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Evapotranspiration-based Irrigation Scheduling for Container-grown *Viburnum odoratissimum* (L.) Ker Gawl.

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Abstract. **The capacity for evapotranspiration (ET)-based irrigation scheduling to reduce runoff volume and nutrient leaching was tested in Fall 2004 and Spring 2005. Runoff (container leachate plus unintercepted irrigation and precipitation) was collected continuously for 17 weeks during production of sweet viburnum [*Viburnum odoratissimum* (L.) Ker Gawl.] in 2.4-L (16-cm top diameter) containers fertilized with an 18N–2.6P–10K polymer-coated, controlled-release fertilizer. Treatments were a factorial arrangement of two irrigation rates (fixed rate of 1 cm·d^{-1} or a variable, ET-based rate) and two fertilizer rates (15 or 30 g/container in 2004 and 10 or 15 g/container in 2005). Averaged over the two experiments and compared with the 1-cm·d^{-1} rate, ET-based irrigation reduced the amount of irrigation water applied (L/container) by 39% and runoff volume (L/container) by 42% with greatest reductions observed during the second half of the 2004 experiment and the first half of the 2005 experiment. Compared with 1-cm·d^{-1} rate, ET-based irrigation reduced runoff nitrogen (N), phosphorus (P), and potassium (K) (mg/container) by 16%, 25%, and 22%, respectively, in 2004 and runoff K 15% in 2005 with irrigation effects varying on a weekly basis. Irrigation treatments did not affect the response of plants to fertilizer rate. Because shoot dry weight was unaffected by irrigation treatments, results indicate that compared with a fixed irrigation rate, ET-based irrigation can reduce irrigation and runoff volumes and to a lesser extent nutrient loss while providing adequate water for plant growth.**

The container nursery industry is continuously seeking new irrigation and fertilization strategies to improve application efficiencies and reduce negative environmental impacts. The objective of these strategies is to strike a balance between the rewards of reduced water and fertilizer inputs and the risks of reduced plant growth and quality. One strategy to optimize irrigation entails supplying an amount of water that is proportional to that lost from ET. Water loss from ET can be measured directly by weighing representative containers or indirectly through monitoring substrate water potential. Estimations of ET can also be made with weather data and appropriate crop coefficients (Beeson, 1993, 2005, 2010; Schuch and Burger, 1997). Furthermore, irrigation can be withheld until substrate water loss exceeds a managed allowable deficit (MAD) (Welsh and Zajicek, 1993). A delay in irrigation afforded by MAD scheduling increases the chance for precipitation to replace some or all of the irrigation demand. Beeson (2006) found that 20% MAD produced acceptable sweet viburnum growth.

By minimizing leaching volume, ET-based irrigation has the potential to reduce nutrient leaching losses during production and, therefore, allow smaller quantities of fertilizer to be applied. Reducing the leaching fraction (volume of leachate divided by the volume of irrigation water) from 0.4–0.6 to 0.0–0.2 decreased N and P leaching losses by greater than 60% for *Cotoneaster dammeri* grown in 3.8-L containers (Tyler et al., 1996). A decrease in the leaching fraction from 56% to 12% reduced total N leaching by ≈50% but resulted in an extremely high (greater than 800 mg·L^{-1}) NO_3-N concentration in leachate from 0.34-L (10-cm diameter) containers (Huett, 1997). By decreasing the daily irrigation rate from 1.3 to 0.6 cm during production of *Ilex cornuta* in 2.3-L containers, cumulative leachate volume was reduced from 3.1 to 0.9 L per container, respectively, and resulted in a 50% reduction in estimated NO_3-N losses (Fare et al., 1999). Constant feed fertilizer rates can generally be halved using ebb-and-flow subirrigation compared with overhead irrigation (Barrett, 1991) indicating that lower fertilizer rates may be possible with water-conserving irrigation practices. Huett (1997) indicated that occasional heavy precipitation can substantially reduce fertilizer nutrient buildup that can occur under minimal-leach irrigation treatments. This suggests that the potential for zero-leach or minimal-leach irrigation strategies to reduce nutrient leaching may be limited in regions with significant precipitation.

The objective of our research was to determine if an ET-based irrigation schedule could reduce irrigation runoff volume and nutrient loss compared with a fixed-rate irrigation schedule. The two irrigation schedules were evaluated using two controlled-release fertilizer (CRF) application rates to determine if fertilizer efficiency could be increased with ET-based irrigation.

Materials and Methods

Experimental site. Experiments were conducted at the University of Florida in Gainesville (lat. 29°67′ N, long. 82 °33′ W) in the Fall of 2004 and in the spring of 2005 and were similar in design to experiments previously reported (Million et al., 2007a, 2007b). The site consisted of four 6.1 × 6.1-m zones each irrigated with four rotary-drive sprinklers (Model PGP-ADJ with No. 2 Nozzle; Hunter Industries Inc., San Marcos, CA) operating at a regulated pressure of 270 kPa and at a height of 150 cm. We adjusted sprinkler irrigation patterns until Christiansen's uniformity coefficient (Haman et al., 1997) was greater than 90% for each irrigation zone. Sprinklers delivered water at 1.8 cm·h^{-1} with little variation between zones. Four 1.2 × 1.2-m platforms designed to collect runoff (container leachate plus unintercepted irrigation and precipitation) were placed within each of the four irrigation zones for a total of 16 platforms. Runoff was collected within an 89 cm × 105-cm (0.937 m^2) area of each platform leaving 0.6 m^2 for border plants. 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 underlain with one layer of 1.1-mm thick pond liner (PondGard; Firestone Building Products, Carmel, IN) to direct runoff water into a collection vessel. Three sections of 1.3-cm-diameter pipe were fastened underneath the pond liner to delineate the collection area from the border area. Two 9.5-cm-diameter cups attached to each platform and maintained at the top of the canopy were used to measure daily inputs of irrigation water and precipitation. An on-site weather station (Vantage Pro Plus® 6162; Davis Instruments Co., Hayward, CA) measured daily minimum and maximum air temperatures (°C), solar radiation (MJ·m^{-2}), and rainfall (mm). Data from the Florida Automated Weather Network's (FAWN; http://fawn.ifas.ufl.edu/) Alachua

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weather station were used to fill any voids in weather data.

Planting detail. The container substrate was a mixture of 2 aged pine bark: 1 sphagnum peatmoss: 1 coarse builder's sand (by volume). The pine bark passed a screen with 2.54-cm openings. During mixing, the substrate was amended with 4.1 $kg \cdot m^{-3}$ of dolomitic limestone (James River Limestone Co., Buchanan, VA) and 0.6 $kg \cdot m^{-3}$ of a micronutrient blend (Micromax; Scotts Co., Marysville, OH). Black, polyethylene, blow-molded, 16-cm top diameter containers (Elite 300; ITML Horticultural Products, Brantford, Ontario, Canada) were filled to a final substrate volume of 2.4 L. The available water-holding capacity of this substrate on a volumetric basis is ≈25% or 600 mL per 2.4 L of substrate. This value is the maximum amount of water we have observed large, established plants to be able to remove from this substrate under conditions of high ET demand. Containers were fertilized with a resin-coated, 18N–2.6P–10K CRF (Osmocote Classic 18-6-12, 8-9 month release at 21 °C; Scotts Co.) at either 15 g (FRT15) or 30 g (FRT30) in 2004 and either 10 g (FRT10) or 15 g (FRT15) in 2005. According to the label, this CRF contained 15%, 2.2%, and 8.3% coated, slow-release N, P, and K, respectively. The CRF was derived from ammonium nitrate, ammonium phosphate, calcium phosphate, and potassium sulfate and contained 8% NO_3-N and 10% NH_4-N. CRF was incorporated on an individual container basis just before planting.

Stem cuttings of sweet viburnum [*Viburnum odoratissimum* (L.) Ker Gawl.] rooted in 180-mL containers (32 per standard tray) were transplanted one per container on 23 Aug. 2004 and 10 Mar. 2005. The substrate used for rooting stem cuttings was a commercial mix (Metro Mix 510LL; Sun Gro Horticulture, Bellevue, WA) comprised of pine bark, sphagnum peatmoss, vermiculite, and bark ash. Containers were placed on platforms at 32 per m^2 (30 per runoff collection area) in a square arrangement. Containers were spaced at the end of Week 10 (2004) and Week 13 (2005) to 16 per m^2 (15 per runoff collection area) by removing every other container.

Initial watering-in of transplants. Transplants were watered-in using a hose and breaker nozzle. The volume of water applied was determined by multiplying the time of irrigation times the nozzle flow rate. The volume of runoff from this initial watering was determined by weighting and samples were taken for nutrient analyses. The same amount of water was applied to three containers containing unfertilized substrate to assess the contribution of the substrate to runoff nutrients during watering-in of the transplants. Two water samples were collected at the same time to provide background levels of N, P, and K in irrigation water. The irrigation and runoff amounts from watering-in were not included in the overall analysis of irrigation and runoff during the two experiments.

Irrigation, evapotranspiration, and plant capture factor. Plants were irrigated predawn (usually at 0500 HR) with either a fixed rate of 1 $cm \cdot d^{-1}$ of water (1CM) or a variable amount of water based on the substrate moisture deficit before irrigation (ETI). Soil moisture deficit (SMD) was the amount of water required to bring a container's substrate water content back to container capacity and was determined by weighing each of eight containers in the evening (usually 1600 HR but often later). Container weights at container capacity were adjusted several times during the season to account for increases that occurred from plant growth and any changes in substrate water retention properties. This adjustment was made after greater than 2 cm of precipitation occurred when all containers were assumed to be at container capacity. Containers were weighed 1 to 2 h after irrigation and drainage (usually at 0800 HR), which provided initial wet weights for ET determinations and verified that containers were being watered to container capacity. ET was estimated by subtracting the container weight at the end of the day when solar radiation levels were low (usually between 0500 HR and 0800 HR depending on the time of year) from the post-irrigation container weight. ET volume (cm^3/container) was converted to ET depth (cm/container) by dividing ET volume by 200 cm^2, the top area of the container. For ETI in 2004, irrigation was applied daily and irrigation run times were adjusted manually to deliver 100% of SMD. In 2005, ETI irrigation was not applied if SMD was less than 1.0 cm (200 cm^3/container). Once this threshold was reached, irrigation was adjusted manually to supply 100% of SMD. A rain sensor (Mini-Clik; Hunter Industries, Cary, NC) automatically shut off irrigation, regardless of irrigation treatment, if precipitation exceeded 1.25 cm during both 2004 and 2005 experiments.

ETI rates were adjusted to account for the influence of the plant canopy on irrigation capture. An irrigation capture factor was determined every 3 weeks on 16 containers per irrigation treatment (four per platform). We randomly chose the containers for these tests at the beginning of the experiment and we determined the irrigation capture factor on the same 32 containers throughout each experiment. For Week 10 in 2004 and Week 13 in 2005, irrigation capture factor determinations were made after spacing containers. For irrigation capture determinations, containers weighed to the nearest gram were placed in 2.5-L plastic leachate collection tubs (16.5 cm top diameter) and a plastic "skirt" was attached to keep irrigation water from entering directly into the collection tub. The assemblies were then placed back onto the runoff platforms. After irrigation, containers were reweighed and the volume of water retained by each container was determined by subtracting the pre-irrigation weight. Volume of leachate collected in each tub was also measured. An irrigation capture factor (CF) was calculated as:

$$CF = [\text{leachate } (cm^3) + \text{water retained } (cm^3)] / \text{water applied } (cm^3)$$

Water applied was the volume of irrigation water that would be intercepted by the container without any canopy effect and was equal to the depth of irrigation water applied (cm) multiplied by the container's top area (200 cm^2). Values for CF were subsequently used to adjust ETI rates according to: ETI (cm) = SMD (cm)/CF.

Runoff and plant data collection. Runoff collected continuously from platforms was measured on a weekly basis and runoff volume reported on an area basis ($L \cdot m^{-2}$). Because water samples were collected once per week, some volatilization loss of N may have occurred between weekly collections. The extent of this potential loss of N was not determined. No attempt was made to distinguish the relative contributions of leachate versus unintercepted irrigation water. Water samples from each weekly runoff collection as well as water samples from initial watering-in of transplants were filtered (Whatman No. 40; Fisher Scientific, Pittsburgh, PA; http://www.fishersci.com) and stored frozen until nutrient analyses were performed. Although sample filtering may have excluded the measurement of nutrient loss associated with particulates greater than 0.8 μm, filtering was necessary to prevent potential damage to analytical instruments.

As a result of hurricanes affecting the experiment in 2004, plants were moved into a glass-covered greenhouse during Week 3 and for several days during both Week 4 and Week 5. While in the greenhouse, we hand-watered containers so that little if any leaching occurred; no runoff was collected. As a result, runoff during these three periods of 2004 was either zero (Week 3) or reduced (Weeks 4 and 5).

Plant canopy dimensions were measured every 3 weeks on the same five plants per platform. Plant height was the distance from the substrate surface to the uppermost foliage and plant width was the average of two perpendicular measurements. Plant size index was calculated as the average of plant height and width. Experiments were ended on 20 Dec. 2004 and 8 July 2005, 17 weeks after transplanting. At this time, plant size index and shoot dry weight were determined on all 15 plants per platform.

Runoff solutions were analyzed for NO_3-N, total Kjehldahl N (TKN), total P, and K by the Analytical Research Laboratory, Univ. of Florida, Gainesville (http://arl.ifas.ufl.edu/). Under typical conditions, the relative amount of nitrite N (NO_2-N) versus nitrate N (NO_3-N) is small (Fernandez-Escobar et al., 2004; Moutonnet and Fardeau, 1997), so that although the NO_3-N analysis includes both forms of these forms of N, for the purposes of this article, we refer to this amount as nitrate N (NO_3-N). TKN analyses did not include NO_3-N. N concentration was calculated as the sum of NO_3-N and TKN concentrations. Weekly N, P, and K loads ($g \cdot m^{-2}$) in runoff were calculated by multiplying weekly N, P, and K concentrations by weekly runoff volumes. Weekly N, P, and K loss in runoff on a per-container basis was calculated by dividing weekly nutrient load by the container density (containers per m^2) for that week.

For runoff volume and concentrations, amounts, and loads of N, P, and K in runoff which were collected on a weekly basis, the experiment was analyzed as a split-split plot design with two blocks, two irrigation treatments as main plots, two fertilizer treatments as split plots, and 17 weekly repeated measurements as split-split plots. Because week by irrigation and week by fertilizer interaction effects were found for most response variables, a separate analysis of variance (ANOVA) was conducted for each week to help determine how the treatment response changed over time. All ANOVA tests were conducted using the PROC GLM procedure of the Statistical Analysis System (Version 8; SAS® Institute, Cary, NC). For plant size and irrigation capture factors that were measured every 3 weeks, a similar ANOVA was made except that there were only seven subplot measurement dates. Final plant size index and shoot dry weight parameters were analyzed as a split-plot design. Treatment effects with $P < 0.05$ were considered to be statistically significant.

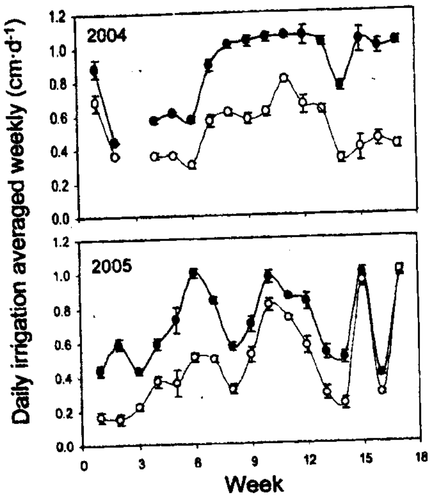

Fig. 1. Daily irrigation rates averaged weekly during 17 weeks of growing *Viburnum odoratissimum* in 2.4-L containers sprinkler-irrigated with either a fixed rate of 1 cm·d^{-1} (●) or evapotranspiration-based schedule (○). Irrigation was not applied if the past day's rainfall exceeded 1.25 cm. Means are averaged over two fertilizer rates (n = 8). Error bars represent a 95% confidence interval (± $t_{0.05,8}$*SE) around the mean.

Results and Discussion

Irrigation and evapotranspiration. ETI reduced the amount of irrigation water applied during both experiments (Fig. 1). Total irrigation water applied was 92 cm for 1CM and 52 cm for ETI in 2004 and 89 cm for 1CM and 59 cm for ETI in 2005. Compared with 1CM, ETI reduced total water applied by 44% in 2004 and by 34% in 2005 for an average reduction of 39%. ETI had less of an effect on irrigation amounts applied in 2005 than in 2004. We attributed this to greater precipitation in 2005 (Fig. 2) and to greater ET values in the second half of 2005 (Fig. 3), which resulted in irrigation rates for ETI that were similar to those of 1CM (Fig. 1).

ET measurements (Fig. 3) showed that daily ET values for 2004 followed a different pattern than those for 2005. For the first 60 d, daily ET values were similar for both experiments, generally falling in the range of 0.5 to 0.8 cm/container. However, for the second half of the experiments, daily ET values for 2004 ranged from 0.3 to 1.2 cm/container, whereas values for 2005 ranged from 0.5 to 2.4 cm/container with less day-to-day variability in 2005 compared with 2004. To calculate equivalent ET values on a production area basis (cm), divide container ET values (cm/container) by 1.6 before spacing containers and divide by 3.2 after spacing containers. Higher ET rates during the second half of 2005 experiment coincided with the transition of spring to summer with associated increases in temperature and solar radiation. Conversely, relatively low and more variable ET values during the second half of 2004 reflected the seasonal effects of late fall and early winter on lowering temperatures and reducing solar radiation levels.

Irrigation capture. The ability of the sweet viburnum plant canopy to capture irrigation water that would normally fall between containers played an important role in reducing ETI rates in both experiments. The capture factor ranged from 1 during the first 6 to 8 weeks of each experiment to 2.3 and 2.5 by the end of 2004 and 2005, respectively (Fig. 4). Theoretical maximum CF values in this experiment were 1.6 and 3.2 for the 32 and 16 containers/m^2 spacings, respectively. Measured increases in CF during the two experiments were related to increases in plant size index (Fig. 5). Beeson and Yeager (2003) reported CF values for sweet viburnum in 11.4-L containers ranging between 0.5 and 1.5. The authors observed higher CF values as containers were placed in wider spacing arrangements. CF values for *Rhododendron* and *Pittosporum* sp. were less than 1 (Beeson and Knox, 1991), indicating that the canopies of these two species tended to "shed" irrigation water rather than "accumulate" it. More research is needed to better quantify irrigation capture as results here show that, at least for sweet viburnum, CF can be very significant and that considerably less irrigation water need be applied than amounts indicated solely by substrate moisture deficit.

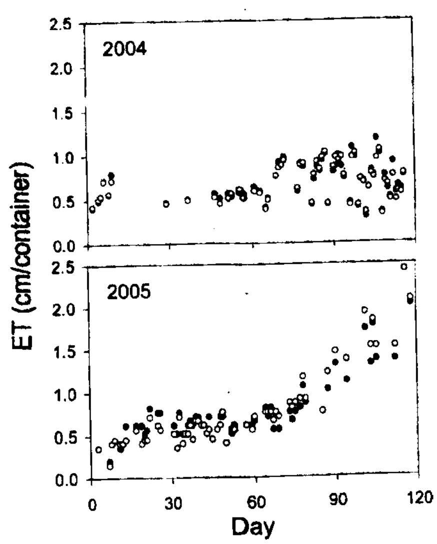

Fig. 3. Container evapotranspiration (ET) measured on weekdays without precipitation during 2004 and 2005 experiments. *Viburnum odoratissimum* liners were transplanted 23 Aug. 2004 and 10 Mar. 2005 into 2.4-L containers and sprinkler-irrigated with either a fixed rate of 1 cm·d^{-1} (●) or a variable, ET-based rate (○) that was proportional to substrate water deficit. ET water loss was determined by weighing containers after early morning irrigation and again in the evening (n = 8). Container ET unit of 1 cm/container is equivalent to 200 mL per container (200-cm^2 top area).

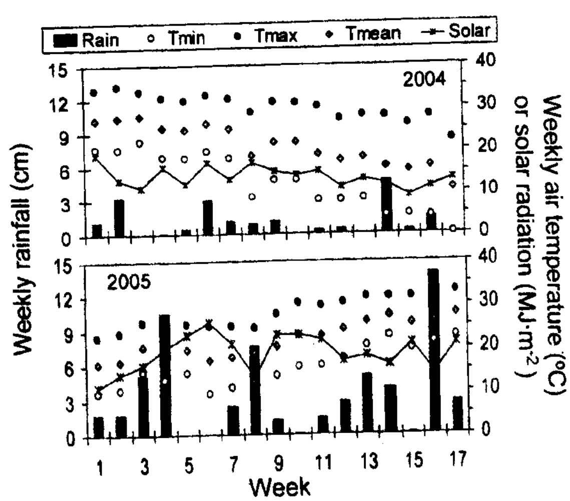

Fig. 2. Weekly precipitation totals and daily air temperatures (T) and solar radiation averaged weekly during 2004 and 2005 experiments. Plant dates were 23 Aug. 2004 and 10 Mar. 2005.

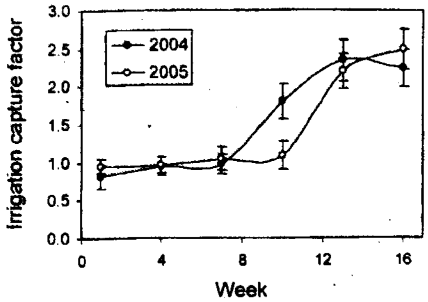

Fig. 4. Irrigation capture factor (CF) measured periodically during production of *Viburnum odoratissium* in 2.4-L (16-cm top diameter) containers. CF describes the amount of water captured by the container with a plant in it relative to the amount of water that would be captured by the container without a plant in it. Means were averaged over two irrigation treatments and two fertilizer rates (n = 16). Vertical bars represent 95% confidence intervals (± $t_{0.05,9}$*SE) around mean values.

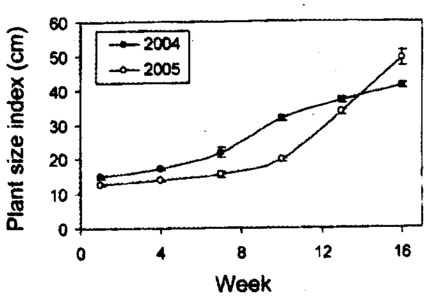

Fig. 5. *Viburnum odoratissimum* plant size index (average of height and width) during 2004 and 2005 experiments. Plant dates were 23 Aug. 2004 and 10 Mar. 2005. Means were averaged over two irrigation treatments and two fertilizer rates (n = 80). Vertical bars represent 95% confidence intervals (± $t_{0.05,73}$*SE) around mean values.

Precipitation. Greater amounts of precipitation fell in 2005 (62 cm) than in 2004 (18 cm; Fig. 2). Average precipitation amounts for these times of the year are 46 cm (2004) and 49 cm (2005) according to the FAWN database for the Alachua County weather station (Florida Automated Weather Network, 2010). Low precipitation in 2004 was the result of, in part, moving containers under cover during hurricane events. Of the 62 cm of precipitation that fell in 2005, 42 cm or 68% fell during Weeks 3, 4, 8, 13, and 16. Of these 5 weeks, rainfall amounts were particularly large during Week 4 (11 cm) and Week 16 (14 cm). Total water inputs (precipitation plus irrigation) for 1CM and ETI, respectively, were 110 and 70 cm in 2004 and 141 and 112 cm in 2005.

Runoff. For both 2004 and 2005 experiments, the effect of irrigation schedule on runoff volume depended on the week of runoff collection (Fig. 6); fertilizer rate had no effect. ETI reduced runoff compared with CM1 during both experiments. When averaged over the two fertilizer rates, ETI reduced total

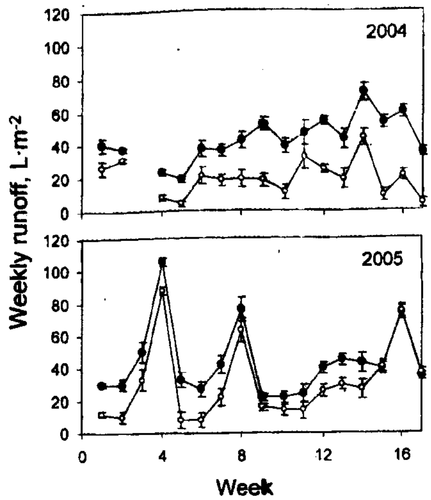

Fig. 6. Weekly runoff collected during production of sweet viburnum in 2.4-L containers sprinkler-irrigated with either a fixed rate of 1 cm·d^{-1} (●) or a variable, evapotranspiration (ET)-based rate that was proportional to substrate water deficit. ET-based irrigation reduced runoff volume for each week of the 2004 experiment and for all weeks except Weeks 8, 15, 16, and 17 of the 2005 experiment. Weekly means were averaged over two fertilizer rates (n = 8). Vertical bars represent 95% confidence intervals (± $t_{0.05,8}$*SE) around mean values.

runoff by 55% (310 versus 690 L·m^{-2}) in 2004 and by 30% (520 versus 740 L·m^{-2}) in 2005. Reductions in runoff resulting from ETI relative to CM1 were greater during the second half of 2004 experiment when reduced ET associated with the onset of winter weather resulted in ETI rates that were lower than 1 cm·d^{-1}. In contrast, reductions in runoff resulting from ETI were greater during the first half of the 2005 experiment when ET was relatively low as a result of cooler weather.

Plant growth. In general, plant growth was little affected by irrigation and fertilizer treatments during either experiment. In 2004, final plant height, width, and plant size index averaged 42, 40, and 41 cm, respectively, and each was unaffected by treatments. Shoot dry weight in 2004 was increased by 8% (32.5 versus 30.1 g/plant) with FRT30 compared with FRT15; irrigation treatment had no effect on shoot dry weight. In 2005, ETI reduced plant height by 5% (44 versus 46 cm) and size index by 4% (48 versus 50 cm), but the effect was difficult to discern visually. Shoot dry weight in 2005 was unaffected by treatments and averaged 35.8 g/plant.

A comparison of plant growth patterns during the two seasons (Fig. 5) indicated that the 2004 crop began a rapid growth phase a few weeks earlier than 2005. Growth tapered off toward the end of the 2004 with the onset of cooler weather. In contrast, plant growth in 2005 was not slowed during the second half of the experiment (summer) so after 17 weeks of growth, plants were considerably larger in 2005 than in 2004.

Nutrient loss during watering-in of transplants. Nutrient loss occurred during watering-in of transplants before irrigation treatments were initiated (Table 1). In 2004, 4.6 cm of precipitation fell during the watering-in period resulting in a greater volume of runoff. Runoff collected during the watering-in of transplants for both experiments contained appreciable quantities of nutrients compared with the unfertilized control. For 2004, total quantities of N, P, and K in container leachate were 92, 6.1, and 58 mg/container, respectively, for FRT15 and 153, 9.9, and 73 mg/container, respectively, for FRT30. For 2005, total quantities of N, P, and K lost in leachate were 10, 0.7, and 24 mg/container, respectively, for FRT10 and 13, 1.0, and 27 mg/container, respectively, for FRT30. Greater nutrient loss during the watering-in stage in 2004 was likely the result of the combination of greater runoff volume and higher temperatures in 2004 than in 2005. For FRT15, which was common to both experiments, the amounts of N, P, and K lost during initial watering-in represented 3%, 2%, and 4%, respectively, of that applied in the CRF, and represented 17%, 10%, and 19%, respectively, of the total amounts of these nutrients subsequently lost in runoff during the experiments. Million et al. (2007b) reported that ≈1% to 4% of applied nutrients were lost

Table 1. Volume and nutrient concentration of runoff collected during watering-in of transplanted *Viburnum odoratissimum* liners into 2.4-L (16.3-cm top diameter) containers.[z]

Expt.	Fertilizer rate (g/container)	Watering-in runoff (L/container)	Nutrient concn in runoff (mg·L^{-1})		
			Nitrogen[y]	Phosphorus	Potassium
2004	15	1.8	51	3.4	32
	30	1.7	90	5.8	43
		Fertilizer effect	**	**	NS
	Unfertilized substrate[x]	2.0	3 (1)	0.4 (0.1)	22 (11)
	Water[x]	—	0 (0)	0.0 (0.0)	1 (0)
2005	10	0.5	19	1.4	47
	15	0.5	25	1.9	53
		Fertilizer effect	*	NS	NS
	Unfertilized substrate[x]	0.7	2 (0)	0.1 (0.0)	26 (4)
	Water[x]	—	0 (0)	0.0 (0.0)	0 (0)

[z]For the 2004 experiment, 4.6 cm of precipitation (equivalent to 0.9 L/container) fell during watering-in period. A polymer-coated, 18N–2.6P–10K, controlled-release fertilizer was incorporated into the container substrate immediately before transplanting. Means (+ SD) are averages of watering-in runoff collected from eight (two irrigation treatments × four replications) 0.94-m^2 platforms each containing 30 containers.

[y]NO_3-N + total Kjeldahl N (TKN analysis did not include NO_3-N).

[x]Control, n = 3 (unfertilized substrate) and n = 2 (water); mean (SD).

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

during initial watering-in of transplants. Unfertilized substrate contributed relatively low amounts of N and P in watering-in runoff but K leaching was significant (Table 1). No tests were conducted to see how K leaching from unfertilized substrate changed over time. Results from collecting watering-in runoff suggest that despite using CRF, significant nutrient loss can occur during watering-in and water should not be indiscriminately applied at this time.

Nutrient loss in runoff. In both experiments, the effect of irrigation treatment on runoff nutrient loss depended on the week runoff was collected (Fig. 7). Although the week by fertilizer rate interaction effect was significant, only results for FRT15 are included in Figure 7 because FRT15 was common to both experiments and the week by irrigation by fertilizer rate interaction effect was not significant. ANOVA conducted on a weekly basis indicated that ETI had a significant effect on decreasing N leaching loss (mg/container) compared with CM1 for Weeks 4, 5, 9, 10, 14, 15, and 17 in 2004 and Weeks 1 through 6, 9, and 15 in 2005. In 2004, the greatest reductions in N leaching loss resulting from ETI compared with CM1 were observed during Weeks 4 and 5. Similar patterns of nutrient loss in runoff were observed for P and K as were observed for N. Compared with 2004 when nutrient loss toward the end of the experiment was diminishing, considerably greater loss of nutrients occurred during the last 4 to 5 weeks of 2005. This late-season increase in nutrient loss for 2005 was associated with increasing air temperatures (Fig. 2). Higher air temperatures likely resulted in higher substrate temperatures resulting in more rapid release of nutrients from CRF during this period (Huett and Gogel, 2003). In contrast, temperatures at the end of 2004 were decreasing and nutrient release would be expected to decrease as well.

ETI reduced cumulative runoff nutrient loss compared with CM1 in both 2004 and 2005 experiments (Table 2). For FRT15 and compared with CM1, ETI reduced total losses of N by 19%, P by 27%, and K 25% in 2004 and N by 10%, P by 16%, and K by 16% in 2005. NO_3-N represented 77% to 80% of N in 2004 and 79% to 85% of N in 2005 and was therefore the predominant form of N in runoff. These NO_3-N percentages were higher than the 65% to 71% reported for two related runoff experiments (Million et al., 2007a, 2007b).

Although ETI decreased cumulative N, P, and K loss in runoff (mg/container) compared with 1CM, average volume-weighted concentrations of N, P, and K in runoff were increased. This was a result of ETI reducing irrigation volume (L/container) to a greater extent than it reduced nutrient leaching losses (mg/container) during each experiment (Table 2). For example, when averaged over both years for FRT15 and compared with CM1, ETI increased average runoff N concentration from 27 to 39 $mg \cdot L^{-1}$, NO_3-N from 22 to 33 $mg \cdot L^{-1}$, P from 3.1 to 4.1 $mg \cdot L^{-1}$, and K from 22 to 29 $mg \cdot L^{-1}$.

Nutrient loads (Table 3) express runoff nutrient loss on an area basis, which may be useful in evaluating the potential amounts of nutrients that can move away from a given amount of production area. Unlike nutrient loss on a container basis, nutrient load values depend on the container density at the time leaching losses occur. As was observed for nutrient loss on a container basis, the effect of irrigation and fertilizer treatments on nutrient loads varied from week to week (data not given). Compared with CM1, ETI decreased N, P, and K loads by 19%, 27%, and 24%, respectively, in 2004; only K load was significantly reduced (16%) in 2005. When averaged over both years for FRT15, ETI

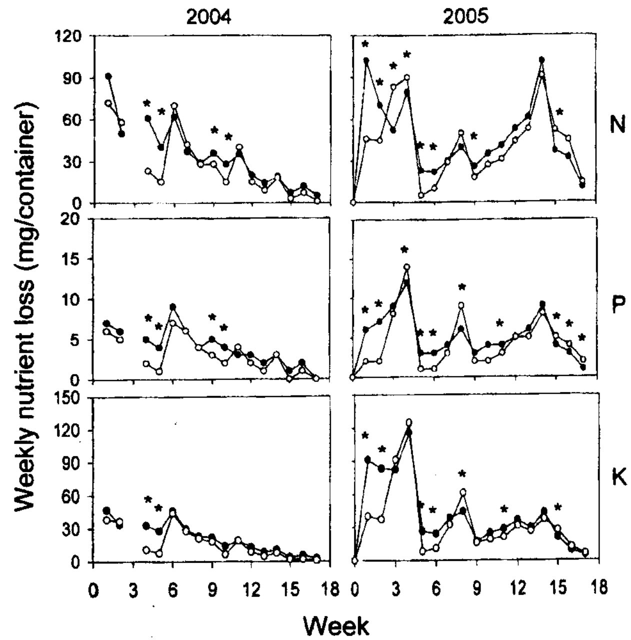

Fig. 7. Weekly amounts of nitrogen (N), phosphorus (P), and potassium (K) in runoff collected continuously during 17 weeks of sweet viburnum production in 2.4-L containers. Sprinkler irrigation water was applied at either a fixed rate of 1 $cm \cdot d^{-1}$ (●) or a variable, evapotranspiration (ET)-based rate (○) that was proportional to substrate water deficit. An 18N–2.6P–10K, polymer-coated, controlled-release fertilizer was incorporated at 15 g/container immediately before planting. Asterisk denotes a significant ($P < 0.05$) irrigation effect for that week.

Table 2. Nutrient loss in runoff collected continuously during 17 weeks of growing *Viburnum odoratissimum* in 2.4-L containers.[z]

Treatment				Runoff nutrient loss (mg/container)		
Irrigation schedule	Fertilizer rate (g/container)	Irrigation (L/container)	Runoff (L/container)	Nitrogen[y]	Phosphorus	Potassium
			2004 Experiment			
1 cm	15	43.1	33.4	546	64	342
1 cm	30	43.2	32.3	1438	158	805
ET	15	23.6	14.9	444	47	258
ET	30	23.6	13.9	1219	119	631
	Effect[x]:					
	Irrigation(I)	***	***	**	**	**
	Fertilizer rate (F)	NS	NS	***	***	***
	F × I	NS	NS	NS	NS	NS
			2005 Experiment			
1 cm	10	30.4	29.4	450	50	514
1 cm	15	29.9	28.5	815	90	717
ET	10	20.2	22.1	414	46	442
ET	15	20.1	22.0	733	76	600
	Effect[x]:					
	Irrigation(I)	***	***	NS	NS	*
	Fertilizer rate (F)	NS	NS	**	**	**
	F × I	NS	NS	NS	NS	NS

[z]Irrigation water was applied at either 1 $cm \cdot d^{-1}$ or at a rate proportional to container evapotranspiration (ET) as determined by weighing. An 18N–2.6P–10K polymer-coated, controlled-release fertilizer was incorporated immediately before planting. Precipitation totaled 7.9 L/container in 2004 and 26.1 L/container in 2005.

[y]NO_3-N + total Kjehldahl N (TKN analysis did not include NO_3-N).

[x]Week × irrigation and week × fertilizer effects were significant for nitrogen, phosphorus, and potassium loss; week × irrigation effect was significant for irrigation and runoff.

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

Table 3. Nutrient load of runoff collected continuously during 17 weeks of growing *Viburnum odoratissimum* in 2.4-L containers.[z]

Treatment			Runoff nutrient load ($g \cdot m^{-2}$)		
Irrigation schedule	Fertilizer rate (g/container)	Runoff ($L \cdot m^{-2}$)	Nitrogen[y]	Phosphorus	Potassium
		2004 Experiment			
1 cm	15	700	15.7	1.82	9.9
1 cm	30	680	39.0	4.27	22.3
ET	15	320	12.7	1.33	7.5
ET	30	300	32.2	3.12	17.1
	Effect[x]:				
	Irrigation(I)	***	**	**	**
	Fertilizer rate (F)	NS	***	***	***
	F × I	NS	NS	NS	*
		2005 Experiment			
1 cm	10	750	13.0	1.49	15.9
1 cm	15	720	23.2	2.58	21.7
ET	10	530	11.6	1.31	13.4
ET	15	520	20.2	2.13	17.9
	Effect[x]:				
	Irrigation(I)	***	NS	NS	*
	Fertilizer rate (F)	NS	**	*	**
	F × I	NS	NS	NS	NS

[z]Irrigation water was applied at either 1 $cm \cdot d^{-1}$ or at a rate proportional to container evapotranspiration (ET). An 18N–2.6P–10K polymer-coated, controlled-release fertilizer was incorporated immediately before planting. Initial container density was 32 containers/m^2, which was reduced to 16 containers/m^2 either 10 weeks after planting (2004) or 13 weeks after planting (2005).

[y]NO_3-N + total Kjehldahl N (TKN analysis did not include NO_3-N).

[x]Week × irrigation and week × fertilizer effects were significant for nitrogen, phosphorus, and potassium loads; week × irrigation effect was significant for runoff.

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

resulted in N, P, and K loads of 17.2, 2.13 and 17.9 $g \cdot m^{-2}$, respectively, and CMI resulted in N, P, and K loads of 19.4, 2.58, and 21.7 $g \cdot m^{-2}$, respectively. Except for K load in 2004, there was no interaction effect between irrigation and fertilizer rate for nutrient loads. Nutrient load values reflect the potential amounts of N, P, and K leaving the production area and do not consider factors that can mitigate the potentially negative effects these nutrients can have on the local environment.

Conclusion

Compared with a fixed-rate irrigation schedule of 1 $cm \cdot d^{-1}$, an ET-based irrigation schedule designed to resupply water at a rate proportional to ET reduced the total volume of irrigation water applied by 39% and the total volume of runoff collected by 42% when averaged over the two experiments. Irrigation treatment effects varied weekly. For the 2004 experiment, benefits of ET-based irrigation were greatest during the second half of the season when ET rates were low and variable. In contrast, the benefits of ET-based irrigation were greater in the first half of the Spring 2005 experiment when ET rates and precipitation were low. The benefits of ET-based irrigation should be even greater in nurseries where daily irrigation rates exceed 1 $cm \cdot d^{-1}$.

ET-based irrigation had less of an effect on reducing nutrient leaching losses compared with the fixed 1-$cm \cdot d^{-1}$ rate than it did in reducing the amount of irrigation water applied and runoff collected. Higher concentrations of nutrients were found in runoff from the ET-based irrigation treatment indicating that nutrients that accumulate during periods of low leaching may be leached when periods of greater leaching occur. This supports the observation of Huett (1997) that there is a practical limit to reducing N leaching under growing conditions where precipitation is likely to be important. This information further supports the conclusion that choosing CRFs with release rates that match plant demand is crucial in minimizing nutrient leaching even with conservative irrigation practices.

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