Nitrogen Fertilizer Rate, Timing, and Application Method Affects Growth of Sweet Viburnum and Nitrogen Leaching from Simulated Planting Beds

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Abstract. Several Florida cities and counties ban fertilization during the summer rainy season (fertilizer blackout). Little research is available to support or contradict the underlying justifications for these policies. We used large-volume lysimeters to address the impacts of several fertilization regimes on plant growth and aesthetics of sweet viburnum (*Viburnum odoratissimum* Ker Gawl.) and nitrogen (N) leaching from landscape beds during shrub establishment and maintenance. Three levels of N fertilization (98, 195, and 293 kg·ha⁻¹), two levels of application method (per plant and broadcast), two levels of fertilization timing (regular and blackout), and an unfertilized control (0 kg·ha⁻¹ N) were applied to lysimeters in a completely randomized design with three replicates (3 × 2 × 2 factorial plus untreated control). Increasing fertilization rate increased plant growth and improved plant quality, but also increased N leaching from lysimeters. Including a summer fertilization blackout period reduced nitrate + nitrite (NO₃ + NO₂-N) loading from lysimeters during sweet viburnum establishment [0 to 28 weeks after planting (WAP)] compared with year-round fertilization at the same total N rate without adversely impacting plant growth or aesthetics. However, NO₃ + NO₂-N loads from lysimeters were higher when fertilizers were applied on the summer blackout application schedule during the shrub maintenance period. Targeted (per plant) fertilization beneath the dripline of sweet viburnum at an annual N rate of 195 kg·ha⁻¹ can maintain plant health while limiting N leaching losses on a year-round or blackout fertilization schedule.

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Excess nutrient loading to water bodies from urban and agricultural landscapes can accelerate eutrophication, which results in excessive algae growth, death of fish and other aquatic species, and degradation of overall water quality (Howarth, 1988). Burkholder et al. (1992) reported surface-water quality degradation at nitrate (NO₃⁻) levels as low as 0.05 to 0.1 mg·L⁻¹. Excessive or poorly timed fertilization of residential landscapes can result in water quality degradation as nutrients, particularly nitrogen (N) and phosphorus (P), are lost in leachate or runoff. For example, Line et al. (2002) reported that the

average total N and P exported from a residential setting was 269% and 302%, respectively, greater than from wooded sites. Although fertilizer is not the sole contributor to N exports from residential landscapes it is the most direct and deliberate addition of these nutrients to the urban ecosystem. As such, improving the fertilizer management practices (e.g., application rates, timing of application, and method of application) of consumers and the commercial green industry is an important step in reducing nonpoint nutrient losses from urban landscapes.

Nationwide, state and local lawmakers have addressed environmental concerns surrounding fertilization of urban landscapes by passing a range of season- and/or formulation-specific fertilization bans (mainly for turf-grass) in areas with impaired water bodies that are linked to watersheds that have elevated nutrient loads (e.g., Chesapeake Bay, Gulf of Mexico delta-Mississippi River basin, Florida Everglades). In 2007, the Florida Legislature appointed the Florida Department of Agriculture and Consumer Services to create the Florida Consumer Fertilizer Task Force, which helped to develop recommendations for statewide policies and programs regarding consumer fertilizer use (Hartman et al., 2008). As Florida's state agencies worked to implement plans for the statewide protection of surface and groundwater, many local governments began to implement their own preventive measures via county and city-wide fertilizer ordinances. As a result of these local actions, several counties and municipalities in the Tampa Bay region (and other areas of Florida) adopted a summer fertilization blackout period with the goal of decreasing nutrient losses during the rainy season (i.e., 1 June to 30 Sept. in Manatee County, FL; Manatee County Florida, 2012). However, the fertilizer blackout period coincides with the period of active plant growth in Florida. The full impact of these fertilizer blackout periods on plant growth and the environment has yet to be evaluated; scientific studies on this topic are limited in the literature.

Beyond directly limiting fertilization, many industry and government organizations have created standards or best management practices (BMPs) that help guide landscape maintenance efforts. For example, the American National Standard Institute's (ANSI) A300 Tree Care Standard for Fertilization and the Florida-friendly Landscaping™ Green Industries BMP manual (American National Standards Institute, 2011; Florida Department of Environmental Protection, 2010) provide standard recommended fertilizer application rates and other guidelines for maintaining woody ornamentals. Industry consensus and limited research serve as the basis for these published application rates (Shober et al., 2010). Shober et al. (2013) found that annual N application rates of 98 to 195 kg·ha⁻¹ were sufficient to maintain acceptable plant growth [i.e., volume or size index (SI), chlorophyll content, and dry weight] and visual quality of several woody

ornamental landscape plant species grown in Florida. Similarly, Werner and Jull (2009) reported annual N application rates of 49 to 146 kg·ha⁻¹ were able to support the healthy growth of young common hackberry (*Celtis occidentalis* L.) trees in Wisconsin. Both researchers reported optimal fertilizer application rates within the ANSI's standard recommendation rate range of 49 to 195 kg·ha⁻¹ annually for woody ornamentals (American National Standards Institute, 2011).

Previous research on fertilization of woody ornamentals in the landscape has focused on root growth (Struve, 2002), shoot growth (Gilman et al., 2000; Struve, 2002), and/or aesthetic plant response (Shober et al., 2013, 2014) to fertilizer applications. Yet, few studies have looked at the environmental impacts when applying fertilizers at rates recommended to optimize shoot growth and aesthetics (Rose, 1999; Shober et al., 2010). Among the studies that evaluate the potential for nutrient losses when fertilizing woody ornamentals, Qin et al. (2013) noted that nutrient losses from urban landscapes (containing turfgrass and ornamentals) were reduced when established woody ornamentals were included in fertilized Florida landscapes. In contrast, Erickson et al. (2008) reported that nutrient losses from mixed ornamental plant beds (once fully established) were similar to those from turfgrass monoculture. Our research expands on previously published work to determine the impacts of application rate, method, and timing on woody ornamental health and N leaching from urban residential planting beds. The overall goal of this study was to refine current fertilization standards and BMPs for woody ornamentals by identifying fertilizer rates, application methods, and timing recommendations that account for both the aesthetics of the ornamentals and the potential for nutrient losses to the surrounding environment.

Materials and Methods

Lysimeter design and construction. The experiment was conducted from 9 May 2012 to 30 June 2015 at the University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) Gulf Coast Research and Education Center in Balm, FL (lat. 27°45'40.4" N, long. 82°13'39.8" W; USDA hardiness zone 9a). We constructed 39 drainage lysimeters using 1135-L stock tanks with a 65 cm depth (Rubbermaid Commercial Products LLC, Winchester, VA) that were uniformly elevated on cinder blocks (Fig. 1). Each lysimeter was fitted with a 10-cm diameter polyvinyl chloride shower drain to allow drainage of water from the lysimeters; filter socks were attached to the drain caps to prevent solids from leaving the lysimeters in drainage. Drainage flowed through the outlet installed at the bottom of each lysimeters and into a 37.9-L catchment containers equipped with an automatic bilge pump capable of pumping water at a rate of 1893

Fig. 1. Construction of lysimeters for evaluation growth and quality of sweet viburnum (*Viburnum odoratissimum*) shrubs and N leaching from application of controlled release N fertilizer at various rates, application methods, and timing between 9 May 2012 and 30 June 2015 in USDA hardiness zone 9a (Balm, FL). Construction began with (A) installation of drain outlets, followed by (B) the addition of rock and sand base, (C) the addition of sandy soil fill material, and (D) installation of two sweet viburnum shrubs.

L·h⁻¹ (Rule RM500A; King Pumps, Inc., Miami, FL). The bilge pump was connected to a 12 kg·m⁻²·s⁻³·A⁻¹ battery to provide power. As the leachate collection container filled, the bilge pump transferred leachate water into a secondary storage container. During data collection, leachate was pumped through a flow meter (TM series water meter; Great Plains Industries, Inc.; Wichita, KS) to empty the secondary storage container and measure leachate volume.

A mixture of pea gravel (25 kg), river stones (100 kg), and play sand (4.5 kg) was added to the bottom of each lysimeter to prevent loss of soil through the drain and to provide space at the bottom of the lysimeter for storage of free water before drainage. The depth of the stone/gravel/sand mixture in the bottom of the lysimeter was ≈8 cm. Lysimeters were then filled with 1592 kg of subsoil (St. Johns fine sand; sandy, siliceous, hyperthermic Typic Alaquods; USDA-NRCS, 2016) that was collected from a local borrow pit (Hills Dirt Pit, LLC., Riverview, FL) from a depth >200 cm to achieve a bulk density of 1.5 g·cm⁻³ and a soil depth of ≈55 cm. This fill soil is representative of material commonly used as "topsoil fill" in new residential landscape construction areas in west central Florida, although the physical and chemical properties of the soil more closely represent soil parent material than a native topsoil (Shurberg et al., 2012). An initial composite sample was collected from the delivered subsoil fill material before filling lysimeters. Collected soil samples were air-dried, and passed through a 2-mm screen before analysis. Initial composite samples were analyzed for soil pH (1:2 soil to deionized water ratio), soil electrical conductivity (EC) (1:2 soil to deionized water ratio), and

soil organic matter (loss on ignition) following standard methods of the UF-IFAS Extension Soil Testing Laboratory (Mylavarapu et al., 2014). The mean initial soil pH was 5.1, soil EC was 1.29 dS·m⁻¹, and organic matter content was 6.80 g·kg⁻¹. Soil pH was adjusted to 6.5 (as confirmed by a soil test) before planting using dolomitic lime (Sunniland Lawn and Garden Lime, Sanford, FL) at the recommended rate based on results of the Adams–Evans lime requirement test (Mylavarapu et al., 2014). Mehlich 3 P and potassium (K) were determined by inductively coupled plasma atomic emission spectroscopy (Perkin Elmer, Waltham, MA) following Mehlich 3 extraction {1:10 ratio of soil to 0.2 M CH₃COOH, 0.25 M NH₄NO₃, 0.015 M NH₄F + 0.013 M HNO₃, 0.001 M ethylenediaminetetraacetic acid [(HOOCCH₂)₂NCH₂CH₂N(CH₂COOH)₂] (Zhang et al., 2014). Mean concentrations of Mehlich 3 P and K were 939 and 161 mg·kg⁻¹, respectively, reflecting high background concentrations of these nutrients in Florida subsoils derived by sandy marine sediments. No applications of P or K were recommended for this soil (Kidder et al., 1998) based on calculated Mehlich 1 nutrient concentrations for these soils (Mylavarapu et al., 2002). Initial soil samples were also extracted using 2 M KCl (Mulvaney, 1996) for colorimetric determination of soil nitrate + nitrite (NO₃ + NO₂-N) [U.S. Environmental Protection Agency (USEPA), 1993b] and ammonium (NH₄-N) (USEPA, 1993a) and digested for determination of total Kjeldahl N (TKN) (Bremner, 1996) using a discrete analyzer (AQ2; Seal Analytical, Mequon, WI). Initial concentrations of soil NO₃ + NO₂-N, NH₄-N, and TKN were 0.66, 6.25, and 70.3 mg·kg⁻¹, respectively.

Two sweet viburnum (*V. odoratissimum*) shrubs grown in 2.84-L (no. 1) nursery containers (Liner Source, Inc., Eusits, FL) were purchased and planted into each lysimeter on 10 May 2012. Sweet viburnum was chosen because it is a hardy shrub that is ubiquitous in residential and commercial landscapes in Florida and the greater southeastern United States. The surface of each lysimeter was kept weed-free by hand-weeding. An automated spray irrigation system with irrigation controller (Hunter SVC, San Marcos, CA) and flow meter (c700; Elster AMCO Water Inc., Ocala, FL) was installed to maintain soil moisture in the absence of rain. Starting 16 May 2012, each individual plant was irrigated with 4.35 L of water twice per week directly on the root ball through two spray stakes (Netafim USA., Fresno, CA) spaced 38 cm apart. The irrigation volume was selected to ensure water stress was not an issue and to prevent irrigation driven leaching based on the results of previous research where irrigation with 3 L of water directly to the roots every 4 to 8 d was sufficient to successfully establish sweet viburnum in the landscape following transplant (Gilman et al., 2009; Shober et al., 2009b). Precipitation data were collected using the Florida Automated Weather Network station that was located on-site.

Fertilizer rate, timing, and application method. Shrubs were fertilized to maintain annual N rates of 0, 98, 195, and 293 kg·ha⁻¹ with a polymer coated urea fertilizer (Polyon, 42N-0P-0K; Harrell's, Lakeland, FL) containing 42% slow release N. The fertilizer application rates were selected based on past research that evaluated woody ornamental growth response and visual quality in response to N fertilizer at various application rates (Shober et al., 2013). Fertilizer was applied per plant (i.e., fertilizer was applied underneath each plant's respective canopy/dripline, adjusting the application amount to maintain the intended dosage for the reduced application area) or broadcast across the entire surface of the planting bed/lysimeter to evaluate the effect of application method on nutrient leaching. Scheduling of fertilization was assessed with and without a locally enforced summer blackout period (Manatee County, FL). Under the regular fertilization treatments (no blackout period during rainy season), fertilizer was applied every 12 weeks based on manufacturer release curve information beginning on 6 Aug. 2012 at a per application N rate of 0, 24.5, 48.8, and 73.3 kg·ha⁻¹ for a total of four applications annually. For blackout fertilization treatments (no fertilizer applied from 1 June to 30 Sept. based on local ordinances), fertilizers were applied every 12 weeks beginning after the initial blackout period (1 Oct., 24 Dec., and 18 Mar.) at a per application N rate of 0, 32.7, 65.0, and 97.7 kg·ha⁻¹ for a total of three annual applications to maintain annual N application rates of 0, 98, 195, and 293 kg·ha⁻¹, respectively.

Plant growth and quality measurements. Plant SI measurements (height, widest width,

and width perpendicular to widest width) were taken at planting and every 6 weeks until experiment completion. The product of these three measurements served as a SI to quantify plant growth over time. Shoot dry weight (g) was measured at the end of the study period by removing the whole above-ground biomass (shoots and leaves) at the soil surface and drying to constant mass at 40.5 °C.

Quality ratings were also recorded every 6 weeks. Quality ratings considered plant size, canopy density, chlorosis, and dieback for each individual plant on the following scale (Shober et al., 2009a): 0 indicated a dead plant; 1 indicated a poor quality plant (low canopy density, small plant, and chlorosis); 2 indicated a below average quality plant (significant dieback, lower canopy density, and chlorosis); 3 indicated an average quality plant (moderate dieback, acceptable canopy density, and chlorosis); 4 indicated an above average quality plant (minimal dieback or chlorosis, above average canopy density); and a quality rating of 5 indicated an outstanding plant (dense leaf canopy and no nutrient deficiencies or dieback).

A portable SPAD meter (SPAD-502; Minolta Corp., Ramsey, NJ) was used to evaluate the spectral reflectance (greenness) of plant tissue. Fisher et al. (2003) reported a linear relationship between tissue chlorophyll concentrations and SPAD ($0.2128 + 0.0295 \times \text{SPAD}$; $r^2 = 0.86$), suggesting that SPAD measurements can be used as a proxy for plant chlorophyll content. Plant SPAD readings were averaged from readings of three recently matured leaves collected from the midsection of each plant every 6 weeks throughout the study period.

Leachate collection and analysis. Starting 23 July 2012 (12 WAP), leachate volume was measured and a subsample was collected daily and stored frozen until analysis. Weekly flow-weighted composite leachate samples (weighted by daily drainage volume) were filtered through a 0.45-µm filter before colorimetric analysis for NO₃ + NO₂-N and NH₄-N using a discrete automated analyzer (AQ2; Seal Analytical, Burgess Hill, UK) as described for soil extracts. Leachate subsamples were digested to allow for determination of TKN based on a modified version of USEPA Method 351.2 (USEPA, 1993b) with a 2.5 to 1 sample to solution ratio (Mylavarapu et al., 2014) using a microsegmented flow analyzer (Astoria 2 Analyzer; Astoria Pacific International, Clackamas, OR). Nutrient loads were calculated by multiplying the total leachate volume by the nutrient concentration.

Experimental design and analysis. In assessing the impact of fertilization on plant health and nutrient loading, three levels of N fertilization (i.e., 98, 195, and 293 kg·ha⁻¹), two levels of application method (i.e., per plant and broadcast), and two levels of fertilization timing (i.e., regular and blackout) were selected. The study was arranged as a completely randomized design with 13 fertilizer treatment combinations (i.e., the 12

unique combinations above plus an unfertilized control). Each treatment combination was applied at the lysimeter level with three lysimeters (replicates) per treatment (total n = 39) arranged in a completely randomized design.

Plant SI and SPAD measurements were analyzed as a repeated measures analysis of variance (ANOVA) using the nlme (Pinheiro et al., 2014) package in R. Plant quality was analyzed using the Friedman test—a non-parametric equivalent to repeated measures ANOVA (de Mendiburu, 2014). All underlying assumptions were checked using residual plots for methods listed earlier before reporting. All inferences for these analyses were based on an $\alpha = 0.05$ level of type I error.

Before analysis, cumulative nutrient loads (i.e., NH₄-N, NO₃ + NO₂-N, TKN) for each lysimeter were calculated by summing nutrient loads over the establishment period (12 to 28 WAP; 23 July 2012 to 9 Nov. 2012) and subsequent 138-week maintenance period (29 to 166 WAP; 10 Nov. 2012 to 30 June 2015). In the first year, the 121-L catchment container was used to collect leachate. During this period, there were 2 weeks where leachate exceeded capacity due to a tropical storm. An additional 208-L capacity container was added to provide a total leachate collection capacity of 329 L. The missing leachate volume measurements from these 2 weeks were imputed using predicted values derived from the model:

$$L^{0.5} = 2.05 + (0.45 \times \text{TW}) + (0.000014 \times \text{LWP});$$

where $L^{0.5}$ was the predicted leachate volume (L) after square root transformation, TW was the total volume of water from irrigation and precipitation (L), and LWP was the leachate collected (L) from each lysimeter during the prior week (adjusted $r^2 = 0.46$). On several occasions during the 3-year trial, leachate volume measurements were omitted from a given lysimeter due to equipment failure. In these instances, the missing volumes were imputed based on the average leachate for the measured containers.

For responses that occurred once over the course of the study (e.g., cumulative loads and shoot dry weight), the data were analyzed using a one-way ANOVA in R [version 3.0.0 (R Core Team, 2011)]. In addition to assessing difference among the treatment combinations using a Tukey's honestly significant difference test, broader differences among the response variables with regard to level of fertilization, application method, and scheduling were assessed using series of a priori contrast statements as described for a one-way ANOVA by Marini (2003) (Model 3).

Results

Plant growth and nutrient leaching during establishment (12 to 28 WAP). Plant SI during the 28-week establishment varied by fertilizer treatment combination ($P = 0.037$;

data not shown) and by week ($P < 0.001$; data not shown) when evaluated as repeated measures over the entire establishment period (0 to 24 WAP). In addition, the interaction between treatment and week was significant ($P < 0.001$; data not shown), which highlighted the increasing differences in plant size as affected by the fertilizer treatment combinations over time. When evaluated at the end of the establishment period, significant treatment effects on SI of sweet viburnum were noted, with a trend toward smaller plants when no fertilizer was applied or when fertilizer was applied on the blackout schedule ($P < 0.001$; Table 1). In contrast, SPAD measurements varied by week ($P < 0.001$), but did not vary by fertilizer treatment when evaluated over the entire shrub establishment period (data not shown) and at 24 WAP ($P = 0.383$; Table 1). Results from the Friedman test for multiple comparisons of treatments did not detect an N fertilizer treatment combination effect on plant quality ratings of sweet viburnum when evaluated over the entire establishment period ($P = 0.123$). However, statistical differences in quality were noted by the end of the establishment period (24 WAP; Table 1), with a trend toward lower plant quality for unfertilized control and lysimeters fertilized following the blackout schedule.

Cumulative $\text{NH}_4\text{-N}$ ($P = 0.182$) and TKN ($P = 0.229$) loads did not differ by treatment during the establishment measurement period (Table 2). In contrast, there was a significant treatment effect on cumulative $\text{NO}_3 + \text{NO}_2\text{-N}$ loads ($P < 0.001$) before shrub establishment (Table 2). A priori contrast tests showed that cumulative $\text{NO}_3 + \text{NO}_2\text{-N}$ loads leached during plant establishment were greater for lysimeters fertilized at the 293 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate (4.45 $\text{kg}\cdot\text{ha}^{-1}$) than from lysimeters fertilized at the 195 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate

(2.82 $\text{kg}\cdot\text{ha}^{-1}$; $P < 0.001$). However, there was no difference in $\text{NO}_3 + \text{NO}_2\text{-N}$ loading between lysimeters fertilized at an annual N rate of 195 $\text{kg}\cdot\text{ha}^{-1}$ and lysimeters receiving N at the 98 $\text{kg}\cdot\text{ha}^{-1}$ rate (1.84 $\text{kg}\cdot\text{ha}^{-1}$; $P = 0.054$). Per plant fertilization during shrub establishment reduced cumulative $\text{NO}_3 + \text{NO}_2\text{-N}$ loads (2.41 $\text{kg}\cdot\text{ha}^{-1}$) when compared with broadcast application (3.66 $\text{kg}\cdot\text{ha}^{-1}$; $P = 0.007$). Similarly, lysimeters fertilized on the summer blackout schedule had lower cumulative $\text{NO}_3 + \text{NO}_2\text{-N}$ loads (1.17 $\text{kg}\cdot\text{ha}^{-1}$) than lysimeters fertilized year-round (4.90 $\text{kg}\cdot\text{ha}^{-1}$; $P < 0.001$).

Plant growth and nutrient leaching during maintenance (29 to 166 WAP). Once established, plant SI continued to differ by fertilizer treatment combination ($P < 0.001$; data not shown) and week ($P < 0.001$; data not shown). As noted for the establishment period, increasing differences in size over time results in the significant treatment by week interaction term ($P < 0.001$; data not shown). When evaluated at a single point at the end of the study (166 WAP), fertilizer treatment combination effects were noted ($P < 0.001$; Table 1), with a trend for larger plants at higher N rates on the broadcast fertilizer schedule. Similarly, SPAD measurements during the maintenance period varied by both treatment ($P = 0.001$; data not shown) and week ($P = 0.003$; data not shown); however, the interaction between treatment and week was not significant ($P = 0.222$; data not shown). Plant quality was affected by fertilizer rate during the longer term maintenance period ($P < 0.001$), with plants responding favorably to the increased fertilizer rates (Table 1).

Final aboveground shrub dry weights differed by fertilizer treatment combination ($P < 0.001$; Fig. 2). Overall, mean dry weights of sweet viburnum shrubs were

significantly affected by N rate and fertilization schedule; plants fertilized on the blackout schedule produced 0.15 kg more dry biomass ($P < 0.001$) than those fertilized on a regular, year-round schedule. Final plant biomass was unaffected by fertilizer application method (i.e., when fertilizer was broadcast across the entire bed vs. when fertilizer application was limited to directly beneath the plant's dripline; $P = 0.61$).

Cumulative $\text{NH}_4\text{-N}$ loads did not vary by fertilizer treatment combination during the nearly 3-year monitoring period following shrub establishment ($P = 0.059$; Table 2). In contrast, fertilizer treatment combinations significantly impacted the cumulative load of $\text{NO}_3 + \text{NO}_2\text{-N}$ ($P < 0.001$) and TKN ($P < 0.001$) leached from the lysimeters during the maintenance period (Table 2). Testing these differences via a priori contrasts showed $\text{NO}_3 + \text{NO}_2\text{-N}$ loads leached from lysimeters fertilized at the 293 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate (11.1 $\text{kg}\cdot\text{ha}^{-1}$) were greater than loads from lysimeters fertilized at the 195 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate (5.71 $\text{kg}\cdot\text{ha}^{-1}$; $P < 0.001$). Similarly, cumulative $\text{NO}_3 + \text{NO}_2\text{-N}$ loads for lysimeters fertilized at the 195 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate were greater than those fertilized at the 98 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate (3.87 $\text{kg}\cdot\text{ha}^{-1}$; $P = 0.028$). The opposite pattern was noted for TKN loads in leachate, with lysimeters fertilized at the 293 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate (6.46 $\text{kg}\cdot\text{ha}^{-1}$) leaching less TKN cumulatively than lysimeters fertilized at the 195 $\text{kg}\cdot\text{ha}^{-1}$ annual N rate (6.65 $\text{kg}\cdot\text{ha}^{-1}$; $P = 0.009$); cumulative TKN loads leached from lysimeters fertilized at the 195 $\text{kg}\cdot\text{ha}^{-1}$ annual N were less than cumulative TKN loads lysimeters fertilized at the 98 $\text{kg}\cdot\text{ha}^{-1}$ rate (8.59 $\text{kg}\cdot\text{ha}^{-1}$; $P < 0.001$).

Per plant fertilization decreased $\text{NO}_3 + \text{NO}_2\text{-N}$ loads (4.87 $\text{kg}\cdot\text{ha}^{-1}$; $P < 0.001$) and

Table 1. Mean (SE) size index (crown volume), quality rating, and SPAD measurements near establishment (24 WAP) and after maintenance (166 WAP) of sweet viburnum (*Viburnum odoratissimum*) shrubs grown in simulated planting beds receiving controlled release N fertilizer at various rates, application methods, and timing between 9 May 2012 and 30 June 2015 in USDA hardiness zone 9a (Balm, FL).

Annual nitrogen rate ($\text{kg}\cdot\text{ha}^{-1}$)	Application method ^w	Fertilizer timing ^x	Size index (m^3) ^z		Quality rating (0–5) ^y		SPAD	
			24 WAP	166 WAP	24 WAP	166 WAP	24 WAP	166 WAP
0	—	—	0.08 (0.01) d ^v	0.15 (0.03) e	3.0 (0.0) c	1.0 (0.0) e	44.1 (2.8)	43.8 (2.9) bc
98	Broadcast	Regular	0.11 (0.02) bcd	0.74 (0.04) cde	3.2 (0.2) bc	2.3 (0.2) cd	49.7 (3.3)	46.5 (1.2) abc
		Blackout	0.08 (0.01) d	0.80 (0.03) cde	2.8 (0.2) c	2.2 (0.2) cd	44.9 (3.4)	49.3 (1.4) abc
	Per plant	Regular	0.14 (0.01) abcd	0.67 (0.07) de	3.7 (0.2) abc	2.0 (0.0) d	49.8 (3.8)	48.1 (0.9) abc
		Blackout	0.08 (0.01) d	1.00 (0.02) cd	2.8 (0.2) c	2.0 (0.0) d	46.7 (0.6)	42.8 (1.7) c
195	Broadcast	Regular	0.17 (0.01) abc	1.71 (0.19) ab	3.7 (0.2) abc	3.0 (0.3) bc	52.0 (6.2)	51.9 (2.0) ab
		Blackout	0.09 (0.01) cd	1.87 (0.03) ab	3.0 (0.0) c	3.0 (0.3) bc	46.9 (1.1)	50.3 (1.2) abc
	Per plant	Regular	0.15 (0.02) abcd	1.39 (0.24) bc	4.0 (0.0) ab	3.0 (0.0) bc	45.7 (2.4)	50.8 (1.7) abc
		Blackout	0.07 (0.01) d	1.84 (0.08) ab	2.8 (0.2) c	3.0 (0.0) bc	46.9 (1.9)	49.8 (1.3) abc
293	Broadcast	Regular	0.19 (0.03) ab	1.81 (0.10) ab	3.7 (0.3) abc	3.8 (0.2) ab	48.4 (4.9)	52.1 (0.3) abc
		Blackout	0.08 (0.02) d	2.10 (0.26) a	3.0 (0.3) c	4.0 (0.0) a	46.6 (1.2)	52.1 (1.9) ab
	Per plant	Regular	0.21 (0.03) a	1.99 (0.11) ab	4.2 (0.2) a	3.3 (0.2) ab	50.6 (2.2)	48.1 (2.7) abc
		Blackout	0.09 (0.02) cd	2.36 (0.07) a	3.2 (0.2) bc	4.2 (0.3) a	50.4 (1.2)	53.3 (1.8) a

WAP = weeks after planting.

^zSize index = $H \times W1 \times W2$, where H is the plant height (m), W1 is the widest width of the plant (m), and W2 is the width perpendicular to the widest width (m). 1 m = 3.2808 ft.

^y0 = dead plant(s); 5 = outstanding plant quality (dense leaf canopy, high-quality flowers, no nutrient deficiencies, no dieback).

^xRegular fertilization occurred every 12 weeks beginning 6 Aug. 2012 at a per application N rate of 0, 24.5, 48.8, and 73.3 $\text{kg}\cdot\text{ha}^{-1}$ (four applications annually); blackout fertilization occurred every 12 weeks beginning after the initial blackout period (1 June to 30 Sept.) at a per application N rate of 0, 32.7, 65.0, and 97.7 $\text{kg}\cdot\text{ha}^{-1}$ (three applications annually).

^wFertilizer application method and timing are not applicable for control lysimeters receiving no N (0 $\text{kg}\cdot\text{ha}^{-1}$).

^vMean separation for each period by Tukey's honestly significant difference test at $P \leq 0.05$.

Table 2. Cumulative nitrate + nitrite ($\text{NO}_3 + \text{NO}_2\text{-N}$), ammonium ($\text{NH}_4\text{-N}$), and total Kjeldahl N (TKN) loads and SE ($\text{kg}\cdot\text{ha}^{-1}$) collected from simulated planting beds during establishment (12 to 28 WAP) and maintenance (29 to 166 WAP) of sweet viburnum (*Viburnum odoratissimum*) shrubs receiving controlled release N fertilizer at various rates, application methods, and timing between 9 May 2012 and 30 June 2015 in USDA hardiness zone 9a (Balm, FL).

Annual nitrogen rate ($\text{kg}\cdot\text{ha}^{-1}$)	Application method ^y	Fertilizer timing ^z	NH ₄ -N load		NO ₃ + NO ₂ -N load		TKN load	
			28 WAP ^y	166 WAP	28 WAP	166 WAP	28 WAP	166 WAP
0	—	—	0.84 (0.18)	2.75 (0.42)	1.11 (0.23) d ^x	1.54 (0.44) e	1.71 (0.44)	10.2 (0.89)
98	Broadcast	Regular	1.07 (0.14)	2.44 (0.82)	3.09 (0.26) cd	2.70 (0.81) cde	1.27 (0.06)	7.62 (0.83)
		Blackout	0.89 (0.07)	2.67 (0.60)	1.19 (0.16) d	7.14 (1.08) abcd	1.27 (0.11)	8.43 (0.47)
	Per plant	Regular	0.82 (0.09)	2.14 (0.11)	2.16 (0.29) d	2.02 (0.26) de	2.02 (0.61)	9.15 (0.53)
		Blackout	0.84 (0.11)	2.15 (0.44)	0.93 (0.10) d	3.62 (0.41) bcde	2.52 (0.69)	9.17 (0.51)
195	Broadcast	Regular	1.23 (0.05)	1.85 (0.34)	5.61 (1.22) bc	6.18 (1.48) abcd	1.46 (0.23)	7.00 (0.65)
		Blackout	1.10 (0.19)	1.35 (0.04)	1.52 (0.66) d	7.82 (1.37) abc	1.12 (0.15)	5.25 (0.57)
	Per plant	Regular	0.78 (0.12)	1.61 (0.10)	3.21 (0.26) cd	2.41 (0.53) cde	1.38 (0.11)	6.94 (0.71)
		Blackout	0.73 (0.14)	1.62 (0.04)	0.94 (0.11) d	6.44 (0.50) abcd	2.38 (0.60)	7.41 (0.69)
293	Broadcast	Regular	0.75 (0.09)	1.77 (0.32)	9.37 (0.36) a	18.0 (4.00) ab	2.77 (0.61)	6.28 (0.81)
		Blackout	0.93 (0.12)	1.43 (0.11)	1.20 (0.20) d	11.8 (3.08) a	1.55 (0.34)	6.10 (0.35)
	Per plant	Regular	0.80 (0.10)	1.59 (0.15)	5.97 (0.89) b	7.34 (3.63) abcd	2.29 (0.78)	7.12 (0.92)
		Blackout	1.03 (0.16)	1.57 (0.20)	1.24 (0.07) d	7.36 (2.40) abcd	1.68 (0.32)	6.33 (0.24)

WAP = week after planting.

^yRegular fertilization occurred every 12 weeks beginning 6 Aug. 2012 at a per application N rate of 0, 24.5, 48.8, and 73.3 $\text{kg}\cdot\text{ha}^{-1}$ (4 applications annually); blackout fertilization occurred every 12 weeks beginning after the initial blackout period (1 June to 30 Sept.) at a per application N rate of 0, 32.7, 65.0, and 97.7 $\text{kg}\cdot\text{ha}^{-1}$ (three applications annually).

^zFertilizer application method and timing are not applicable for control lysimeters receiving no N (0 $\text{kg}\cdot\text{ha}^{-1}$).

^xMean separation for each period by Tukey's honestly significant difference test at $P \leq 0.05$.

Fig. 2. Aboveground biomass dry weight (kg) of sweet viburnum (*Viburnum odoratissimum*) shrubs harvested at 166 weeks after planting from simulated planting beds receiving controlled release N fertilizer at various rates, application methods, and timing between 9 May 2012 and 30 June 2015 in USDA hardiness zone 9a (Balm, FL). Mean separation for each period by Tukey's honestly significant difference test at $P \leq 0.05$.

increased TKN loads ($7.69 \text{ kg}\cdot\text{ha}^{-1}$; $P = 0.021$) that were leached during the maintenance period when compared with broadcast fertilization (8.94 and $6.78 \text{ kg}\cdot\text{ha}^{-1}$ for $\text{NO}_3 + \text{NO}_2\text{-N}$ and TKN, respectively). Withholding fertilization during the summer blackout period increased cumulative $\text{NO}_3 + \text{NO}_2\text{-N}$ loads ($8.40 \text{ kg}\cdot\text{ha}^{-1}$) in leachate compared with year-round fertilization ($5.40 \text{ kg}\cdot\text{ha}^{-1}$; $P < 0.001$) at the same total N rate. However, cumulative TKN loads were unaffected by fertilization scheduling (7.11 and $7.35 \text{ kg}\cdot\text{ha}^{-1}$

for blackout and year-round fertilization, respectively; $P = 0.447$).

Discussion

Fertilizer treatment combination effects on plant SI during both the establishment and maintenance periods were confirmed by measurements of aboveground biomass at the end of the study. In general, both SI and biomass increased as the rate of applied N increased linearly, resulting in a clear delineation

among the fertilizer treatment combinations by the end of the study. Maximum growth was likely not achieved, even with the $293 \text{ kg}\cdot\text{ha}^{-1}$ rate; yet the goal of our work was to evaluate N rates that result in adequate growth, while maintaining acceptable plant quality (Shober et al., 2013). We also noted few differences in SI, SPAD, and aesthetic quality of unfertilized plants at 28 WAP when compared with plants receiving most fertilizer treatment combinations (Table 1). Broschat and Moore (2010) reported no difference in color or growth of unfertilized areca palm [*Dypsis lutescens* (H. Wendl.) Beentje & J. Dransf.] or Chinese hibiscus (*Hibiscus rosa-sinensis* L. 'President') plants when compared with plants fertilized with a complete fertilizer with micronutrients for 6 months or longer following transplant into sandy Florida soils. We also found that nutrient deficiency symptoms from under-fertilization did not manifest visually or with reduced growth during the establishment phase, but were noted by the end of the study. An annual N fertilization rate of $98 \text{ kg}\cdot\text{ha}^{-1}$ was not sufficient to maintain visual quality at an acceptable level; unfertilized controls were chlorotic with sparse canopies and significant dieback. At the $98 \text{ kg}\cdot\text{ha}^{-1}$ rate, the amount of N applied was likely at or below N uptake by shrubs, resulting in lower aesthetic quality. In fact, an annual N rate of $195 \text{ kg}\cdot\text{ha}^{-1}$ was required to maintain a quality rating of 3 (average), which was our threshold for aesthetic performance, which was inline with N recommendations of up to $195 \text{ kg}\cdot\text{ha}^{-1}$ to maintain aesthetic quality of viburnum grown in the landscape by Shober et al. (2013). Shrubs evaluated by Shober et al. (2013) were grown in field soils with higher organic matter content ($23.4 \text{ g}\cdot\text{kg}^{-1}$), and therefore higher fertility, than the fill soils ($6.8 \text{ g}\cdot\text{kg}^{-1}$) used in this work, which could explain why N at the higher end of our recommended range was needed to maintain acceptable aesthetic quality. Moore et al.

(2014) also reported that aesthetic quality of several annual and perennial plants was as good, if not better, when plants were grown in field soils compared with fill soil material from the same source as in our current work. Alsup and Trewatha (2006) reported that soil conditions affected the growth and quality of several ornamental species, with improved growth and quality of plants grown in field soils than plants grown in bag culture due to improved access of roots to water in the field. Therefore, it is also possible that access to water was more limited in the lysimeters than would be expected in the field due to the container-like conditions of the lysimeters, which could result in lower growth and aesthetic quality when comparing plants grown in the lysimeters to plants grown in the field.

The blackout period for fertilizer application actually improved some measures of

plant performance (mainly SI; Table 1) as compared with a regular, year-round fertilizer schedule. The shrubs that did not receive fertilizer during the blackout period produced a greater overall mean dry weight (0.99 kg) than those fertilized year-round (0.85 kg; Fig. 2) without an adverse effect on plant aesthetics (Table 1). In contrast, a change in fertilization methods from broadcast to per plant did not yield any statistical differences in biomass dry weight and did not improve plant quality or growth parameters (Table 1). Plots fertilized at the annual N rate of 293 kg·ha⁻¹ had significantly higher NO₃ + NO₂-N loads during the establishment period than plots fertilized at the annual N rate of 195 kg·ha⁻¹, whereas no differences in NO₃ + NO₂-N loads were noted for the 195 and 98 kg·ha⁻¹ annual N rates (Table 1).

Although growth of sweet viburnum shrubs increased when additional fertilizer

was applied beyond the annual N rate of 195 kg·ha⁻¹, the increased leaching loads suggest that application rates of 293 kg·ha⁻¹ provided N at concentrations that exceeded what could be effectively intercepted and taken up by roots. The 293 kg·ha⁻¹ N rate corresponds to the higher end of the recommended fertilizer rates for woody ornamentals from American National Standards Institute (2011) and a recent study by Shober et al. (2013), where growth and quality response of ‘Alba’ indian hawthorn [*Rhaphiolepis indica* (L.) Lindl.], sweet viburnum, and “RADrazz” rose (*Rosa*) to N fertilization was evaluated. We also completed a 1 year assessment of shrub quality response to N fertilizer treatment combination (48.8, 146, or 244 kg·ha⁻¹ of N on an annual basis) under field conditions for six species: yesterday, today, and tomorrow (*Brunfelsia grandiflora* D. Don), beautyberry (*Callicarpa americana* L.), golden dewdrop

Fig. 3. Temporal trends in mean weekly (A) applied rainfall and irrigation depth, (B) nitrate + nitrite (NO₃ + NO₂-N) loads by fertilization rate, (C) NO₃ + NO₂-N loads by fertilization schedule, and (D) NO₃ + NO₂-N loads by fertilization method collected from lysimeters planted with sweet viburnum (*Viburnum odoratissimum*) shrubs receiving controlled release N fertilizer over 166 weeks between 9 May 2012 and 30 June 2015 in USDA hardiness zone 9a (Balm, FL). Controlled release N fertilizer was applied every 12 weeks (15, 27, 39, 57, 63, 75, 87, 99, 111, 123, 149, and 159 weeks) after planting for lysimeters on the year-round schedule; fertilizer was applied every 12 weeks starting on 1 Oct. (23, 35, 47, 75, 87, 99, 127, 139, and 151 weeks) for lysimeters fertilized on the blackout schedule.

(*Duranta repens* L.), florida privet [*Forestiera segregata* (Jacq.) Krug & Urb.], firebush (*Hamelia patens* Jacq.), and sweet viburnum. With the exception of yesterday, today, and tomorrow, all plants maintained acceptable quality over the 42-week assessment period (>3 of 5) regardless of N fertilizer rate. The yesterday, today, and tomorrow only achieved acceptable plant quality when receiving N at an annual rate of 244 kg-ha⁻¹ (A.L. Shober, unpublished data). Therefore, we suggest that the N fertilizer rate recommended to maintain quality of sweet viburnum and limit leaching losses extends to other woody ornamental species commonly planted in Florida (and other humid subtropical) landscapes.

Although fertilization rate was linked to N loads, it is important to highlight that N was also leached from unfertilized control lysimeters. Normalization of N loads in leachate across the fertilizer and control treatments was not likely related to concentrations of organic N (based on soil TKN minus NH₄-N at 70.3 and 6.25 mg-kg⁻¹, respectively), which indicated the absence of significant stores of potentially mineralizable organic N in the soil before fertilization. About 14 and 6 mg-kg⁻¹ of plant available N was received in rainfall and irrigation, respectively, over the course of one year by plants grown in lysimeters constructed at Apopka, FL, in 2011 (A.L. Shober, unpublished data). Therefore, we cannot rule out the potential for N contributions from rainfall and/or irrigation water on N leaching from unfertilized lysimeters (Table 2).

Fertilizing immediately after planting ornamentals or turfgrass is generally not advised given concerns regarding unnecessary plant stress (Smiley et al., 2013) and nutrient leaching (Telenko et al., 2015). Recently, researchers showed minimal root growth of newly planted woody ornamentals beyond the plant canopy for up to 22 WAP (Moore et al., 2009). Similarly, Shober et al. (2009b) reported minimal root growth beyond the plant canopy of sweet viburnum shortly after planting. In fact, both Moore et al. (2009) and Shober et al. (2009b) suggested that the roots of newly planted woody ornamentals are confined to their planting hole and can take anywhere from 20 to 104 WAP to become fully established. Significantly lower NO₃ + NO₂-N loads for per plant treatments than broadcast treatments were likely due to the inability of the confined root balls to take up nutrients broadcast over the whole plot during the 28-week establishment period.

One of the main concerns regarding the implementation of a fertilizer blackout period in Florida is that fertilizer application is pushed to less active growing and dormant periods, which could increase the potential for leaching (Hochmuth et al., 2011, 2012). However, Shaddox et al. (2016) reported that fertilizing 'Floritam' st. augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] and centipedegrass [*Eremochloa ophiuroides* (Munro) Hack.] during the dormant season did not impact NO₃ + NO₂-N leaching (<25.0 kg-ha⁻¹) when low doses of fertilizer were applied. We reported lower cumulative NO₃ +

NO₂-N loads in leachate when shrubs were fertilized on a blackout schedule during establishment of sweet viburnum despite increasing the per application rate of fertilization during the "dormant season" to make up for the loss of an application date during the blackout period. Schoene and Yeager (2006) confirmed the cyclical nature of root and shoot growth in sweet viburnum, suggesting that these plants (and other woody species) may not actually be dormant during the winter months. Schoene and Yeager (2007) also identified greater N uptake during periods of root elongation, suggesting that fertilization during active root growth could reduce N leaching compared with fertilization during active shoot growth.

The decreased load for blackout fertilization was partly due to delaying the first fertilizer application from 6 Aug. 2012 (15 WAP for year-round fertilization) to 1 Oct. 2012 (23 WAP for blackout fertilization) when plant roots were likely more established or when plants were experiencing a period of active root growth (Hershey and Paul, 1983; Schoene and Yeager, 2007). However, trends shifted during maintenance of sweet viburnum, where NO₃ + NO₂-N loads were higher for lysimeters fertilized on the blackout schedule when compared with the year-round fertilization. Peak NO₃ + NO₂-N loads during the study period corresponded with fertilizer applications immediately preceding a significant rainfall event (Fig. 3). Higher peak loading events during maintenance occurring with blackout scheduling may be the result of the higher per application N application rate (Fig. 3). Alternatively, fertilization of shrubs during the maintenance phase may have corresponded to periods of shoot growth, with N uptake is less efficient (Hershey and Paul, 1983; Rose and Biernacka, 1999; Schoene and Yeager, 2007). Cycles of root and shoot growth, coupled with the high frequency of heavy rainfall events over the summer months and the prevalence of sandy soils, were likely driving the fertilizer timing effects on leachate NO₃ + NO₂-N loads.

Summer rainy season fertilization bans in Florida were implemented as a means of reducing nonpoint urban nutrient pollution sources. Initially met with concern, research is now beginning to shed light on the consequences of these policies with regard to plant growth and pollution mitigation. For the soil, plants, and fertilization factors tested, the summer fertilization ban did not negatively impact plant growth and aesthetic quality; anticipated reductions in N loading due to blackout fertilizer scheduling were not always realized due to heavy precipitation events that occurred near the time of fertilization. In contrast, N leaching load reductions were reported with more targeted application of fertilizer (beneath the dripline of the shrubs vs. broadcast over the planting bed). Although additional calculations are needed to determine the per plant dosage (i.e., determining how much area is underneath the drip line by calculating the area of a circle), this application method represents

cost savings to the consumer as less fertilizer is applied—especially for small shrubs that do not fill the planting bed. This economic benefit, combined with the environmental benefit, makes per plant fertilization a potentially useful tool for landscape managers. Fertilizer rate remains a key driver of plant health in poor urban soils and it is also one of the main drivers of N loading. As such, we recommend targeted (per plant) fertilization of shrubs at an annual N rate of 195 kg-ha⁻¹ for woody ornamental plants grown in humid, subtropical climates (i.e., southeastern United States), where ornamental plant growth is expected to occur year round. Application of fertilizers at higher rates will increase the potential for nutrient losses in leachate, especially during large rainfall events. Year-round or blackout fertilizer scheduling appear to be acceptable to ensure plant growth and quality and environmental protection. The potential for N leaching was highest during heavy storm events, even when fertilization events occurred several weeks before the storm (Fig. 3); however, we recommend delaying fertilizer applications if significant rainfall is forecasted within 2 to 4 d of scheduled fertilization, especially when fertilizing newly installed woody plants with immature root systems or if using fertilizers that contain water soluble fertilizers. Fertilization of woody ornamentals in cooler climates should be adjusted to account for plant dormancy in winter months. Under cooler conditions in Wisconsin, Werner and Jull (2013) reported that fertilization of young common hackberry trees was important to provide adequate N needed to facilitate rapid growth due to lower N storage capacity by young trees due to death of stem wood in winter. In contrast, the authors reported that mature common hackberry trees required less fertilization due to a greater ability of the trees to store N. As such, fertilization rates and timing recommended based on our work with sweet viburnum in Florida may not translate directly to cooler climates. Regardless, judicious and responsible fertilization based on actual plant size will remain a key aspect of surface and groundwater protection.

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