Research Reports

Consequences of Excessive Overhead Irrigation on Runoff during Container Production of Sweet Viburnum[1]

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Abstract

The effects of irrigation rate on volume and nutrient content of runoff were investigated. Runoff (leachate plus un-intercepted irrigation and rain) was collected weekly for 20 weeks during production of trade #1 (2.7-liter) sweet viburnum [*Viburnum odoratissimum* (L.) Ker-Gawl.] fertilized with a resin-coated, controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)]. Treatments were a factorial arrangement of two irrigation rates [1 (IRR1) or 2 (IRR2) cm/day (0.39 or 0.79 in)] and two fertilizer rates [15 (FRT15) or 30 (FRT30) g/container (0.53 or 1.06 oz)]. Total runoff volume was 970 liters/m^2 (2380 gal/100 ft^2) for IRR1 and 2220 liters/m^2 (5450 gal/100 ft^2) for IRR2 which was 49 and 69%, respectively, of total irrigation plus rainfall. Increasing the irrigation rate from 1 to 2 cm/day increased leaching losses of N, P, and K 34, 38, and 45%, respectively, with FRT15 and 21, 28, and 23%, respectively, with FRT30. Increasing the irrigation rate increased nutrient loads (g/m^2) but decreased nutrient concentrations (mg/liter) in runoff.

Index words: controlled-release, leaching, nutrient load, nitrogen, Osmocote, phosphorus, potassium, pour-through, water quality.

Significance to the Nursery Industry

We applied 1 and 2 cm/day of overhead irrigation water and measured the volume and nutrient content of runoff (un-intercepted irrigation plus rain) collected continuously during production in #1 containers. Ninety-five percent of the additional water applied with the higher irrigation rate was collected as runoff indicating that 2 cm/day was excessive. The higher irrigation rate decreased plant biomass and this effect was not reduced by a higher rate of CRF application. Consequences of excessive irrigation in increasing runoff volume and nutrient losses were quantified providing justification for evaluating and implementing precision irrigation practices designed to minimize runoff during container production.

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Introduction

Agricultural production practices are being scrutinized for their potentially detrimental impact on local and regional water resources. The container nursery industry is no exception and considerable effort is being made to implement best management practices (BMP) in order to minimize environmental effects. Information on the direct effects of irrigation and fertilizer application on runoff quality and quantity is useful

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in developing and selecting BMP in order to minimize economic risks and maximize environmental stewardship. This information may also support the development of physically-based models used to estimate water and nutrient dynamics in container production.

Due to limited substrate volume and the large number of containers per unit area, production in small-sized containers [<trade #7 (30 liter)] typically entails daily overhead irrigation (2). Irrigation application uniformity is often low and precise application volumes are uncertain (12, 28). Under these circumstances, many irrigation managers err on the side of caution and apply more water than is actually needed to maintain the crop. The likelihood for excessive irrigation is especially great during early stages of crop growth when evapotranspiration rates are lower. Coupled with the fact that containers occupy a fraction of the production surface even with dense spacing arrangements, it is not surprising to find that overhead irrigation efficiency (irrigation retained/irrigation applied) is low, typically 20 to 30% (4, 6, 32).

Container plant production commonly uses controlled-release fertilizer (CRF) applied in one or two applications to supply a plant's season-long demand for nutrients. Release of nutrients from CRF prills is temperature-dependent (19, 23) while movement through and out a container is driven primarily by irrigation and rainfall-induced leaching (15, 17). During early stages of plant growth, nutrient uptake is low (10) and leaching losses are greater than during later periods of active growth with well-established root systems (18, 24). Also, a CRF may have a significant fraction of quickly released product to provide adequate nutrition for young plants with limited root systems. As a consequence, the potential for fertilizer nutrient leaching can be relatively high at the beginning of the season (17, 24). To ensure adequate nutrition, high CRF application rates are often used and fertilizer use efficiency can be low (27).

Several studies have quantified the affect of leachate volume on nutrient leaching. Tyler et al. (31) observed that increasing the irrigation volume 1.8-fold, increased the leaching volume 2.7-fold, the amount of P leached 2.4-fold and the amount of N leached 1.2-fold suggesting that P was more affected by the increase in irrigation volume than N. They also noted that irrigation volume had less of an effect when N was limiting than when higher, non-limiting fertilizer rates were used. Increasing the leachate volume 3.5-fold resulted in a 1.5 fold increase in cumulative N leaching (17). The relative effect of increasing leaching volume on N leaching loss was greatest at low leaching volumes and decreased as the leaching volume increased (17). On the other hand, a 4-fold increase in leachate volume (50 to 200 mL per 335-mL container) resulted in a 1.5-fold increase in N loss but had no affect on P loss. Because relative increases in N leaching losses were less than the relative increases in N leaching volumes, leachate N concentrations in these studies decreased as irrigation volumes increase.

The objective of this experiment was to quantify the effects that overhead irrigation rate have on the volume and nutrient content of runoff generated during container production. Treatments, which included moderate and high application rates of water and fertilizer, were designed to: 1) determine the relationship between increased irrigation volume and increased runoff volume and nutrient loss, 2) determine if the effect of increased irrigation volume on nutrient loss depends on the CRF rate, and, more generally, 3) provide information that may be useful for improving the production and environmental management of water and nutrients during container production. To this end, we compared the volume and nutrient content of runoff collected continuously from runoff platforms on which a container crop of sweet viburnum was grown. Sweet viburnum was chosen because it has a relatively high requirement for nutrients and water and has received attention as a model crop for irrigation and growth studies (1, 21, 24, 25).

Materials and Methods

The experiment was conducted at the University of Florida, Gainesville and was similar in design to research reported previously (24). The site consisted of four 6.1 × 6.1 m (20 × 20 ft) irrigation zones each irrigated with four overhead sprinklers operating at a regulated pressure of 207 kPa (30 psi). The sprinkler pattern was adjusted to deliver water uniformly at 1.8 cm/hr (0.7 in/hr). Four 1.2 × 1.2 m (4 × 4 ft) platforms designed to collect all runoff (leachate and un-intercepted irrigation and rainfall) were placed within each of the four irrigation zones for a total of 16 platforms. Runoff was collected within an 89 × 105 cm (35 × 41 in) [0.937 m^2 (10.1 ft^2)] area leaving 0.6 m^2 (6.5 ft^2) for border plants (24). There were no border plants on the lower edge of the collection area to allow uninterrupted flow of runoff into the collection vessel. Platforms were covered with standard nursery-grade polypropylene groundcloth (Green Line Style 31411; LINQ Industrial Fabrics, Summerville, SC) underlain with one layer of 45-mil-thick (1.1 mm) pond liner (PondGard, Firestone Building Products; Carmel, IN) to divert runoff water into a 110 liter (31 gal) collection vessel. Three sections of 1.3 cm (i.d.; 0.5 in) pipe were fastened underneath the pond liner to delineate the collection area from the border area. Two 9.5 cm (i.d.; 3.7 in) cups were attached to each platform to monitor daily inputs of irrigation and rain.

The container substrate was 2:1:1 aged pine bark:sphagnum peatmoss:coarse sand (by vol). During mixing of components, the substrate was amended with 4.1 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, 16.5-cm-top diameter (6.5 in) containers (Elite 300; ITML Horticultural Products, Brantford, Ont., Canada) were filled to a final substrate volume of 2.4 liter [fill height of 15 cm (5.9 in)]. The water holding capacity of the substrate was determined by hand watering five substrate-filled containers several times a day over a period of 4 days until container weights, after allowing for drainage, stabilized. Substrate from each container was subsequently removed and air dried. Available water content was calculated as: [(saturated substrate weight – air-dried substrate weight) ÷ substrate volume]. Water holding capacity averaged 25% (0.25 cm^3 of H_20 per cm^3 of substrate) which was equivalent to 600 mL (20 fl oz) per container or a depth of 3 cm (1.2 in) of water. Each container was fertilized with either 15 g (FRT15) or 30 g (FRT30) of a resin-coated CRF [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F); Scotts Co., Marysville, OH] which was derived from ammonium nitrate, ammonium phosphate, calcium phosphate, and potassium sulfate and contained 8% NO_3-N and 10% NH_4-N. Due to imperfect coating of the CRF prills, only 83% of the CRF was labeled as controlled-release product. The FRT15 rate supplied 2.7, 0.39, and 1.5 g/container of N, P, and K, respectively, and FRT30 supplied 5.4, 0.79, and 3.0

Table 1. **Volume, electrical conductivity (EC), and nutrient content of water collected during the watering-in of containers (32 container/m^2) immediately after transplanting but before the first irrigation. Water was applied by hand with a breaker nozzle. Water collected included container leachate plus un-intercepted irrigation water. Controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)] was incorporated.**

Fertilizer rate[z] (g/container)	Runoff volume[y] (liters/container)	EC (dS/m)	Nutrient concentration in runoff water (mg/liter)					
			NO_3-N	NH_4-N	TKN[x]	N[w]	P	K
15	1.0	0.50	48	28	62	110	5.4	61
30	1.1	0.63	81	50	96	177	8.9	74
Controls[v]								
Unfertilized substrate	1.0	0.42	0	0	3	3	0.4	33
Irrigation water	—	0.36	0	0	0	0	0.0	1

[z]Significant ($P < 0.05$) fertilizer rate effect for EC and all nutrient concentrations except K.
[y]Mean volume of 30 containers.
[x]TKN = total Kjehdahl N.
[w]N = NO_3-N + TKN.
[v]n = 3 (unfertilized substrate) and n = 2 (irrigation water).

g/container of N, P, and K, respectively. The CRF was incorporated on an individual container basis to ensure accurate application rates and uniform distribution. Rooted cuttings of sweet viburnum [*Viburnum odoratissimum* (L.) Ker-Gawl.] grown as 700-mL liners (32 per trade tray) were transplanted one per container on March 24, 2004. Containers were placed on platforms at 32 container/m^2 (300 container/100 ft^2) in a square 'pot-to-pot' arrangement and watered by hand using a hose and breaker nozzle. The volume of water applied was 80 liters/m^2 (196 gal/100 ft^2), which was sufficient to thoroughly wet the substrate. The volume of drainage from this initial watering was determined and samples were collected for nutrient analyses in the same manner as runoff water samples. Containers were spaced at the end of week 13 by removing every other container. This resulted in a density of 16 container/m^2 (150 container/100 ft^2) until the end of the experiment. There were 30 containers per collection area for the 32 containers/m^2 spacing and 15 containers per collection area for the 16 container/m^2 spacing.

Plants were irrigated daily with either 1 cm (IRR1; 0.39 in) or 2 cm (IRR2; 0.79 in) of water applied predawn (usually at 0500 HR) in one continuous application. In our experience, IRR1 is normally sufficient for producing a sellable sweet viburnum crop with this container and substrate. The irrigation water was from a municipal source and contained low levels of N, P, and K (Table 1). Runoff water was collected on a weekly basis. No attempt was made to distinguish the relative contributions of leachate versus un-intercepted irrigation water. Water samples from each weekly runoff collection were filtered and stored frozen at –20C (–4F) until nutrient analyses were performed.

After 1 week and every 3 weeks thereafter, substrate solution was extracted from five containers per platform by adding 200–300 mL (6.8–10.4 fl oz) of de-ionized water, which was enough to collect 120 mL (4.1 fl oz) of leachate. The pour-through procedure was performed between 0800 HR and 0900 HR, 2 to 3 hours after irrigation. The pour-through extracts were filtered and stored frozen at –20C (–4F) until nutrient analyses were performed.

Plant height, width, and size index were determined every 3 weeks on five plants per platform. Plant height was the distance from the substrate surface to the top of the canopy. Plant width was the average of two perpendicular measurements with one measurement being the widest. Plant size index was calculated as: (plant height + plant width) ÷ 2. The experiment was terminated on August 12, 2004, 20 weeks after planting. Plant size index and shoot (aerial tissue) dry weight were determined on each of the 15 plants per platform.

Runoff and pour-through solutions were analyzed for NH_4-N, NO_x-N (NO_3-N), total Kjehldahl N (TKN), orthophosphate P (ortho-P), total P (P), and K by the Analytical Research Laboratory, University of Florida, Gainesville. The analytical procedure for TKN did not include NO_3-N. Weekly nutrient load in runoff was calculated by multiplying nutrient concentration by weekly runoff volume. Weekly nutrient loss on a per-container basis was calculated as weekly nutrient load divided by the container density for that week. For parameters collected on a weekly basis, the experiment was analyzed as a split-plot design with two blocks, four treatments as main plots, and 20 weekly measurements as subplots. The four treatments were a factorial arrangement of two irrigation rates and two fertilizer rates. If a week by treatment interaction effect was found to be significant and important, an ANOVA was conducted for each week to help determine how the treatment response changed over time. Final plant size index and shoot dry weight data were analyzed as a randomized complete block design. All ANOVA tests were conducted using the PROC GLM procedure of the Statistical Analysis System Version 8.0 (SAS Institute, Cary, NC).

Results and Discussion

Water inputs and runoff volume. Weekly irrigation plus rain (W) averaged 93 liters/m^2 (228 gal/100 ft^2) for IRR1 and 160 liters/m^2 (393 gal/100 ft^2) for IRR2. An interaction ($P < 0.05$) between irrigation rate and week (Table 2) was due to higher rainfall (Fig. 1) and thus greater W during the second half of the season (Fig. 2). Water inputs for IRR1 averaged 77 liters/m^2 (189 gal/100 ft^2) for weeks 1 to 10 and 110 liters/m^2 (270 gal/100 ft^2) during weeks 11 to 20 while water inputs for IRR2 averaged 144 liters/m^2 (353 gal/100 ft^2) for weeks 1 to 10 and 175 liters/m^2 (430 gal/100 ft^2) for weeks 11 to 20. Total irrigation applied for IRR1 and IRR2 was 1353 and 2674 liters/m^2 (3321 and 6563 gal/100 ft^2), respectively. Rainfall during the experiment totaled 52 cm (20.5 in). The rainfall [520 liters/m^2 (1276 gal/100 ft^2)] was

Table 2. **Analysis of variance of the split-plot design used to evaluate irrigation rate and fertilizer rate 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.**

		Significance ($P > F$)[z]				
				Nutrient loss in runoff[y]		
ANOVA source[x]	df	Irrigation + rain[w]	Runoff volume[w]	N	P	K
Block	1	—	—	—	—	—
Irrigation rate (I)	1	***	***	**	**	**
Fertilizer rate (F)	1	NS	NS	***	***	***
I × F	1	NS	NS	NS	NS	NS
Main plot error	3	—	—	—	—	—
Week	19	***	***	***	***	***
I × week	19	***	***	***	***	***
F × week	19	NS	NS	***	***	***
I × F × week	19	NS	NS	*	***	***
Sub-plot error	236	—	—	—	—	—

[z]NS, *, **, *** Non-significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

[y]Grams/container.

[x]Split-plot design with irrigation rate and fertilizer rate as main plot factors and week as sub-plot factor. Total df = 319.

[w]Liters/m^2.

equivalent to 28% of total W for IRR1 and 16% of total W for IRR2. Of the 52 cm of rain, 46 cm (18.1 in) or 88% fell during weeks 11 to 20. Total W for the experiment was 1869 liters/m^2 (4587 gal/100 ft^2) for IRR1 and 3190 liters/m^2 (7830 gal/100 ft^2) for IRR2. On a per-container basis, this was equivalent to 81 liters/container (21.4 gal) for IRR1 and 137 liters/container (36.2 gal) for IRR2.

Weekly runoff volume (RV) averaged 48 liters/m^2 (118 gal/100 ft^2) for IRR1 and 111 liters/m^2 (272 gal/100 ft^2) for IRR2 with a significant ($P < 0.05$) irrigation by week interaction (Table 2). As noted with W, the interaction between irrigation rate and week on RV was attributed to greater rainfall during the second half of the season. Runoff volume for IRR1 averaged 32 liters/m^2 (79 gal/100 ft^2) for weeks 1 to 10 and 65 liters/m^2 (160 gal/100 ft^2) during weeks 11 to 20 and RV for IRR2 averaged 97 liters/m^2 (238 gal/100 ft^2) for weeks 1 to 10 and 126 liters/m^2 (309 gal/100 ft^2) for weeks 11 to 20 (Fig. 2). Total RV was 966 liters/m^2 (2371gal/100 ft^2) for IRR1 and 2225 liters/m^2 (5461 gal/100 ft^2) for IRR2. On a per-container basis, RV for IRR1 and IRR2 was 44 and 98 liters/container (11.6 and 25.9 gal), respectively. Runoff volume as a fraction of W was increased from 49 to 69% when the irrigation rate was increased from 1 to 2 cm/day. Evi-

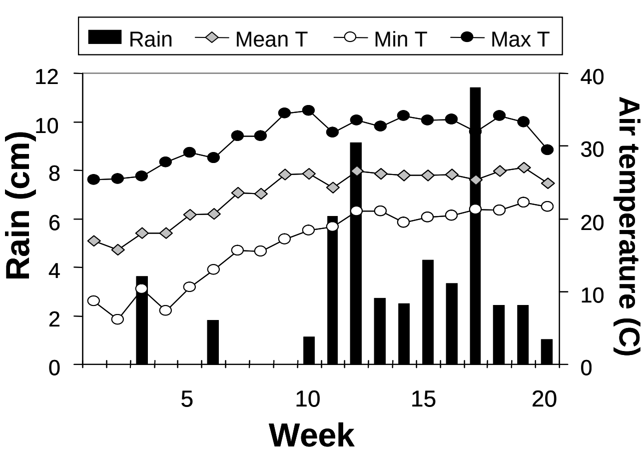

Fig. 1. Rain and air temperatures (T) during the experiment conducted in Gainesville, Florida from March 24 to August 12, 2004.

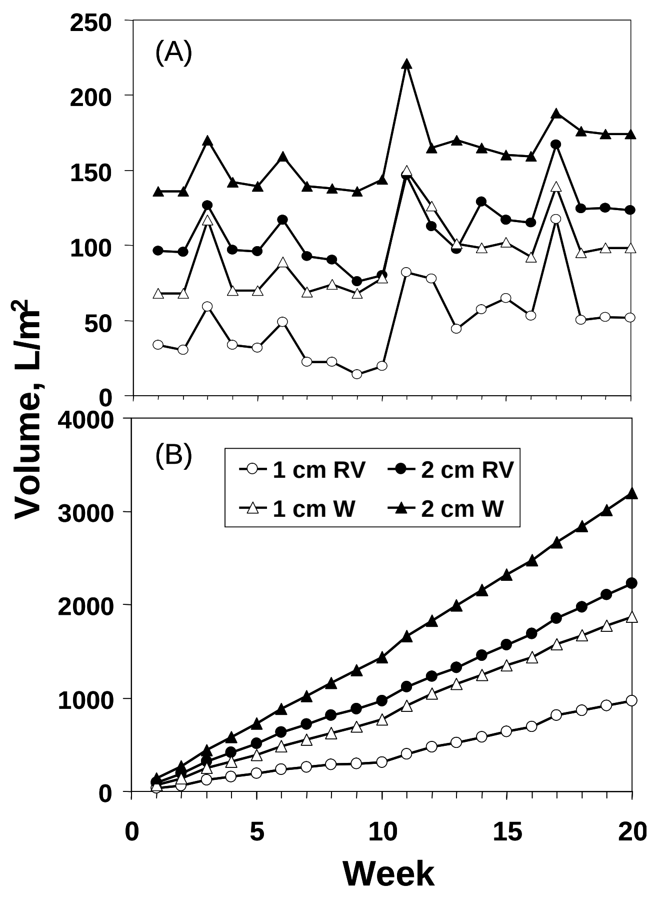

Fig. 2. (A) Weekly and (B) cumulative volumes of irrigation plus rainfall (W) and runoff (RV) during the production of sweet viburnum in trade #1 (2.7 liter) containers. Irrigation was applied daily at either 1 or 2 cm (0.39 or 0.79 in). Means were averaged over two fertilizer rates (n = 8).

dence that IRR2 was excessive was found in the fact that the increase in RV from increasing the irrigation rate from 1 to 2 cm/day (1259 liters/m^2) represented 95% of the increase in W attributed to the same effect (1321 liters/m^2).

Plant growth. Plant growth was affected ($P < 0.05$) by both fertilizer rate and irrigation rate independently. When averaged over the two irrigation rates, doubling the fertilizer rate increased shoot dry weight 32% (53 vs 40 g/plant), plant size index 11% [51 vs 46 cm (20.1 vs 18.1 in)], plant width 7% [57 vs 53 cm (22.4 vs 20.9 in)] and plant height 15% [46 vs 40 cm (18.1 vs 15.7 in)]. The growth response to fertilizer rate was elicited during the period from week 7 to week 10; relative changes in shoot size index thereafter were not affected ($P > 0.05$) by fertilizer rate (Fig. 3). Doubling the irrigation rate decreased ($P < 0.05$) shoot dry weight 6% (44.8 vs 47.7 g/plant), however, plant size index was unaffected ($P > 0.05$). A reduction in shoot dry weight is further evidence that IRR2 was excessive in this experiment.

Nutrient loss during initial watering-in of transplants. Initial hand-watering of containers immediately after transplanting liners resulted in nutrient loss (Table 1). Of the 80 liters/m^2 (196 gal/100 ft^2) applied to wet the substrate and water-in transplanted liners, 40% or 33 liters/m^2 (81 gal/100 ft^2) was recovered as runoff. The runoff contained relatively high concentrations of all nutrients, and with the exception of K, these concentrations were increased by the higher fertilizer rate. While unfertilized substrate contributed low levels of N and P to runoff, K loss from unfertilized substrate was approximately half of that lost from fertilized substrate. Nutrient losses as a percent of that applied in fertilizer were 3 to 4% for N, 1% for P, and 3 to 4% for K. Nutrient quantities lost during initial watering-in of transplanted liners represented approximately 10% of total nutrient quantities subsequently collected in runoff during the experiment.

Nutrient loss in runoff. Both irrigation rate and fertilizer rate affected nutrient loss in runoff and the interaction between these two factors varied with week during the experiment (Table 2). In general, doubling the irrigation rate from 1 to 2 cm/day had a greater relative effect in increasing nutrient loss with FRT15 than with FRT30. With FRT15, doubling the irrigation rate increased cumulative loss of N 34% (852 vs 637 mg/container), P 38% (111 vs 80 mg/container), and K 45% (694 vs 479 mg/container). With FRT30, doubling the irrigation rate increased cumulative loss of N 21% (1884 vs 1553 mg/container), P 28% (228 vs 178 mg/container), and K 23% (1227 vs 997 mg/container). For most weeks the above noted effects of irrigation and fertilizer rates held true, however, there were some weeks where effects were different (Fig. 4). For weeks 2, 3, 5, 6, 12, 13, and 15, there was no effect ($P < 0.05$) of irrigation on runoff N loss. Also, during weeks 11 and 17 N loss was greater for IRR1 than for IRR2. During weeks 11 and 17 significant rainfall (Fig. 1) occurred apparently leaching N that had been accumulating at a higher rate with IRR1 than with IRR2. In contrast, high rainfall in week 12 did not affect N runoff loss similarly. This was likely because most of any accumulated N had been leached during week 11.

Increasing irrigation from 1 to 2 cm/day increased percent N loss from 24 to 32% with FRT15 and from 29 to 35% with FRT30. Similarly for P, increasing irrigation from 1 to 2 cm/day increased percent P loss from 21 to 28% with FRT15 and from 23 to 29% with FRT30. For K, increasing irrigation from 1 to 2 cm/day increased percent K loss from 32 to 46% with FRT15 and from 33 to 41% with FRT30. Research has shown percent nutrient leaching losses with CRF in container production to be 10 to 40% for N, 5 to 20% for P, and 20 to 40% for K (7, 8, 9, 13, 22, 26, 28, 30). While our percent N and K loss results fell within the upper ends of the above ranges, percent P losses were higher. High P losses in this trial were likely due to the high temperatures and high rainfall experienced during the second half of the experiment (Fig. 1).

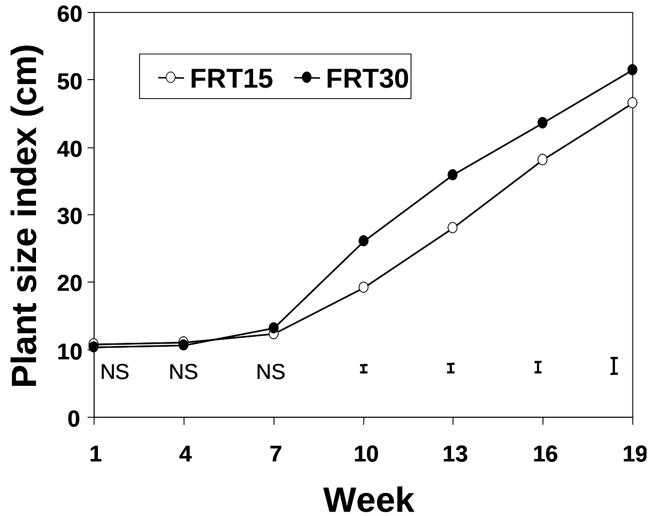

Fig. 3. Plant size index [(plant height + average plant width) ÷ 2)] of sweet viburnum grown in trade #1 (2.7 liter) containers. Controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70C)] was incorporated at 15 or 30 g per container. Means were averaged over two irrigation rates (n = 40). The main effect of fertilizer rate was significant ($P < 0.05$) for weeks 10, 13, 16, and 19 (vertical bars represent 95% confidence intervals).

Nutrient loss in runoff was greatest (Figs. 4, 5) immediately after planting (weeks 1 to 3) and during a 3 to 4 week period immediately after containers were spaced (weeks 14 to 17). For all treatments, 16 to 25% of total N loss for the experiment was recovered during week 1 and 30 to 35% by week 3. For P, 14 to 19% of total P loss in the experiment occurred during week 1 and 30 to 32% by week 3. For K, 17 to 22% of total K loss occurred during week 1 and 34 to 38% by week 3. Early runoff nutrient loss was probably due to the CRF itself which contained 17% imperfectly coated product and therefore behaved as a relatively soluble fertilizer source. The second period of increased nutrient loss (week 14 to 17) may have been due to increased nutrient release from CRF after spacing containers. By placing containers at a wider spacing, greater radiation exposure to container walls can increase substrate temperature (20, 24) and hence CRF release. A similarly-sized spike in nutrient loss immediately after spacing containers was not observed in a companion trial with the same CRF (24), however, the latter experiment was conducted in the fall and containers were spaced when temperatures and solar radiation levels were lower than in the present experiment. Increased nutrient loss in runoff during the second half of the present experiment coincided with significant increases in air temperatures (Fig. 1). Birrenkott

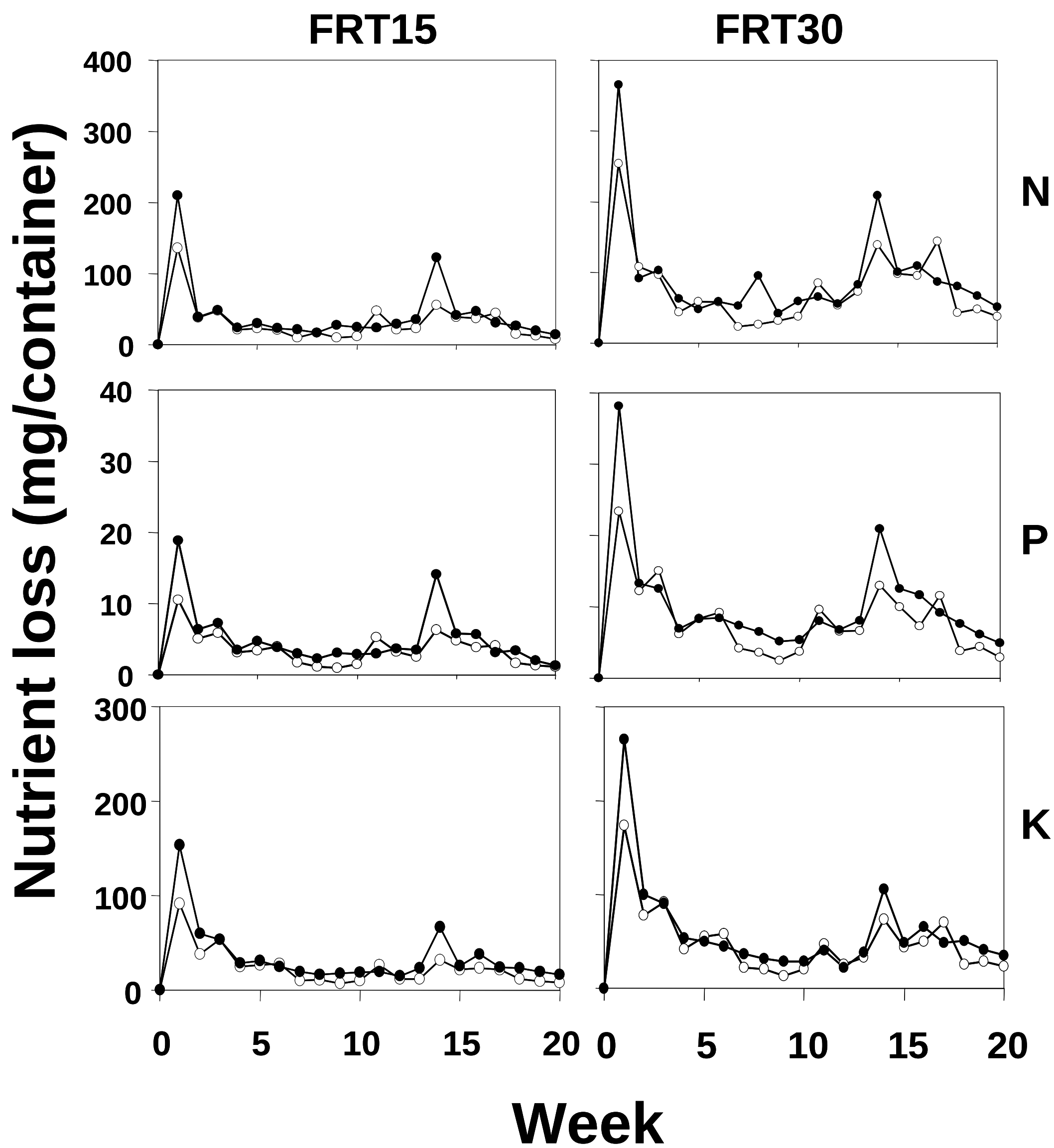

Fig. 4. Weekly loss of nutrients in runoff during the production of trade #1 (2.7 liter) sweet viburnum. Irrigation water was applied at 1 (–○–) or 2 (–●–) cm per day (0.39 or 0.79 in) and controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12) 8–9 month 21C (70F)] was incorporated at 15 g (FRT15) or 30 g (FRT30) per container. N = NO_3-N + Total Kjeldahl N. A week × fertilizer rate × irrigation rate interaction (*P* < 0.05) was observed for each of the three nutrient elements. (n = 4).

et al. (5) reported a similar pattern of increased nutrient release as temperatures increased during the transition from spring to summer months.

Nitrate-N was the predominant form of N in runoff accounting for 68 to 70% of total N loss leaving TKN accounting for 30 to 32% of total N loss. Ammonium-N accounted for 24 to 32% of total N loss in runoff or 77 to 99% of TKN. Orthophosphate-P accounted for 89 to 92% of P. A linear equation relating P (y) and ortho-P (x) concentrations (mg/liter) in runoff was found to be: y = 0.03 + 1.10x (R^2 = 0.99, n = 320). There was low variation in the distribution of N and P forms in runoff due to treatments indicating that irrigation rate and fertilizer rate had greater effect on the total amounts of N and P and relatively little effect on the forms of N and P in runoff.

Nutrient load is the mass of a nutrient element being moved from one location to another (27). In many areas, regulatory agencies have established total maximum daily loads (TMDL) for specific areas which if exceeded, indicate that ecologically-damaging nutrient enrichment may occur. As reported here, nutrient loads represent the potential for the movement of nutrients away from the production area. Increasing the irrigation rate increased nutrient load but decreased nutrient concentration in runoff. Doubling the irrigation rate increased runoff NO_3-N load 30% for FRT15 (15.3 vs 11.8 g/m^2) and 25% (34.6 vs 27.6 g/m^2) for FRT30 but decreased average flow-weighted NO_3-N concentration 46% (7 vs 13 mg/liter) for FRT15 and 43% (16 vs 28 mg/liter) for FRT30. All treatments except the IRR2/FRT15 resulted in average flow-weighted NO_3-N concentrations >10 mg/liter, the maximum allowable in drinking water (14). Similar results were observed for ortho-P where doubling the irrigation rate increased runoff ortho-P load 40% (3.0 vs 2.2 g/m^2) for FRT15 and 27% (6.1 vs 4.8 g/m^2) for FRT30 but decreased average flow-weighted ortho-P concentration 42% (1.3 vs 2.3 mg/liter) for FRT15 and 44% (2.8 vs 4.9 mg/liter) for FRT30. Since total

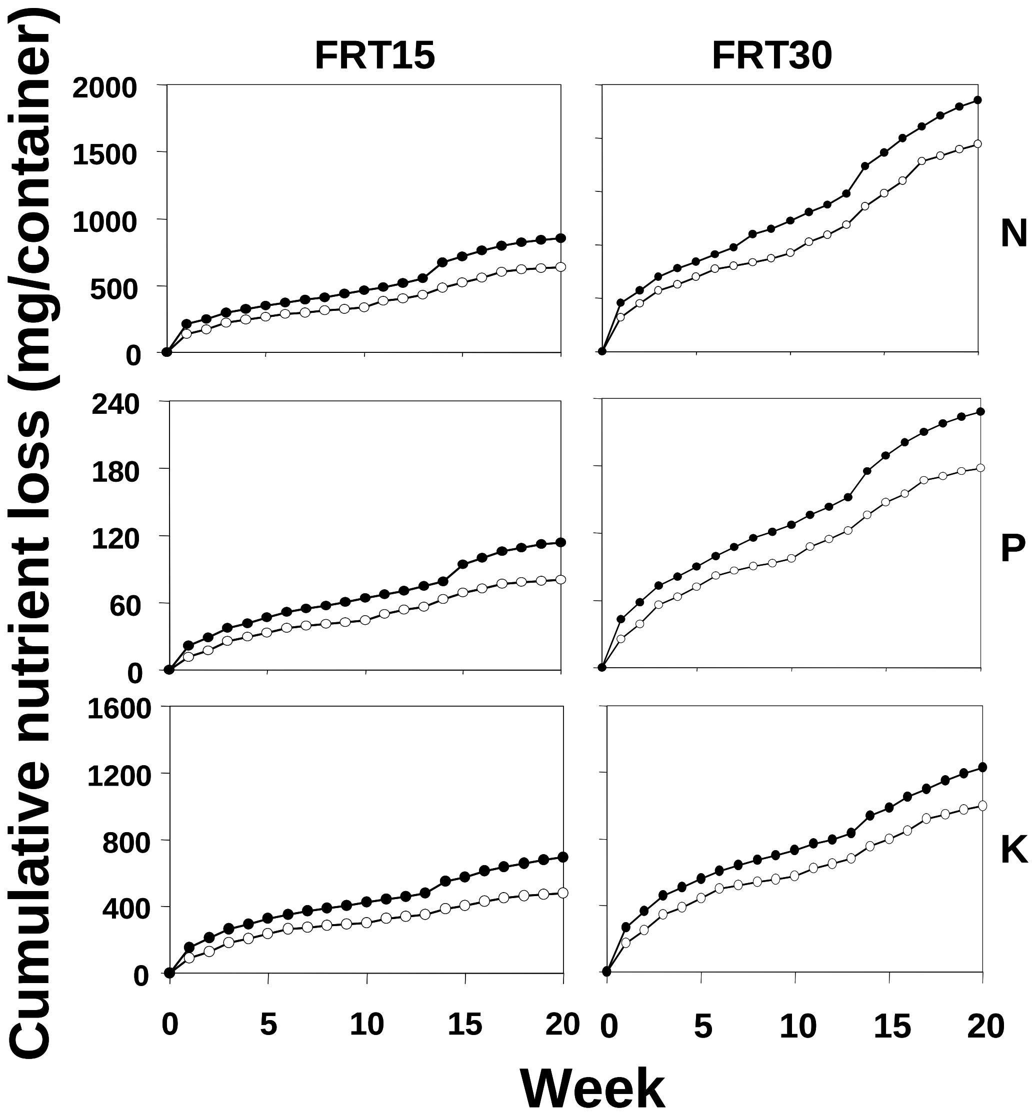

Fig. 5. Cumulative loss of nutrients in runoff during the production of trade #1 (2.7 liter) sweet viburnum. Irrigation water was applied daily at 1 (–○–) or 2 (–●–) cm and controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12) 8–9 month 21C] was incorporated at 15 g (FRT15) or 30 g (FRT30) per container. N = NO_3-N + Total Kjeldahl N (n = 4).

maximum daily load (TMDL) assessments target ortho-P levels of 0.1 mg/liter or less (11, 16), results from this experiment indicate that runoff from container production beds under the conditions imposed during this experiment exceeded these concentrations and thus would be regarded as a potential source of undesirable P enrichment of water resources.

Pour-through leachate tests. EC of PT leachate was higher at week 1 than at week 4, additional evidence for an initial burst of nutrient release from the CRF (Fig. 6). A second period of increased PT EC began around week 10 and peaked at week 16. This corresponded to the second period of elevated runoff losses observed during weeks 14 to 17 which we attributed previously to higher daily air temperatures and the spacing of containers. Doubling the irrigation rate reduced PT EC throughout the experiment reflecting the observed increase in nutrient runoff losses caused by the higher irrigation rate.

Nutrient concentrations in PT leachate followed the observed duel peak pattern of PT EC, as exemplified by PT NO_3-N concentrations (Fig. 6). Lowest PT nutrient concentrations were observed at week 7 when temperatures were apparently low enough to prevent high rates of nutrient release and previously released nutrients had been reduced by leaching. Doubling the irrigation rate greatly reduced PT nutrient concentrations. For example, during the second half of the experiment for FRT30, PT NO_3-N was 50–90 mg/liter with IRR1 but only 25–50 mg/liter with IRR2 and PT ortho-P was 5–11 mg/liter with IRR1 but only 1–4 mg/liter with IRR2 (data not shown). Similar reductions in PT nutrient concentrations due to the higher irrigation rate were observed with FRT15 but concentrations were lower. Since plant size index was affected by fertilizer rate during weeks 7–10, PT results at this point in the season may indicate general sufficiency levels. For weeks 7 and 10, PT N averaged over both irrigation rates was 29–63 mg/liter for FRT30 and 10–25 mg/

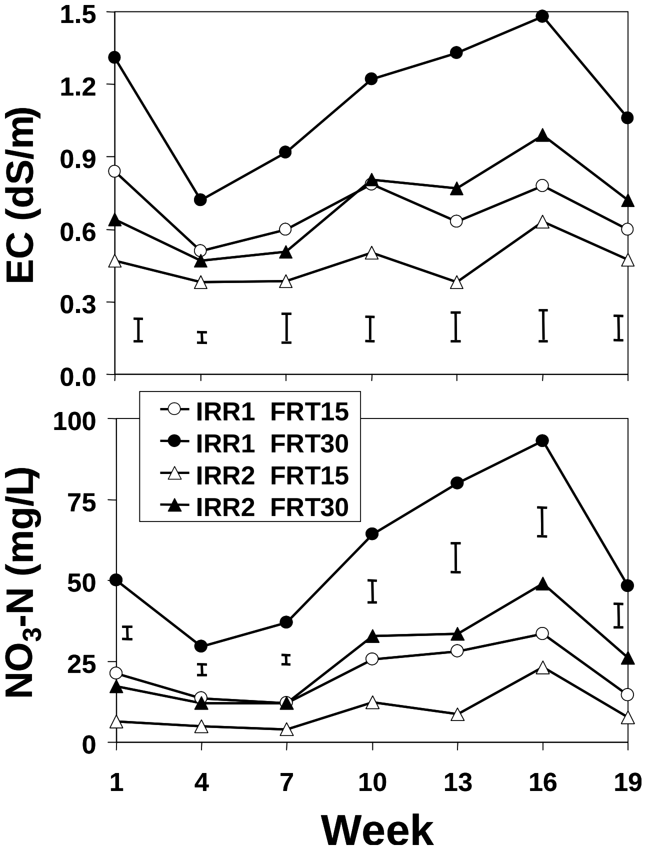

Fig. 6. Pour-through EC and NO_3-N concentration during production of sweet viburnum in trade #1 (2.7 liter) containers. Overhead irrigation was applied daily at 1 cm (IRR1) or 2 cm (IRR2) and controlled-release fertilizer [Osmocote 18N–2.6P–10K (18–6–12), 8–9 month 21C (70F)] was incorporated at 15 g (FRT15) or 30 g (FRT30) per container. Vertical bars represent 95% confidence intervals for interaction means (n = 20).

liter for FRT15. Similarly, PT EC for weeks 7 and 10 was 0.7–1.0 dS/m for FRT30 and 0.4–0.5 dS/m for FRT15. Based solely on PT results from this experiment, plant growth was reduced when PT N and PT EC during the early stages of rapid shoot growth were <25 mg/liter and <0.5 dS/m, respectively.

Nutrient loads in runoff. Total runoff N for IRR1 and IRR2 was 17 and 22 g/m^2, respectively, for FRT15, and 40 and 49g/m^2, respectively, for FRT30. Assuming two 20-week crops per year using 75% of a site, equivalent N runoff loads would be 250–330 kg/ha/yr (220–290 lb/A/yr) from the N application of 1100 kg/ha/yr (980 lb/A/yr) for FRT15 and 600–730 kg/ha/yr (540–650 lb/A/yr) from the N application of 2200 kg/ha/yr (1960 lb/A/yr) for FRT30. Total runoff P loads were 2.2–3.0 g/m^2 for FRT15 and 4.8–6.1 g/m^2 for FRT30. Assuming two 20-week crops per year using 75% of a site, equivalent P runoff loads would be 33–45 kg/ha/yr (29–40 lb/A/yr) from the P application of 150 kg/ha/yr (130 lb/A/yr) for FRT15 and 72–92 kg/ha/yr (64 lb/A/yr) from the P application of 300 kg/ha/yr (270 lb/A/yr) for FRT30. These runoff N and P loads were approximately twice as great as runoff loads reported previously for a similar experiment conducted in the fall (241). Greater nutrient loads in the present study appeared to be associated with greater losses during the second half of the season when temperatures were relatively high for a longer period of time.

In conclusion, the results of this experiment support our contention that the application of 1 cm of overhead irrigation water per day is normally sufficient for producing marketable-sized sweet viburnum in #1containers. Before rapid shoot growth occurs, 1 cm per day supplies 200 mL of water per container or one-third of the water holding capacity of our substrate. Based on previous experience water usage during this early stage of production is typically 0.3 to 0.5 cm or 60 to 100 mL per day. When rapid shoot growth occurs (after week 7 in this experiment), water usage increases rapidly so that by the time the sweet viburnum plants reach a marketable size water usage is normally 2.0 cm or 400 mL per container. Beeson (3) reported that marketable-size sweet viburnum required an average of 410 mL of water per day over a two-year period. The reason that 1 cm of irrigation water per day is sufficient despite the plant's requirement of 1 to 2 cm of water per day during later stages of plant growth is due to the capacity for sweet viburnum foliage to channel irrigation water into the containers that would normally fall between containers if no foliage was present. We have observed sweet viburnum to increase capture of overhead irrigation > 200% when plants are nearing marketable size and containers are spaced at 16 container/m^2. This indicates that 1 cm of irrigation water can provide > 2 cm of water to containers when sweet viburnum plants have well-developed canopies and helps to explain why the application of 1 cm of overhead irrigation water was sufficient and 2 cm excessive for growing sweet viburnum in this experiment.

Consequences of applying excessive irrigation in this experiment were several-fold. Excessive irrigation decreased plant shoot dry weight 6% and this effect occurred irrespective of the amount of CRF applied. In other words, the effect was not overcome by applying a greater amount of fertilizer. In this experiment, not only was IRR2 an inefficient use of water and energy resources but it also reduced product quality. A second consequence of applying excessive irrigation was increased runoff volume. Approximately 95% of the increase in the amount of irrigation water applied with IRR2 versus IRR1 was collected as runoff. In plant nurseries, increased runoff puts greater pressure on growers to control water movement within and away from production areas within their nurseries. A third consequence of doubling the irrigation rate was to increase leaching losses of applied nutrients 21 to 45% depending upon the nutrient element and the fertilizer rate. One would expect that these increases in nutrient losses would be greater during seasons with low rainfall. This is supported by the observation that greater nutrient loss occurred for IRR1 versus IRR2 during weeks with high rainfall which followed weeks with little rainfall. We attributed this effect to the rain-induced leaching of nutrients that had accumulated to a higher level in IRR1 containers than in IRR2 containers. In contrast, one might expect that excessive irrigation rates would have a reduced effect on nutrient leaching during seasons with high rainfall.

Assessing the impact of fertilizer rate on runoff loads was complicated by the fact that doubling the fertilizer rate also increased plant growth. Results indicate that FRT15 provided insufficient nutrition for producing maximum growth of sweet viburnum during this experiment. Enhanced plant growth during weeks 7 to 10 indicated that the beneficial effect of FRT30 in part was to provide better nutrition during this stage of early rapid growth rather than FRT15 providing insufficient nutrition later on in the season. Although an optimal fertilizer rate could not be determined from the two rates used in this experiment, it was likely between FRT15 and FRT30. Although less than optimal in this experiment, FRT15 may be adequate under strategic irrigation schedules designed to minimize leaching, especially during early stages of production when highest leaching losses occur, or during seasons with lower rainfall. Weekly leaching patterns indicate that there may be limits to the capacity of irrigation management to minimize leaching of applied nutrients during seasons with high rainfall.

In deciding optimal application rates of fertilizer and water for producing a successful crop, growers must balance running the risk of producing a substandard crop by applying too little fertilizer and/or water with running the risk of reducing profits and increasing potential water quality problems by applying excessive amounts of fertilizer and water. Greater precision in irrigation and fertilizer management is needed to minimize either risk. While the irrigation and fertilizer rates used in this experiment may not be directly applicable to other growing situations, our results provide further evidence that the rewards for improved irrigation management can be great.

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