Effects of Container Spacing Practice and Fertilizer Placement on Runoff from Overhead-Irrigated Sweet Viburnum[1]

Jeff Million[2], Tom Yeager[2] and Joseph Albano[3]
Department of Environmental Horticulture, University of Florida
IFAS, 1545 Fifield Hall, Gainesville, FL 32611-0670

Abstract

Information on how management practices affect runoff volume and nutrient content is needed to improve irrigation and fertilizer efficiency while minimizing environmental impacts. Runoff (leachate plus unintercepted irrigation and rain) was collected weekly for 20 weeks during production of sweet viburnum (*Viburnum odoratissimum* (L.) Ker-Gawl.) in trade #1 (2.7 liter) containers fertilized with 15 g (0.53 oz) of a resin-coated, controlled-release fertilizer Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)] and overhead-irrigated with water at 1 cm/day (0.39 in). Treatments were a factorial arrangement of two container spacing practices [spaced at planting (SP) or spaced midseason (SM)] and two fertilizer placement methods [incorporated (INC) or surface-applied (SURF)]. Cumulative runoff volume averaged 1590 liters/m^2 (3900 gal/100 ft^2) or 66% of irrigation plus rain and was 9% higher for SP than SM. A 37% reduction in shoot dry weight of SP versus SM plants was attributed to heat stress in SP containers. SURF decreased N, P, and K leaching losses (mg/container) 42, 42, and 25%, respectively, at SP and 16, 25, and 4%, respectively, at SM. Nutrient leaching losses as a percent of applied were 11–18% for N, 7–13% for P, and 19–28% for K. Total nutrient loads in runoff were 4.6–11.1 g/m^2 for N, 0.48–1.25 g/m^2 for P, and 5.8–10.1 g/m^2 for K with peak nutrient loss occurring during the first two weeks after planting.

Index words: controlled-release, nutrient load, leach, ornamental, Osmocote, pour-through, water quality.

Significance to the Nursery Industry

Our results showed that spacing out containers at planting instead of at midseason once plant canopies become developed reduced plant growth (attributed to heat stress) and increased leaching loss of applied nutrients, particularly when fertilizer was incorporated. Compared to incorporation method, surface application of controlled-release fertilizer decreased container leaching losses of applied N and P without reducing plant growth, indicating that this method deserves further scrutiny as a means to reduce potential environmental impacts of fertilizer applications. The greatest nutrient loss occurred during the first six weeks of the experiment indicating that additional research to limit leaching losses of applied nutrients during this period of production is warranted. Runoff nutrient data represent important new information because continuous runoff collection allowed for determination of nutrient loads (g/m^2), which along with runoff volumes (liters/m^2) can be useful for making environmental risk assessments of container production practices.

Introduction

The application of water and fertilizers during plant production places an onus on container nurseries to minimize the potentially harmful effects of nutrient contamination of runoff water. Experiments that quantify runoff volume and nutrient content during production provide insight as to the relative roles various production practices play in utilizing water and nutrients most efficiently. Runoff data is also important in the design and management of on-site conservation and mitigation systems such as containment ponds for recycling (20) or constructed wetland areas for treatment of runoff (22). On a regional scale, runoff information is important in composing accurate environmental impact statements including total maximum daily loading (TMDL) assessments (17, 33).

Maximizing irrigation and fertilizer efficiency for production in smaller containers is especially important due to the use of high container densities and overhead irrigation. Despite the fact that controlled-release fertilizers (CRF) are commonly used, losses of N and P in leachate can be substantial, particularly during the beginning of a crop cycle (9, 23, 25). Overhead sprinkler irrigation is inherently less efficient than low volume drip or spray-stake systems used for production in larger containers. Efficiency of overhead irrigation was found to be only 13–25% (43). Beeson and Knox (1) reported average irrigation efficiencies of 25–37% and that efficiencies depended upon the plant canopy as well as container spacing. In large-scale plots, runoff from a single irrigation event was 75% of the 1.3 cm of irrigation water applied (3). While runoff (leachate plus unintercepted irrigation and rainfall) rates are required to calculate nutrient loading rates from a production area, they are seldom determined. More commonly, nutrient losses are reported on a per-container basis, requiring extrapolation to estimate loading rates and nutrient concentrations in runoff.

Container spacing is managed by growers during production. Container spacing affects container temperature (29), irrigation interception (1), and total nutrient input loading (e.g., kg/ha/yr). Because temperature plays a significant role in the nutrient release rate of CRF (6, 27) and irrigation interception affects irrigation efficiency and thus leaching, container spacing management should affect nutrient runoff directly. Many growers start containers 'pot-to-pot' and subsequently space them one or more times during the season to prevent overcrowding of the plant canopies. However, due to time and labor considerations, growers may start containers at their final plant spacing. No literature was found di-

[1]Received for publication September 18, 2006; in revised form December 12, 2006. This research was supported by the Florida Agricultural Experiment Station and a grant from the Floral and Nursery Research Initiative, USDA, ARS, Specific Cooperative Agreement 58-6618-2-0208, CRIS 6618-13000-002-04S.

[2]Research Associate and Professor, resp.

[3]Professor, U.S. Horticultural Research Laboratory, USDA, ARS, Ft. Pierce, FL 34945

rectly relating container spacing treatments with nutrient loads in runoff.

Two common methods of applying CRF for container production are pre-plant incorporation and surface-application at or near the time of planting. While higher rates of fertilizer release and leaching losses from CRF have been observed for incorporated versus surface-applied (42, 44, 46), placement has been found to have a variable effect on crop growth (2, 15). Greater nutrient release with incorporated CRF has been attributed to greater and more uniform moisture (4, 15, 34), shorter distances to leach through container (6, 42), and increased substrate temperatures around container walls (44). Fertilizer prill damage during mixing (26) may also play a role. The current best management practice (BMP) guideline (45) does not promote one application method over another, although surface application is not recommended if containers are prone to overturning during production.

The objective of this study was to determine if and how container spacing and fertilizer placement method interact to affect the quantity and nutrient content of runoff generated during the production of a common ornamental shrub with medium to high water and nutrient requirements. Realizing that the irrigation practice employed would play a major role in the generation of runoff during production, we selected an application rate of 1 cm of water per day, which from our experience is a sufficient and reasonable rate for producing a marketable sweet viburnum crop in trade #1 (2.7 liter) containers. Another major factor to consider was fertilizer type and rate of application. In this regard we applied an industry standard form of CRF at the label-recommended rate.

Materials and Methods

This experiment was conducted at the University of Florida in Gainesville. The site consisted of four 6.1 × 6.1 m (20 × 20 ft) irrigation zones each irrigated with four overhead sprinklers (Model PGP No. 2 Nozzle; Hunter Industries Inc., San Marcos, CA) each operating at a regulated pressure of 207 kPa (30 psi) and at a height of 150 cm (60 in). Sprinklers were adjusted to apply water uniformly within each irrigation zone at the rate of 1.8 cm (0.7 in)/hr. Irrigation was considered uniform when Christiansen's uniformity coefficient (19) within each irrigation zone was greater than 90%. Four runoff platforms were placed within each of the four irrigation zones for a total of 16 platforms. Each platform consisted of a square 1.2 × 1.2 m (4 × 4 ft) piece of 1.9 cm thick (¾ in) plywood that was supported underneath by a framework of lumber. Platforms were supported in each corner and raised to a final height of 50 cm (20 in). To facilitate runoff collection, slope (2%) was created by placing wooden shims under the high end of each platform. To separate a border row of containers from interior experimental plants, three pieces of 1.3 cm (o.d.) plastic pipe were fastened to the surface of the plywood so as to form a three-sided framework 17 cm (6.7 in) inside the perimeter of the platform; no pipe (no border row) was placed on the lower side to allow drainage (Fig. 1). The collection area delineated by this framework was 0.937 m^2 (10.1 ft^2), leaving 0.6 m^2 (6.5 ft^2) for border containers which did not drain into the collection vessel. The plywood and pipe framework were covered with pond liner (45-mil PondGard; Firestone Building Products; Carmel, IN) and standard nursery-grade polypropylene groundcloth (Green Line Style 31411; LINQ Industrial Fab-

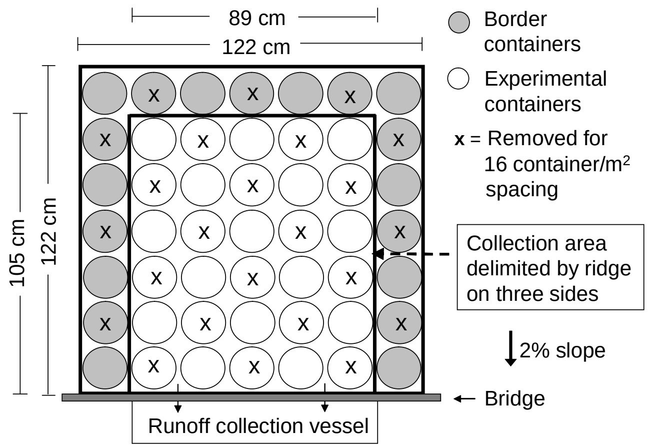

Fig. 1. Overhead view of the raised platform used to collect runoff (leachate plus un-intercepted irrigation plus rain) generated during the production of an overhead-irrigated container (trade #1; 2.7 liter) crop. Sloped platforms were underlain with pond liner to divert runoff into a 110 liter (30 gal) collection vessel. A piece of pond liner (not shown) was attached to the bridge to form a cover over the collection vessel. Each platform was an experimental unit (n = 16).

rics, Summerville, SC) to collect runoff and divert it to a collection vessel below and at the low end of the platform. A horizontal piece of lumber (bridge; Fig. 1) was secured 1.5 cm above and along the lower edge of the platform to delineate the collection area at the lower end of the platform while allowing runoff water to pass underneath and into a collection vessel. A section of pond liner was stapled to the horizontal piece to form a cover between the platform and a 110 liter (31 gal) collection vessel placed under the lower end of the platform. The collection vessel was a rectangular polyethylene tub 70 cm long × 40 cm tall × 40 cm wide (28 × 16 × 16 in). In order to measure daily inputs of irrigation and rain, two gauges were secured to each platform. The gauges consisted of 9.5 cm (3.7 in) i.d. cups fastened to 1.2 m (4 ft) sections of pipe which could be raised and lowered with changes in canopy height. A rain gauge was placed at the perimeter of the experimental area to monitor daily rainfall.

The container substrate was a mix of aged pine bark, sphagnum peatmoss, and coarse sand (2:1:1, by vol). The available water holding capacity of this substrate was 25% (0.25 cm^3 of H_20 per cm^3 of substrate) which was equivalent to a volume of 600 mL per container or a depth of 3 cm of water. During mixing, the substrate was amended with 4.2 kg/m^3 (7 lb/yd^3) of dolomitic limestone and 0.9 kg/m^3 (1.5 lb/yd^3) of a micronutrient blend (Micromax, Scotts Co., Marysville, OH). Black polyethylene, blow-molded, trade #1 (2.7 liter) containers (C-650; Lerio Corp., Mobile, AL) were filled to a final substrate volume of 2.4 liter [16 cm (6.3 in) top diameter and fill height of 15 cm (5.9 in)]. Containers were fertilized with 15 g of a resin-coated CRF [Osmocote 18.0N–2.6P–10.0K (18–6–12), 8–9 month 21 C; Scotts Co., Marysville, OH] which supplied 2.7, 0.39, and 1.5 g per container of N, P, and K, respectively. The CRF, which was derived from ammonium nitrate, ammonium phosphate, calcium phosphate and potassium sulfate, contained 8% NO_3-N and 10% NH_4-N. The CRF was either incorporated (INC) by hand into the substrate on an individual pot basis just prior to planting or was surface-applied (SURF) at transplanting. Rooted cuttings of sweet viburnum grown in 700-mL containers (32 per industry standard tray) were planted one per container on August 28, 2003. Planted containers were hand-watered before placing out onto platforms. Drainage water from this initial watering was not collected as runoff.

Containers were placed on runoff platforms in one of two treatment spacing arrangements. For spaced at midseason (SM), plants were grown at 32 containers/m^2 (300 containers/100 ft^2) during the first 14 weeks and at 16 containers/m^2 (150 containers/100 ft^2) for the final six weeks. The 32 containers/m^2 spacing was equivalent to a 'pot-to-pot' square arrangement; the 16 containers/m^2 spacing was achieved by removing every other container from the 32 containers/m^2 arrangement (Fig. 1). For spaced at planting treatment (SP), plants were grown at 16 containers/m^2 throughout the experiment. There were 30 containers within the runoff collection area for the 32 containers/m^2 spacing and 15 for the 16 containers/m^2 spacing. Border plant containers reflected the same spacing as the containers in the collection area.

Plants were irrigated daily with 1 cm (0.39 in) of water applied predawn (usually at 0500 HR). Rain sensors were not used to automatically cutoff irrigation. Without plant canopy effects, 1 cm of water was equivalent to an application of 200 mL per container or 33% of the available water holding capacity of the substrate. Gauges were read daily to monitor all inputs of irrigation water and rainfall. Runoff from platforms was collected on a weekly basis and runoff volume determined. No attempt was made to distinguish the relative contributions of leachate versus unintercepted irrigation water. Water samples from each weekly runoff collection were filtered and stored frozen at –20C (–4F) until nutrient analyses were performed.

At the end of week one and every three weeks thereafter, the nutritional status of five containers per platform was monitored by leaching each container with 200–300 mL of de-ionized water (enough to collect approx. 120 mL per container) and collecting the leachate. The pour-through procedure was performed between 0800 HR and 0900 HR approximately 2–3 hours after irrigation was completed.

Substrate temperature was measured once every three weeks by inserting a bimetal dial thermometer (Fisher Scientific, Model 15076) 2.5 cm (1 in) inside the southwest-facing wall to a depth of 8 cm (3 in). Temperature measurements were conducted on two containers per platform (n = 8) in the late afternoon (usually 1500 to1600 HR) of a sunny day during the week. Therefore, the measurements reflected conditions when substrate temperatures would be highest (28) rather than indicating an average daily affect. Corresponding air temperatures were recorded by a weather station at the site.

Plant height and average plant width were measured every three weeks on a separate group of five plants per platform. Plant size index was calculated as: (plant height + plant width) / 2. Plant height was the distance from the substrate surface to the top of the foliage while plant width was the average of two perpendicular measurements with one being the widest dimension of the plant canopy. The experiment was terminated on January 15, 2004, 20 weeks after planting. At this time, plant size index and shoot dry weight were determined on all 15 plants per runoff platform.

Runoff and pour-through leachate solutions were analyzed for NH_4-N, NO_x-N (NO_3-N), total Kjeldahl N (TKN), orthophosphate-P, total P (P), and K by the Analytical Research Laboratory, University of Florida, Gainesville. The TKN analytical procedure did not include NO_x-N. Total-N (N) was calculated as the sum of NO_3-N and TKN. Weekly nutrient load was calculated by multiplying nutrient concentration by runoff volume. Weekly nutrient loss on a per-container basis was calculated by dividing weekly nutrient load by the container density during the weekly collection period.

For parameters collected on a weekly basis, the experiment was analyzed as a split-plot design with four blocks, four treatments as main plots, and 20 weekly measurements as sub-plots. The four treatments were a factorial arrangement of two container spacing arrangements and two fertilizer placement methods. Experiment totals were calculated by multiplying average weekly means by 20, the number of weeks in the season. Where a significant interaction was observed between treatments and week, a separate ANOVA was conducted for each week to help determine how the response changed over time. Final plant size and shoot dry weight parameters were analyzed as a RCBD. All ANOVA tests were conducted using the PROC GLM procedure of the Statistical Analysis System (SAS® Institute, Cary, NC).

Nutrient loss in runoff is reported several ways. Weekly nutrient load (g/m^2) was calculated as the quantity of nutrient lost from a production area under a given treatment. Because we tested two different container densities, we also report nutrient loss on a per-container basis (mg/container) to better evaluate the efficiency of treatments. Nutrient concentrations in runoff were included because they can be pertinent to water quality standards. Nutrient concentration of runoff averaged over the 20 weekly runoff collections was calculated as the total nutrient load divided by total runoff volume and therefore was 'flow-weighted'.

Results and Discussion

Water inputs and runoff. Weekly irrigation plus rain (W) averaged 80 liters/m^2 (196 gal/100 ft^2) or 8.0 cm (3.1 in) and was unaffected ($P < 0.05$) by treatments but varied by week (Table 1). Weekly W ranged from a baseline of 70–75 liters/m^2 (172–184 gal/100 ft^2) without rainfall to 110 liters/m^2 (270 gal/100 ft^2) with 4 cm of rainfall (week 5; Fig. 1). Rainfall during the experiment totaled 23.5 cm (9.3 in), which was equivalent to 235 liters/m^2 (576 gal/100 ft^2) or 15% of total W [1590 liters/m^2 (3896 gal/100 ft^2)]. This amount of rain was 40% less than the historical average of 40 cm (15.7 in) of rain that would be expected during this same time period. Water input on a container basis was 3.2 liters/container/week (0.85 gal) for SM, but because of a lower container density, this was equivalent to a water input of 5.0 liters/container/week (1.32 gal) for SP.

Weekly runoff volume (RV) averaged 52 liters/m^2 (127 gal/100 ft^2) with an interaction ($P < 0.05$) between spacing and week. Higher ($P < 0.05$) RV for SP versus SM was observed for weeks 1–5, 8 and 10 (Fig. 2). As a result, by the end of the first 14 weeks of production at which time SM containers were spaced, total RV was 15% higher for SP versus SM [790 vs. 690 liters/m^2 (1936 vs. 1691 gal/100 ft^2)]. The highest volumes of runoff were observed during weeks 1, 5, and 11 when greater than 50% of total rainfall [12.6 cm (5.0 in)] occurred: 4.7 cm (1.85 in; week 1), 4.3 cm (1.69 in; week 5), and 3.6 cm (1.42 in; week 11). From week 12 until the end of the experiment there were no differences ($P < 0.05$) in RV attributed to plant spacing treatments so that by the end of the experiment average weekly RV was 9% higher

Table 1. Analysis of variance of the split plot design used to evaluate container spacing and fertilizer placement effects on water inputs of irrigation plus rain (W), runoff volume (RV) and losses of N, P, and K in runoff collected weekly during 20 weeks of sweet viburnum production. Because of different container spacing densities, the ANOVA was conducted for results presented on both a per-container basis as well as an area basis. Containers were spaced at planting (SP) or spaced midseason (SM) and controlled-release fertilizer was either incorporated (INC) or surface-applied (SURF). Total df = 319.

		Signficance (P > F)									
		Per-container basis[z]					Area basis[y]				
ANOVA source[x]	df	W	RV	N	P	K	W	RV	N	P	K
Block	3	—	—	—	—	—	—	—	—	—	—
Spacing (S)	1	***	***	NS	NS	*	NS	NS	*	***	***
Fertilizer (F)	1	NS	NS	*	**	NS	NS	NS	*	***	NS
S × F	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Main plot error	9	—	—	—	—	—	—	—	—	—	—
Week	19	***	***	***	***	***	***	***	***	***	***
S × week	19	NS	***	NS	*	NS	NS	**	***	***	***
F × week	19	NS	NS	***	***	***	NS	NS	***	***	***
S × F × week	19	NS	NS	**	NS	*	NS	NS	NS	NS	NS
Sub plot error	228	—	—	—	—	—	—	—	—	—	—

NS, *, **, *** Non-significant or significant at P = 0.05, 0.01, or 0.001, respectively

[z]W and RV units in liters/container; N, P, and K units in mg/container

[y]W and RV units in liters/m^2; N, P, and K units in g/m^2

[x]Split-plot design with container spacing and fertilizer placement as main plot factors and week as the sub-plot factor

[55 vs. 50 liters/m^2 (135 vs. 123 gal/100 ft^2)] for SP than for SM. Due to differences in container density, runoff volume on a per-container basis was 66% higher [3.4 vs. 2.1 liters/container (0.91 vs. 0.55 gal)] for SP versus SM indicating that irrigation efficiency was reduced when plants were spaced at planting.

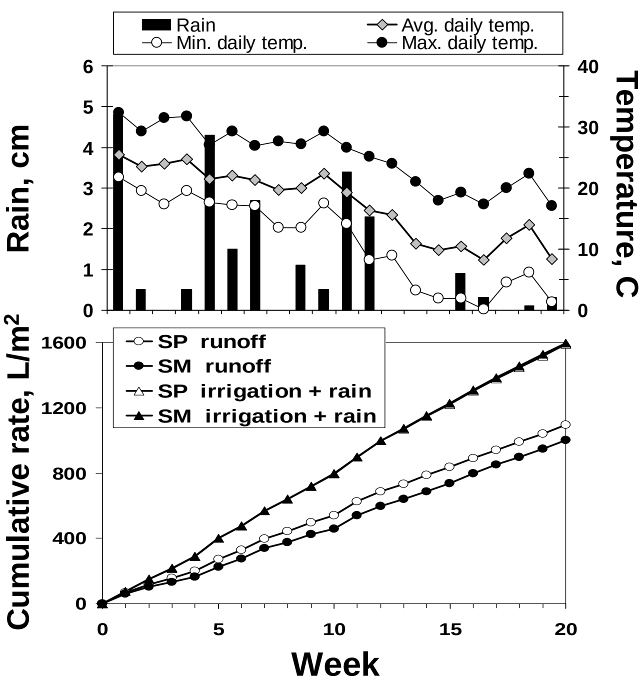

Fig. 2. Cumulative water inputs and associated runoff (un-intercepted irrigation plus rainfall) during the production of sweet viburnum irrigated daily with 1 cm of water. Containers were either spaced at planting (SP) or spaced midseason at week 14 (SM). Runoff means are averaged over two fertilizer placement methods (n = 8). Increases (P < 0.05) in weekly runoff due to SP compared to SM were observed for weeks 1–5, 8 and 10.

Runoff volume as a fraction of W averaged 63% for SM and 69% for SP. These values correspond to irrigation efficiencies of 37 and 31%, respectively, similar to the 25–37% efficiencies reported by Beeson and Knox (1). Minimum and maximum percent runoff was 41% (week 3) and 80% (week 11), respectively, for SM, and 58% (week 3) and 88% (week 1) for SP. Based on a container top surface area of 200 cm^2 and assuming no plant canopy effects, the theoretical minimum percent runoff would be 36% for the 32 container/m^2 spacing and 64% for the 16 container/m^2 spacing. While the daily application of 1 cm (0.39 in) of irrigation water may not have resulted in optimal efficiency in this study, it was lower than the average daily rate of 1.6 cm (0.63 in) typically applied by nursery growers in Alabama (14) and 2.5 cm in Georgia (18). No survey data were found for Florida. However, based upon our experience 1.3–2.5 cm (0.5–1.0 in) of daily irrigation is common.

Plant growth and substrate temperatures. Plant growth was affected more by container spacing than by fertilizer placement method. Shoot dry weight of SP plants was reduced (P < 0.05) 37% (16.6 vs. 22.8 g/plant) compared to the SM plants; there was no effect (P < 0.05) of fertilizer placement on shoot dry weight. Final plant size index of SP plants was reduced (P < 0.05) 22% [27 vs. 34 cm (10.6 vs. 13.4 in)], shoot height 26% [(29 vs. 39 cm (11.4 vs. 15.4 in)] and plant width 17% [25 vs. 30 cm (9.8 vs. 11.8 in)] compared to SM plants. Most of the reduction in plant size index due to SP was observed by week 13 so that changes in shoot size index measured thereafter were unaffected (P < 0.05) by container spacing (Fig. 3). Although there was no effect (P < 0.05) of fertilizer placement on final plant size, INC reduced (P < 0.05) plant size index at weeks 7, 10, and 13 (SP containers only), with the effect greater for plants grown in containers spaced at planting than for plants grown in containers spaced midseason. However, this fertilizer placement effect diminished after week 13. Midseason reduction in growth due to INC may have been related to elevated salt levels from rapid nutrient release of INC fertilizer while the 'catching up' of

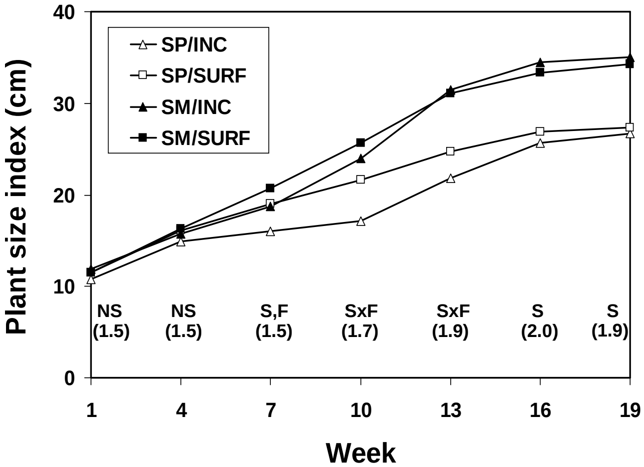

Fig. 3. Plant size index [(shoot height + average shoot width) / 2] as affected by container spacing and fertilizer placement treatments. Plants were either spaced at planting (SP) or spaced midseason (SM) and controlled release fertilizer was either surface-applied (SURF) or incorporated (INC). Non-significant (NS) or significant ($p < 0.05$) spacing (S), fertilizer placement (F), or interaction (S × F) effects are indicated along with $LSD_{0.05}$ values in parentheses. n = 20.

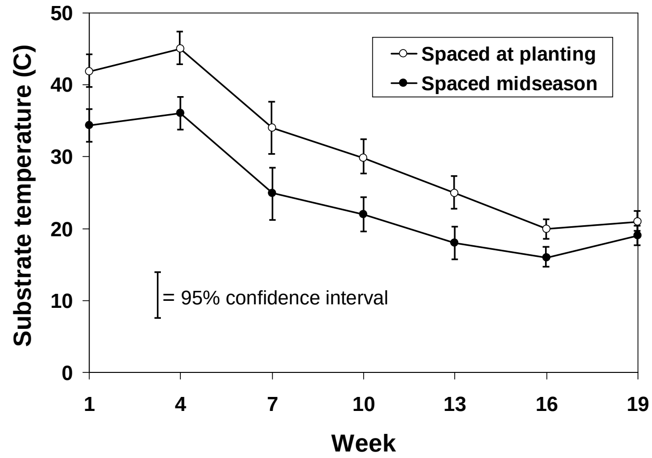

Fig. 4. Substrate temperatures measured periodically during the production of sweet viburnum in trade #1 (2.7 liter) containers either spaced at planting or spaced midseason after canopy development. Measurements were taken during the late afternoon with thermometers placed 2.5 cm inside the southwest-facing wall of the containers at a depth of 8 cm. n = 8.

INC plants may have been related to greater nutrient availability in INC containers during the middle of the season.

We attributed the reduction in SP plant growth to heat stress associated with elevated substrate temperatures. SP resulted in higher ($P < 0.05$) substrate temperatures for every test date except week 19 (Fig. 4). Increases in substrate temperature due to SP versus SM were 8, 9, 9, 6, 7, and 4C (14.4, 16.2, 16.2, 10.8, 12.6, and 7.2F) for weeks 1 (September 4), 4 (September 25), 7 (October 16), 10 (November 3), 13 (November 24), and 16 (December 17), respectively. Corresponding air temperatures were 30, 33, 26, 29, 18, 16, and 20C (86, 91, 79, 84, 64, and 68F), respectively. Ingram et al. (29) shielded the same sized containers and noted an average decrease in substrate temperature of 8C (14.4F). Container temperatures above 40C (104F), common during summer months, may reduce plant growth (31). These results confirm that container spacing can have a considerable effect on substrate temperature. Compared to SP, SM resulted in increased shading of adjacent containers thereby limiting the amount of solar radiation absorption by the black sidewalls of the containers during the early stages of growth. Reduced shoot growth observed for SP plants also decreased shading of adjacent containers and likely contributed further to the heat stress effect.

Nutrient loss on a per-container basis. An evaluation of nutrient loss on a per-container basis provided insight on how treatments directly affected leaching of applied nutrients. The ANOVA for losses of N and K on a per-container basis indicated a significant interaction between container spacing and fertilizer placement and that this interaction varied with time during the experiment (Table 1). The aforementioned interaction with time was a result of much greater leaching losses of nutrients that occurred during the first two weeks of the experiment such that treatment effects were prominent during this period (Fig. 5). For example, during the first week INC increased ($P < 0.05$) N loss approximately three-fold (185 vs. 65 mg/container) when containers were spaced but had no effect ($P < 0.05$) when containers were placed in a 'pot-to-pot' arrangement. The three-fold increase in N loss during the first week represented approximately 50% of the total increase in N loss attributed to the same effect over the entire 20 weeks of the experiment (Fig. 6). From week 2 through week 8 there was little effect of fertilizer placement on N leaching regardless of spacing arrangement (Fig. 5). From week 9 through week 12 there was a second period of increased leaching of N due to INC that did not depend ($P < 0.05$) on spacing arrangement. During this 4-week period INC increased N loss 3.5-fold (58.9 vs. 17.6 mg/container) compared to SURF. However, the total amount of N lost over the 4-week period was approximately one-third of that lost during week 1 alone. By the end of the experiment, incorporation versus surface-application of CRF increased total N loss 71% (496 vs. 290 mg/container) under SP but only 19% (368 vs. 308 mg/container) under SM (Fig. 6).

Losses of K in runoff were affected by treatments similarly to that described previously for N (Fig. 5). During week 1 when nutrient loss in runoff was greatest, the amount of K lost in runoff from spaced containers was doubled (124 vs. 60 mg/container) when fertilizer was incorporated compared to surface-applied; fertilizer placement had no effect ($P < 0.05$) on K loss during the first week when containers were 'pot-to-pot'. Losses of K during the first week were approximately 25% of the total K losses for the entire 20-week experiment (Fig. 6). During week 9 through week 12, when N losses were affected by treatments, INC increased K loss 1.7-fold (45.8 vs. 26.9 mg/container) compared to SURF when CRF was incorporated but had no effect ($P < 0.05$) when CRF was surface-applied. By the end of the experiment, incorporation compared to surface-application of CRF increased total K loss 34% (484 vs. 362 mg/container) when containers were spaced at planting but only 4% (334 vs. 320 mg/container) when containers were spaced midseason.

Container losses of P were affected by both fertilizer placement and container spacing but unlike N and K, the ANOVA indicated that there was no interaction between the two fac-

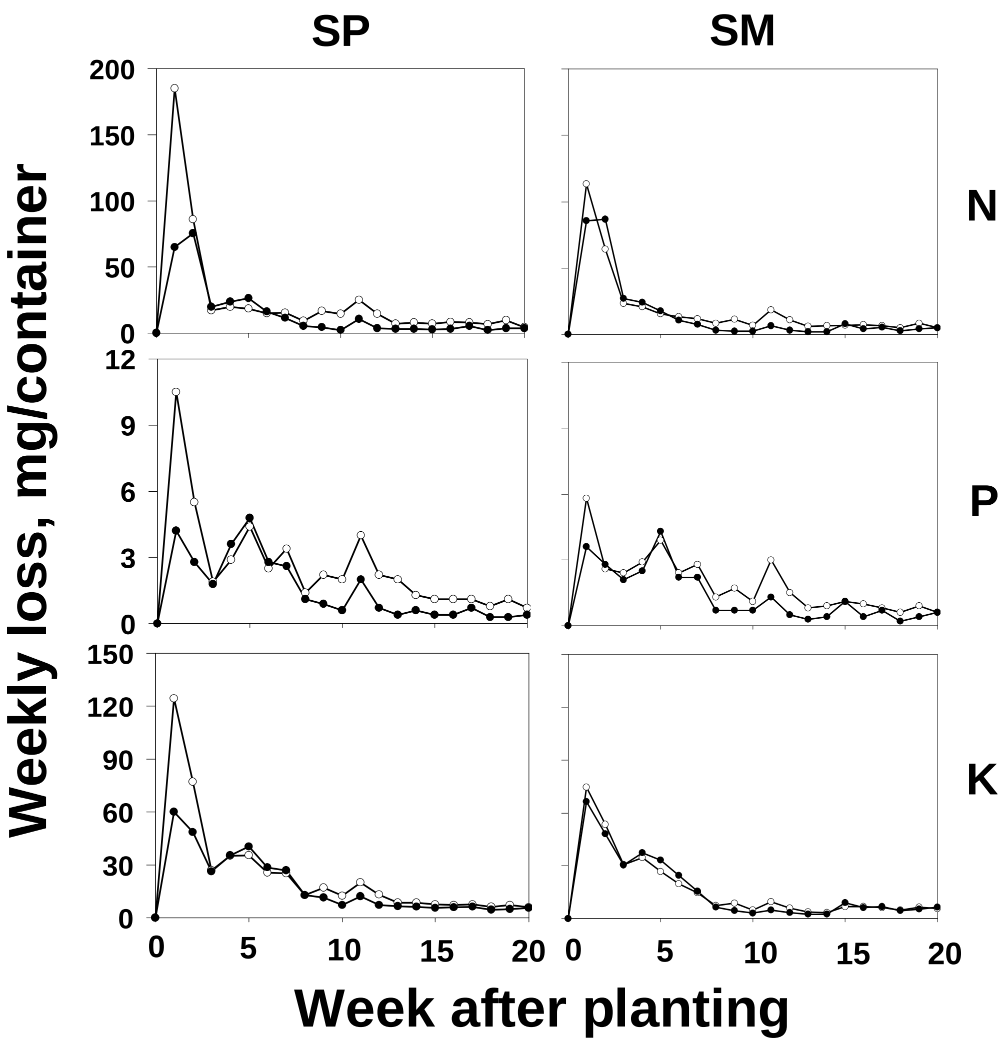

Fig. 5. Nutrient loss in runoff collected weekly during the production of sweet viburnum in trade #1 containers as affected by container spacing and fertilizer placement. Resin-coated controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9-month 21C (70F)] was either incorporated (— ○ —) or surface-applied (— ● —) at 15 g/container and containers were either spaced at planting (SP) or spaced midseason (SM). There was a significant (P < 0.05) week by spacing × fertilizer placement interaction for all three fertilizer elements. No mean separation statistics are given. N = NO_3-N + total Kjeldahl N (TKN analysis excluded NO_3-N). n = 4.

tors (Table 1). The effects of fertilizer placement and container spacing each depended ($P < 0.05$) on the week of runoff collection. As observed for N and K, greatest losses of P occurred during the first week. During the first week, losses of P were increased ($P < 0.05$) 2.1-fold (8.2 vs. 3.9 mg/container) with INC compared to SURF placement and were increased ($P < 0.05$) 56% (7.4 vs. 4.7 mg/container) with SP compared to SM (Fig. 5). Losses of P in runoff during the first week represented approximately 15–20% of the total P losses for the entire 20-week experiment (Fig. 6). Compared to N, and to a lesser degree K, the decline in leaching losses of P after the first few weeks was not as rapid. Incorporation versus surface application of CRF increased P losses in runoff for all weeks except weeks 2–6, 10, and 20. During the week 9–12 period, INC increased P losses 2.4-fold (8.9 vs. 3.7 mg/container). During the same period, SP increased P losses 39% (7.3 vs. 5.3 mg/container) compared to SM. By the end of the experiment, cumulative P loss was increased 53% (45.1 vs. 29.6 mg/container) when CRF was incorporated compared to surface-applied and was increased 27% (41.8 vs. 32.9 mg/container) when containers were spaced at planting compared to spaced midseason.

Nitrate N was the predominant form of N in runoff. By the end of the experiment, NO_3-N accounted for 66, 69, 65, and 73% of recovered N for SP/INC, SP/SA, SM/INC, and SM/SURF treatments, respectively. TKN accounted for 34, 31, 35, and 27% of recovered N for SP/INC, SP/SA, SM/INC, and SM/SURF treatments, respectively. Total Kjeldahl N, which included all reduced N forms including NH_4-N, was essentially all recovered during the first two weeks. NH_4-N accounted for 7–9% of recovered N. Ortho-P in runoff was highly correlated with runoff P so that treatment effects were the same for both analyses. The equation relating orthophosphate-P concentration (y) with P concentration (x) was: $y = 0.154 + 0.752x$ ($R^2 = 0.92$, n = 320).

Total nutrient losses (mg/container) as a percent of that applied in fertilizer were 11–18% N, 7–13% P, and 21–32% K. Huett (25) reported leaching losses of 20–38% N, 2–8% P, and 12–42% K using a 17N–2.6P–8.3K CRF while Broschat (5) reported losses of 29–35% NO_3-N, 12–18%

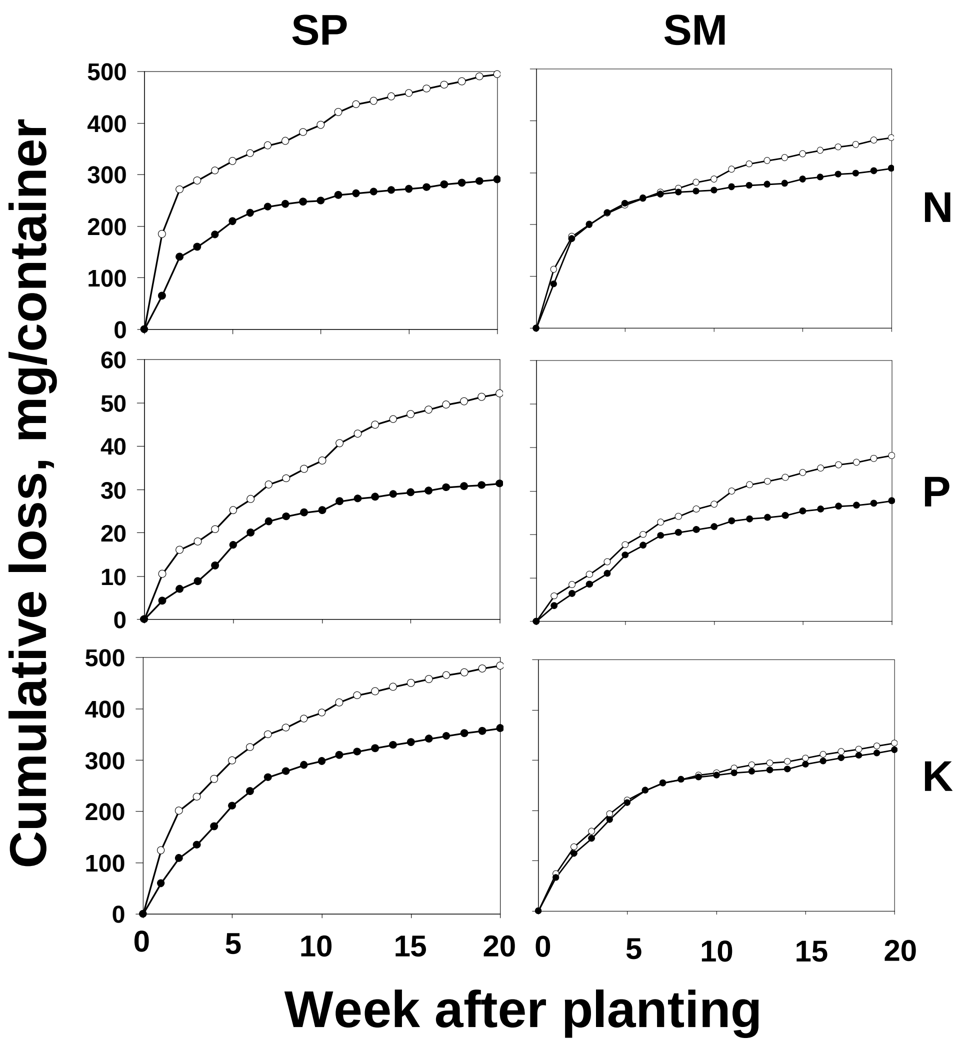

Fig. 6. **Cumulative pattern of nutrient loss in runoff collected weekly during the production of sweet viburnum in trade #1 containers as affected by container spacing and fertilizer placement. Resin-coated controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)] was either incorporated (— ○ —) or surface-applied (— ● —) at 15 g/container and containers were either spaced at planting (SP) or spaced midseason (SM). There was a significant (*P* < 0.05) week by spacing × fertilizer placement interaction for N and K and significant (*P* < 0.05) week × spacing and week × fertilizer placement interactions for P. N = NO_3-N + total Kjeldahl N (TKN analysis excluded NO_3-N). n = 4.**

orthophosphate-P, and 19–28% K with several Osmocote CRF formulations. Conover and Poole (8) found leaching losses of 20% N and 3% P with the same CRF used in this experiment. Other research reported leaching losses of N to be 7–9% (39), 19% (7), 18% (38), 26–32% (40), 30% (16), and 32% (30). The wide range in percent loss values is probably due to the wide range of cultural and management practices (e.g. fertilizer, irrigation, and species) used. In general, our results were within the range of losses noted above although percent N losses in our experiment were lower than most. Low recoveries of applied N are common in leaching studies even after accounting for plant uptake. Although tissue N was not determined in this experiment, finished sweet viburnum plants typically contain 2.0–2.5% N in shoots and 1.0–1.5% N in roots. Assuming that shoot biomass accounted for approximately 80% of total plant biomass, total uptake of N in roots and shoots was estimated to be 0.4–0.7 g/plant or 15–26% of the 2.7 g of N applied per container. Together, N leaching loss and plant uptake of N were estimated to have accounted for only 26–44% of applied N. The 56–74% of N unaccounted for by leaching and plant uptake could not be determined from this trial but volatilization losses, microbial immobilization, incomplete release of N from CRF, and losses during initial watering-in of transplants are possible reasons.

Results from this study indicate that irrigation management practices designed to minimize leaching may have the greatest potential benefit during early stages of production when nutrient leaching losses were observed to be the greatest. At least 50% of cumulative losses of N, P, and K occurred by week 2, 6 and 4, respectively, in this experiment (Fig. 6). Broschat (4) observed the same relative order of N, P, and K release from a 15N–3.9P–10K (15–9–12) Osmocote CRF. High leaching losses early in this experiment were likely due in large measure to the 17% of fertilizer product labeled as uncoated. This portion of the fertilizer would be relatively soluble and readily leached. Coupled with low plant nutrient and water uptake rates, this soluble fertilizer component likely resulted in the peak nutrient losses observed during the first two weeks of the experiment. Damaged prills may also have

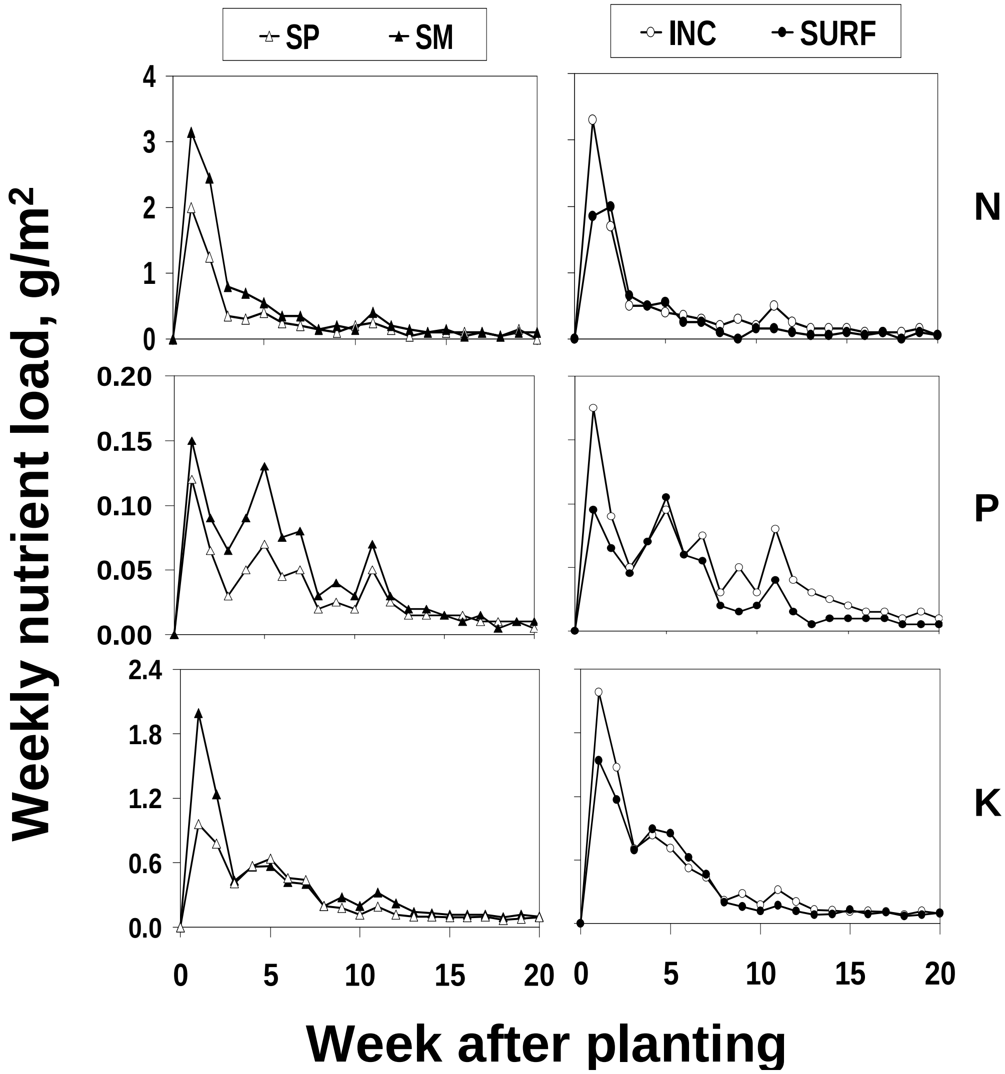

Fig. 7. Weekly nutrient loads of N, P, and K in runoff during the production of sweet viburnum in trade #1 containers as affected by container spacing (left side graphs) and fertilizer placement (right side graphs). Resin-coated controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)] was either incorporated (INC) or surface-applied (SURF) at 15 g/container and containers were either spaced at planting (SP) or spaced midseason (SM). There were significant (*P* < 0.05) week by container spacing as well as a week by fertilizer placement interactions for all three nutrient elements; no mean separation statistics are given. N = NO_3-N + total Kjeldahl N (TKN analysis excluded NO_3-N). n = 8.

contributed to early release of nutrients from CRF (26). Since nutrient release from resin-coated CRF granules is largely affected by temperature at normal substrate moisture levels (34), irrigation management practices designed to minimize leaching can postpone leaching until a significant leaching event occurs due to rainfall. Although this would extend the time period for plant uptake and substrate adsorption possibly reducing nutrient losses, plant nutrient uptake is relatively low during the early establishment phase of growth (10) and substrates have limited capacity to adsorb N and P. In this trial, irrigation was applied daily at 1 cm, which we have found in most situations supplies sufficient water to a trade #1 sweet viburnum crop until a sellable plant is grown. It is likely that this rate was excessive at times during the beginning of the crop when evapotranspiration was low.

Nutrient loads in runoff. Nitrogen, P, and K loads in runoff were affected ($P < 0.05$) by both container spacing and fertilizer placement and these effects varied depending upon the week runoff was collected (Table 1). There was no interaction ($P < 0.05$) between container spacing and fertilizer placement on nutrient loads in runoff. As described previously for nutrient losses on a per-container basis, the interaction of spacing and fertilizer placement effects with time on nutrient runoff loads was due to greater leaching losses that occurred during the beginning of the experiment (Fig. 7). Peak nutrient loads were observed during week 1. For week 1, weekly runoff loads of N, P, and K were increased 58% (3.15 vs. 2.00 g/m^2), 25% (0.15 vs. 0.12 g/m^2), and 107% (1.99 vs. 0.96 g/m^2), respectively, for SM versus SP spacing. Observing greater nutrient loads for SM compared to SP during the beginning of the experiment was expected since SM container density through week 13 was twice that of SP. However, because of the previously noted increase in nutrient losses on a per-container basis with SP, nutrient loads for SM were less than 2-fold during the first 14 weeks. By the end of the experiment, increases in cumulative nutrient load for SM relative to SP were 1.6-fold (10.3 vs. 6.3 g/m^2) for N,

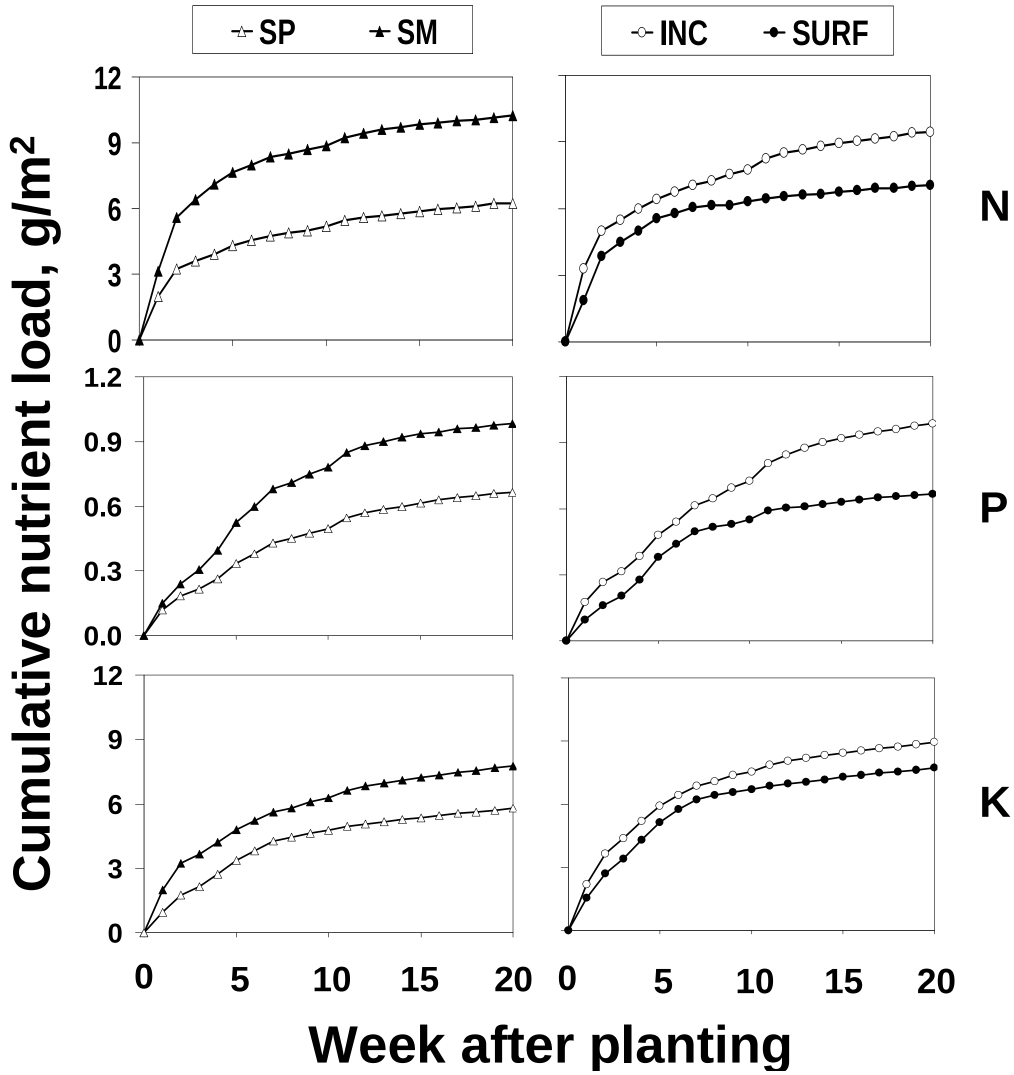

Fig. 8. Cumulative nutrient loads of N, P, and K in runoff during the production of sweet viburnum in trade #1 containers as affected by container spacing (left side graphs) and fertilizer placement (right side graphs). Resin-coated controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)] was either incorporated (INC) or surface-applied (SURF) at 15 g/container and containers were either spaced at planting (SP) or spaced midseason (SM). There were significant (*P* < 0.05) week by container spacing as well as a week by fertilizer placement interactions for all three nutrient elements; no mean separation statistics are given. N = NO_3-N + total Kjeldahl N (analysis exluded NO_3-N). n = 8.

1.5-fold (0.99 vs. 0.67 g/m^2) for P, and 1.3-fold (7.8 vs. 5.8 g/m^2) for K (Fig. 8).

Surface application of CRF decreased cumulative nutrient loads of N, P, and K 25% (9.45 vs. 7.05 g/m^2), 32% (0.665 vs. 0.985 g/m^2), and 13% (7.74 vs. 8.94 g/m^2), respectively, compared to CRF incorporation. This effect was greatest during week 1 when SURF decreased nutrient loads of N, P, and K 44% (1.85 vs. 3.30 g/m^2), 46% (0.10 vs. 0.18 g/m^2), and 30% (1.54 vs. 2.19 g/m^2), respectively. The ratio of nutrients in cumulative runoff (N:P:K) was 1.00:0.10:0.95 for INC and 1.00:0.10:1.10 for SP, suggesting that fertilizer placement had more effect on total amounts than on the relative amounts of nutrients in runoff.

Due to the presence of sandy soils and high water tables, Florida's groundwater supply is highly susceptible to the leaching of fertilizer N (35) and P (12). Furthermore, agricultural operations are often adjacent to surface bodies of water so that runoff and shallow water subsurface flow can have an immediate impact into water resources. For example, >38% of vegetable production in Florida is within 1000 ft of a body of water (24). The impact container nurseries might have on groundwater and surface water bodies will depend in large part upon whether or not production beds in the nursery are underlain with an impermeable material to help channel runoff into collection ponds or ditches. If runoff is collected onsite, then runoff data from this study may be useful for planning reuse strategies or designing treatment structures that allow natural processes to remove nutrient contaminants before entering off-site water bodies. Without an impermeable layer beneath containers, nutrient loads in runoff represent the potential for nutrients to move into underlying soils and groundwater. Since complex soil and hydrological processes ultimately control the fate of runoff N and P once these nutrients move out of containers (37), nutrient load results from this study may provide input data for assessing any impacts of container runoff on water quality.

Total N in runoff during the 20-week production was 4.6–11.1 g/m^2. For two 20-week crops per year using 75% of a

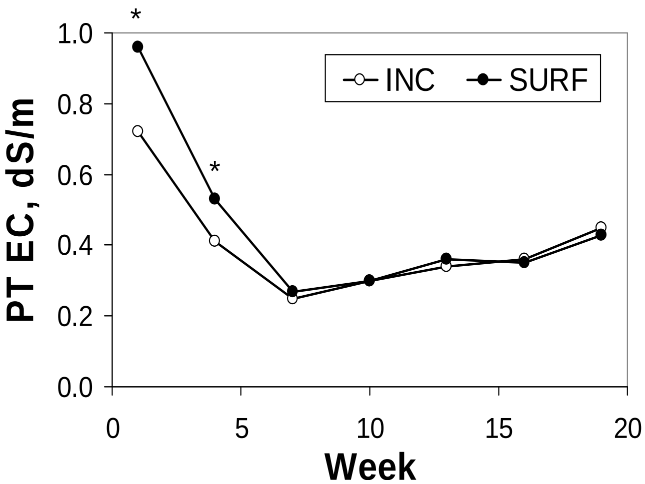

Fig. 9. Electrical conductivity (EC) of pour-through (PT) solutions obtained periodically during the production of sweet viburnum in trade #1 (2.7 liter) containers. Controlled-release fertilizer was either incorporated (INC) or surface applied (SURF) at planting. Means were averaged over two container spacing treatments (n = 40). * = significant ($P < 0.05$) fertilizer placement effect for that week.

site, the equivalent N runoff load would be 70–170 kg/ha/yr (60–150 lb/A/yr) from the N application of 650–1100 kg/ha/yr (580–980 lb/A/yr). With excessively irrigated turfgrass, 32 kg/ha/yr (30 lb/A/yr) of N leached from an application of CRF supplying N at 244 kg/ha/yr (218 lb/A/yr; 36). A residential mixed landscape fertilized with N at 150 kg/ha/yr (133 lb/A/yr) resulted in N leaching losses of 48 kg/ha/yr (43 lb/A/yr; 13). Tomato and pepper production typically leaves >100 kg/ha (89 lb/A) of N per crop (24) from the N application of 200–400 kg/ha (180–360 lb/A) per crop. Maximum leaching losses of N for citrus when fertilized with 230 kg/ha/yr (210 lb/A/yr) of N were 70 kg/ha/yr (63 lb/A/yr; 41). Based on these numbers alone, it appears that the potential impact of container production can be equal to or greater than other agricultural operations in Florida and that management practices designed to improve fertilizer efficiency in containers are needed.

Nutrient concentrations in runoff. Nutrient concentrations in runoff based on total runoff collected for all treatments during the experiment were 4.2–11.2 mg/liter of N, 2.9–7.5 mg/liter of NO_3-N, 0.4–0.8 mg/liter of NH_4-N, 1.3–3.9 mg/liter of TKN, 0.45–1.15 mg/liter P, 0.44–1.25 mg/liter orthophosphate-P, and 5.3–10.3 mg/liter K. Except for P, highest nutrient concentrations in runoff water were observed during the first or second week. For P, highest concentrations were observed during week 1 for INC (2.8 mg/liter) but not until week 5 for SURF (1.7 mg/liter). Peak NO_3-N concentrations, which occurred during week 2, were 19–53 mg/liter. By week 5, NO_3-N concentrations in runoff were <10 mg/liter and did not exceed 10 mg/liter for the remainder of the experiment. All treatments resulted in experiment-averaged NO_3-N concentrations <10 mg/liter, the drinking water standard (32). Although an absolute water quality standard has not been established for P, several watershed projects in Florida have used 0.01–0.05 mg/liter as critical concentrations below which P in surface water has minimal ecological impact in the watershed (11, 21). In general, average runoff P concentrations in this experiment were 10 to 100-fold higher than this range.

Pour-through substrate leachate tests. Pour-through (PT) EC provided a general indication of the rapid release of nutrients during the first four weeks of production but did not reflect the reduced nutrient leaching observed for SURF (Fig. 9). The ANOVA indicated a significant ($P < 0.05$) fertilizer placement by week effect. PT EC was higher ($P < 0.05$) for SURF than INC for weeks 1 (0.96 vs. 0.72 dS/m) and 4 (0.53

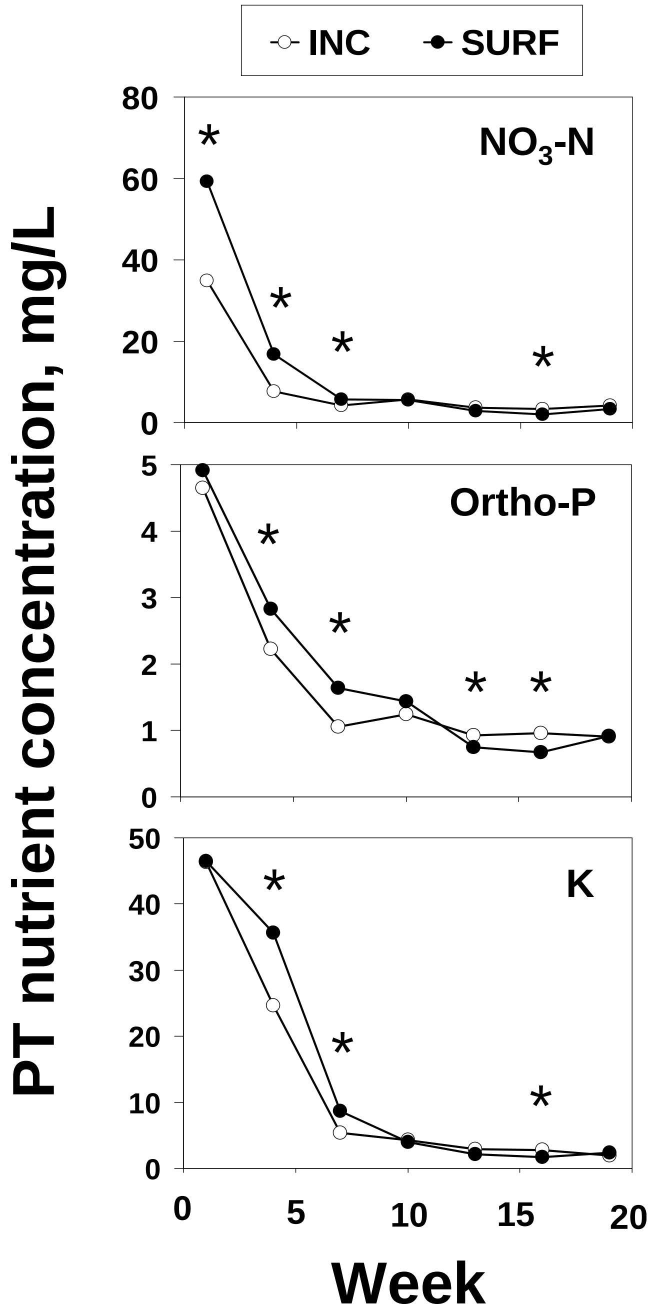

Fig. 10. Nutrient concentration of pour-through (PT) solutions obtained periodically during the production of sweet viburnum in trade #1 (2.7 liter) containers. Controlled release fertilizer was either incorporated (INC) or surface applied (SURF) at planting. Means were averaged over two container spacing treatments (n = 40). * = significant ($P < 0.05$) fertilizer placement effect for that week.

vs. 0.41 dS/m) but not thereafter. Higher PT EC for SURF compared to INC was not indicative of the relative nutrient leaching losses observed in runoff as INC resulted in greater leaching losses for nutrients than did SURF. The reason for this is not known but could be attributed to the pour-through method technique which may have 'flushed' released nutrients concentrated at the surface of SURF containers that were not readily leached with daily irrigation. Regardless, tri-weekly pour-through tests were not good indicators of how treatments affected runoff losses of nutrient. Treatments had no effect ($P < 0.05$) on PT pH (data not given). Pour-through pH ranged from a low of 5.8 at week 1 to a high of 6.4 at week 7. In general, PT pH levels indicated acceptable substrate pH conditions during the experiment. PT NO_3-N and PT K concentrations dropped below 10 mg/liter by week 7, the time at which active shoot growth was beginning (Fig. 10). Nutritional guidelines for container plant production suggest PT NO_3-N should be 15–25 mg/liter and PT K 10–20 mg/liter (46). Based upon these guidelines, container nutrition was less than optimal after the first month of growth. However, plants did not appear to be N deficient and continued to grow rapidly during the second half of the experiment when PT levels were low. Because we only applied one rate of fertilizer, we can not be certain of the adequacy of the N rate we used.

It is clear from this study that container spacing management can play an important role in plant growth and nutrient runoff. Shoot dry weight of SP plants was reduced 37% compared to SM. This effect was may have been exacerbated by the late summer planting when solar radiation levels and high air temperatures likely caused high substrate temperatures. For late fall to early spring plantings when solar radiation levels and air temperatures are lower, potential substrate heat stress problems associated with the SP container treatment may be reduced. Besides reduced plant growth, nutrient losses in runoff were also increased by spacing containers at planting instead of midseason. This latter effect was more important when CRF was incorporated than when surface-applied. When CRF was incorporated, spacing out containers at planting increased nutrient leaching losses (mg/container) of N, P, and K, 35, 30, and 45%, respectively. Based on this study, a recommendation for SM over SP would be justified by increased plant growth, improved irrigation utilization, and a reduction in runoff nutrient loss, particularly when CRF is incorporated.

Surface application of CRF did not affect plant growth but reduced nutrient leaching losses (mg/container), especially when containers were spaced at planting. When containers were spaced midseason, which is more representative of a typical spacing arrangement than SP, SURF reduced N and P leaching losses 16 and 25% respectively. Warren et al. (42) reported nutrient losses decreased 53–72% for N and 25–45% for P when a CRF was surface-applied versus incorporated. Based on the results of these studies and those of others (6, 44), surface application of CRF can reduce nutrient losses compared to incorporation method. Since the effects of fertilizer placement on plant growth are less certain, recommending one placement method over another may not always be as clear cut as it was in this experiment. INC is usually a simpler if not cheaper method of CRF application, but may result in less precise or less uniform application of CRF than SURF. There is also concern about damage to CRF coating during incorporation. Disadvantages of SURF include application labor costs and potential losses due to spillage during intense rains and high winds. With these caveats, our results indicate that compared to INC, SURF has the potential to reduce leaching losses of nutrients while maintaining equivalent plant growth.

Our results showed that reduced container substrate temperatures associated with SM compared to SP were associated with reduced nutrient leaching losses when CRF was incorporated but not when it was surface-applied. This was attributed to an increase in substrate temperature of 8–9C (14.4–16.2F) measured during week 1 and 4 for SP versus SM containers. Substrate temperatures at week 1 and 4 for the cooler SM containers were 33 and 35C (91 and 95F), respectively, much higher than the 21C (70F) which is the temperature at which the CRF was rated as an 8–9-month product. Cabrera (6) reported that the nutrient release response of resin-coated CRF to temperature was curvilinear with release becoming relatively constant with average daily temperatures above 25C (77F). Since average daily ambient temperatures in Florida approach or exceed 25C during summer months with active plant growth, it is not surprising to see why this CRF in our region has historically been used on 4–5 month crops despite its 8–9 month rating.

The impact of containerized plant production on water quality is being scrutinized by regulatory agencies. Water quality standards are complex, often nebulous, and vary depending on regional conditions. For example, the NO_3-N drinking water standard of 10 mg/liter is an important standard in rural areas with wells in close proximity to agricultural operations. However, for large receiving bodies of water such as lakes and estuaries, concentrations of N (including NO_3-N) and P are lower and more stable due to dilution and transformation processes that occur during the movement of water to these receiving bodies. In these situations, impacts of elevated nutrient levels in lakes and estuaries are typically ecological in nature, and nutrient loads are more applicable in assessing environmental impacts than are nutrient concentrations (37). Total maximum daily load assessments designed to achieve acceptable water quality are currently being conducted by water management districts in Florida. Results from this study provide data for these assessments and provide insight into the relative impacts that several management practices can have on runoff volume and quality.

Literature Cited

1. Beeson, Jr., R.C. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848–850.

2. Blessington, T.M., E.J. Garvery, and L.M. Howell. 1981. Effects of application methods of controlled-release fertilizers on growth and quality of *Rhododendron obtusum* 'Hinodegiri' grown in various media. HortScience 16:676–677.

3. Briggs, J., T. Whitwell, M.B. Riley, and T. Lee. 1998 . Cyclic irrigation and grass waterways combine to reduce isoxaben losses from container plant nurseries. J. Environ. Hort. 16:235–238.

4. Broschat, T.K. 2005. Rates of ammonium-nitrogen, nitrate-nitrogen, phosphorus, and potassium from two controlled-release fertilizers under different substrate environments. HortTechnology 15:332–335.

5. Broschat, T.K. 1995. Nitrate, phosphate, and potassium leaching from container-grown plants fertilizer by several methods. HortScience 30:74–77.

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

7. Colangelo, D.J. and M.H. Brand. 2001. Nitrate leaching beneath a containerized nursery crop receiving trickle or overhead irrigation. J. Environ. Qual. 30:1564–1574.

8. Conover, C.A. and R.T. Poole. 1992. Medium leachate characteristics and plant growth responses to four controlled-release fertilizer formulations. Proc. Fla. State Hort. Soc. 105:187–190.

9. Cox, D.A.1993. Reducing nitrogen leaching-losses from containerized plants: the effectiveness of controlled-release fertilizers. J. Plant Nutrition 16:533–545.

10. Craig, J.L, B.A. Birrenkott, and D.K. Struve. 2003. Nutrient uptake and dry weight patterns of three container-grown woody species. J. Environ. Hort. 21:209–215.

11. DeBusk, T.A., F.E. Dierberg, and K.R. Reddy. 2001. The use of macrophyte-based systems for phosphorus removal: an overview of 25 years of research and operational results in Florida. Water Sci. Tech. 44:39–46.

12. Elrashidi, M.A., A.K. Alva, Y.F. Huang, D.V. Calvert, T.A. Obreza, and Z.L. He. 2001. Accumulation and downward transport of phosphorus in Florida soils and relationship to water quality. Commun. Soil Sci. Plant Anal. 21:3099–3119.

13. Erickson, J.E., J.L. Cisar, J.C. Volin, and G.H. Snyder. 2001. Comparing nitrogen runoff and leaching between newly established St. Augustinegrass turf and an alternative residential landscape. Crop Sci. 41:1889–1895.

14. 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.

15. Fare, D.C., M. Halcomb, and S. Mullican. 1999. Application method affects controlled-release fertilizer response in pot-in-pot production. Proc. Southern Nurserymen's Assoc. Research Conf. 44:97–102.

16. Fernandez-Escobar, R., M. Benlloch, E. Herrera, J.J. Garcia-Novelo. 2004. Effect of traditional and slow-release N fertilizers on growth of olive nursery plants and N losses by leaching. Scientia Hortic. 101:39–49.

17. Frankenberger, J.R. and M.D. Smolen. 2003. Land-grant universities: research, education, and local leadership to improve TMDLs. *In*: Total Maximum Daily Load (TMDL) Environmental Regulations II. Proc. of the Nov. 8–12, 2003, Amer. Soc. Agric. Eng. Specialty Conf., St. Joseph, MI, p. 349–355.

18. Garber, M.B., J.M. Ruter, and J.T. Midcap. 2002. Survey of container nursery irrigation practices in Georgia. Proc. Southern Nurserymen's Assoc. Research Conf. 47:600–602.

19. Haman, D.Z., A.G. Smajstrla, and D.J Pitts. 1997. Uniformity of sprinkler and microirrigation systems for nurseries. Bulletin 321. Florida Cooperative. Extension Service. Institute Food Agricultural Sciences. Univ. Florida. Gainesville, FL.

20. Hasek, R.F., R.H. Sciaroni, and R.L. Branson. 1986. Water conservation and recycling in ornamentals production. HortScience 21:35–38.

21. Havens, K.E. 1995. Secondary nitrogen limitation in a subtropical lake impacted by non-point source agricultural pollution. Environ. Pollution 89:241–246.

22. Headley, T.R., D.O. Huett, and L. Davison. 2001. The removal of nutrients from plant nursery irrigation runoff in subsurface horizontal-flow wetlands. Water Sci. Technology 44:77–84.

23. Hershey, D.R. and J.L. Paul. 1982. Leaching losses of nitrogen from pot chrysanthemums with controlled-release or liquid fertilization. Scientia Hortic. 17:145–152.

24. Huang, W., E.D. Beach, J. Fernandez-Cornejo, and J.D. Uri. 1994. An assessment of the potential risks of groundwater and surface water contamination by agricultural chemicals used in vegetable production. Sci. Total Environ.153:151–167.

25. Huett, D.O. 1997. Fertiliser use efficiency by containerized nursery plants. 2. Nutrient leaching. Aust. J. Agric. Sci. 48:259–265.

26. Huett, D.O. and S.C. Morris. 1999. Fertiliser use efficiency by containerized nursery plants. 3. Effect of heavy leaching and damaged fertilizer prills on plant growth, nutrient uptake, and nutrient loss. Aust. J. Agric. Res. 48:259–265.

27. Husby, C.E., A.X. Niemiera, J.R. Harris, and R.D. Wright. 2003. Influence of diurnal temperature on nutrient release patterns of three polymer-coated fertilizers. HortScience 38:387–389.

28. Ingram, D.L. 1981. Characterization of temperature fluctuations and woody plant growth in white poly bags and conventional black containers. HortScience 16:762–763.

29. Ingram, D., C. Martin, and B. Castro. 1988. Container spacing treatments influence temperature fluctuations and holly growth. Proc. Fla. State Hort. Soc. 101:328–331.

30. Jarrell, W.M., S.J. Whaley, and B. Miraftabi. 1983. Slow-release fertilizer and water management with container-grown Ligustrum texanum. Scientia Hort. 19:177–190.

31. Johnson, C.R. and D.L. Ingram. 1984. *Pittosporum tobira* response to container medium temperature. HortScience 19:524–525.

32. Kuhl, K.A., R.J. Budell, and B.L. McNeal. 1996. Nitrogen BMP program implementation. Soil Crop Sci. Soc. Florida Proc. 55:67–70.

33. Lea-Cox, J.D., D.S. Ross, A.G. Ristvey, and J.D. Murray. 2002. Estimating nitrogen and phosphorus total maximum daily loads for container nursery and greenhouse production systems. *In*: Total Maximum Daily Load (TMDL) Environmental Regulations. Proc. of the March 11–13, 2002, Amer. Soc. Agric. Eng. Specialty Conf. Ft. Worth, TX. p. 466–471.

34. Lunt, O.R. and J.J. Oertli. 1962. Controlled release of fertilizer minerals by incapsulatin membranes: II. Efficiency of recovery, influence of soil moisture, mode of application, and other considerations related to use. Soil Sci. Soc. Amer. Proc. 26:584–587.

35. McNeal, B.L., C.D. Stanley, W.D. Graham, P.R. Gilreath, D. Downey, and J.F. Creighton. 1995. Nutrient-loss trends for vegetable and citrus fields in west-central Florida: I. Nitrate. J. Environ. Qual. 24:95–100.

36. Morton, T.G., A.J. Gold, and W.M Sullivan. 1988. Influence of overwatering and fertilization on nitrogen losses from home lawns. J. Environ. Qual. 17:124–130.

37. Pionke, H.B. and R.R. Lowrance. 1991. Fate of nitrate in subsurface drainage waters. *In*: R.F. Follet, D.R. Keeney, and R.M. Cruse (eds.). Managing Nitrogen for Groundwater Quality and Farm Profitability. Soil Sci. Soc. Amer., Madison, WI

38. Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and Alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32–35.

39. Ristvey, A.G., J.D. Lea-Cox, and D.S. Ross. 2001. Nitrogen uptake, partitioning and loss in container-production systems. Proc. Southern Nurserymen's Assoc. Research Conf. 46:101–107.

40. 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.

41. Syvertsen, J.P. and M.L. Smith. 1996. Nitrogen efficiency and leaching losses from lysimeter-grown Citrus trees fertilized at three rates. J. Amer. Soc. Hort. Sci. 121:57–62.

42. Warren, S.L., T.E. Bilderback, and H.H. Tyler. 1997. Does method of fertilizer application (surface or incorporation) affect nutrient losses of controlled release fertilizers? Proc. Southern Nurserymen's Assoc. Research Conf. 42:141–143.

43. Weatherspoon, D.M. and C.C. Harrell. 1980. Evaluation of drip irrigation for container production of woody landscape plants. HortScience 15:488–489.

44. Witcher A.L., E.W. Bush, D. Bates, and A. Gray. 2002. Evaluation of fertilizer and irrigation production systems for large containers. Proc. Southern Nurserymen's Assoc. Research Conf. 47:606–610.

45. Yeager, T., C. Gilliam, T. Bilderback, D. Fare, A. Niemiera, and K. Tilt. 1997. Best management practices — guide for producing container-grown plants. Southern Nursery Association. Atlanta, GA.

46. Yeager, T.H., D.L. Ingram, and C.A. Larsen.1989. Response of Ligustrum and azalea to surface and growth medium-incorporated fertilizer applications. Proc. Fla. State Hort. Soc. 102:269–271.