and viburnum growth with the split application.

Substrate pH. Substrate pH was affected by rate of fertilization, however, fertilizer, potting date and all interactions were nonsignificant. Holly substrate pH averaged 5.9, 5.6, 5.5, and 5.3 for 0.5X/0.5X, 1X, 1.5X, and 2X, respectively, whereas viburnum substrate pH averaged 5.8, 5.6, 5.4, and 5.3 for 0.5X/0.5X, 1, 1.5X, and 2X, respectively. Since both CRFs had either urea or ammonium nitrate as the N source, this was expected. However, all pH values were within acceptable range throughout the study (Wright and Niemiera, 1987).

Literature Cited

1. Bevington, K.B. and W.S. Castle. 1985. Annual root growth patterns of young citrus trees in relation to shoot growth, soil temperature, and soil water content. J. Amer. Soc. Hort. Sci. 110:840–845.

2. Bilderback, T.E., S.L. Warren, and J.H. Daniels. 1997. Managing irrigation by electrical conductivity. *In*: A.P. Papadopoulos (Ed.). Proc. Intl. Symp. on Growing Media and Hydroponics. Acta Hort. 481:403–408.

3. Brinkman, J.A. and R.E.J. Boerner. 1994. Nitrogen fertilization effects on foliar nutrient dynamics and autumnal resorption in maidenhair tree (*Gingko biloba* L.). J. Plant Nutr. 17:433–443.

4. Cabrera, R.I. 1997. Comparative evaluation of nitrogen release patterns from controlled-release fertilizers by nitrogen leaching analysis. HortScience 32:669–673.

5. Colangelo, D.J. and M.H. Brand. 1997. Effect of split fertilizer application and irrigation volume on nitrate-nitrogen concentration in container growing area soil. J. Environ. Hort. 15:205–210.

6. DeHayes, D.H., M.A. Ingle, and C.E. Waite. 1989. Nitrogen fertilization enhances cold tolerance of red spruce seedlings. Can. J. For. Res. 19:1037–1043.

7. Fain, G.B, C.H. Gilliam, K.M. Tilt, J.W. Olive, and B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18:142–144.

8. Goatley, J.M., V.L. Maddox, and K.L. Hensler. 1998. Late-season applications of various nitrogen sources affect color and carbohydrate content of 'Tiflawn' and Arizona common bermudagrass. HortScience 33:692–695.

9. Glenn, D.M. and W.V. Welker. 1993. Root development patterns in field grown peach trees. J. Amer. Soc. Hort. Sci. 118:362–365.

10. Harris, J.R., N.L. Bassuk, R.W. Zobel, and T.H. Whitlow. 1995. Root and shoot growth periodicity of green ash, scarlet oak, turkish hazelnut and tree lilac. J. Amer. Soc. Hort. Sci. 120:211–216.

11. Hicklenton, P.R. and K.G. Cairns. 1992. Solubility and application rate of controlled-release fertilizer affect growth and nutrient uptake in containerized woody landscape plants. J. Amer. Soc. Hort. Sci. 117:578–583.

12. Martin, C.A. and D.L. Ingram. 1991. Root growth of southern magnolia following exposure to high root-zone temperatures. HortScience 26:370– 371.

13. Maust, B.E. and J.G. Williamson. 1994. Nitrogen nutrition of containerized citrus nursery plants. J. Amer. Soc. Hort. Sci. 119:195–201.

14. Pellet, H.M. and J.V. Carter. 1981. Effect of nutritional factors on cold hardiness of plants. Hort. Rev. 3:144–171.

15. Phillips, E.L. and T.E. Bilderback. 1990. Comparison of container leachate levels and plant response to slow release fertilizers. Proc. Southern Nurseryman's Assoc. Res. Conf., 35th Annu Rpt. p.80–83.

16. Robinson, J.T. and D.F. Hamilton. 1980. Effects of time and rate of nutrient application on foliar nutrient concentration and cold hardiness in viburnum species. Scientia Hort. 13:271–281.

17. Rose, M.A. and B. Biernacka. 1999. Seasonal patterns of nutrient and dry weight accumulation in Freeman maple. HortScience 34:91–95.

18. Rose, M.A., M. Rose, and Hao Wang. 1999. Fertilizer concentration and moisture tension affect growth and foliar N, P, and K contents of two woody ornamentals. HortScience 34:246–250.

19. Ruter, J.M. 1992. Influence of source, rate, and method of applicating controlled release fertilizer on nutrient release and growth of 'Savannah' holly. Fert. Res. 32:101–106.

20. Shiflett M.C., A.X. Niemiera, and C.E. Leda. 1994. Mid-season reapplication of controlled release fertilizers affect 'Helleri' holly growth and N content of substrate solution and effluent. J. Environ. Hort. 12:181–186.

21. Struve, D.K. 1995. Nitrogen, phosphorus and potassium recovery of container-grown red oak and blackgum seedlings under different fertilizer application methods. J. Environ. Hort. 13:169–175.

22. Tyler, H.H., K.B. Perry, and S.L. Warren. 1993. Composted turkey litter: Effect on the thermal characteristics of an amended pine bark substrate. Proc. Southern Nurseryman's Assoc. Res. Conf., 38th Annu Rpt. p. 92–95.

23. Walden, R.F. and G. Epelman. 1992. Growth response of 'Convexa' holly to dormant leaf tissue N level and timing of spring fertilization. Proc. Southern Nurseryman's Assoc. Res. Conf., 37th Annu Rpt. p. 56–59.

24. Weinbaum, S.A., M.L. Merwin, and T.T. Muraoka. 1978. Seasonal variation in nitrate uptake efficiency and distribution of absorbed nitrogen in non-bearing prune trees. J. Amer. Soc. Hort. Sci. 103:516–519.

25. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227–229.

26. Wright, R.D. and A.X. Niemiera. 1987. Nutrition of container-grown woody nursery crops. *In*: J. Janick (Ed.). Hort Reviews. AVI publishing Co. Inc. Westport, CT. p. 76–101.

27. Yeager, T.H. 1996. Dwarf yaupon holly response to fertilizer application rate and frequency. HortTechnology 6:41–45.

28. Yeager, T.H., R.D. Wright, and M.M. Alley. 1980. Response of Ilex crenata Thunb. cv. Helleri to timed fertilizer applications. J. Amer. Soc. Hort. Sci. 105:213–215.