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Growth and Quality Response of Woody Shrubs to Nitrogen Fertilization Rates during Landscape Establishment in Florida

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SUMMARY. Despite inconsistent reports of nitrogen (N) fertilization response on growth of landscape-grown woody ornamentals, broad N fertilization recommendations exist in the literature. The objective of this research was to evaluate the growth and quality response of three landscape-grown woody shrub species to N fertilizer. Three ornamental shrub species, 'Alba' indian hawthorn (*Raphiolepis indica*), sweet viburnum (*Viburnum odoratissimum*), and 'RADrazz' (Knock OutTM) rose (*Rosa*) were transplanted into field soils in central Florida (U.S. Department of Agriculture hardiness zone 9a). Controlled-release N fertilizer was applied at an annual N rate of 0, 2, 4, 6, and 12 lb/1000 ft² for 100 weeks. Plant size index measurements, SPAD readings (a measure of greenness), and visual quality ratings were completed every month through 52 weeks after planting (WAP) and then every 3 months through 100 WAP. Plant tissue total Kjeldahl N (TKN) concentrations and shoot biomass were measured at 100 WAP. Results of regression analysis indicated little to no plant response (size index, biomass, SPAD) to N fertilizer rate. Shrub quality was acceptable for all species through 76 WAP regardless of the N fertilization rate. However, quality of rose and sweet viburnum fertilized with N at the low rates (<2 lb/1000 ft²) was less than acceptable (<3 out of 5) after 76 WAP. Results suggest that posttransplant applications of fertilizer may not increase plant growth, but that low-to-moderate levels of N fertilization (2 to 4 lb/1000 ft² per year) may help plant maintain quality postestablishment.

Fertilization requirements for establishment of shrubs in the landscape have received limited attention in part because woody dicots often perform well with little or no supplemental fertilizer (Broschat et al., 2008). However, much of the available research evaluating the growth response of woody ornamentals to N fertilization has reported variable results. Ferrini and Baietto (2006) found

no improvement in plant establishment and growth of sweetgum (*Liquidambar styraciflua*), japanese pagoda tree (*Styphnolobium japonicum*), and european ash (*Fraxinus excelsior*) in an urban environment after transplanting. The authors attribute the lack of growth response to N inputs to the altered conditions present in the urban environment, including climate, soil physical conditions,

and restricted space for root growth. Similarly, Gilman and Yeager (1990) saw no effect of N rate on caliper diameter of laurel oak (*Quercus laurifolia*) and japanese ligustrum (*Ligustrum japonicum*) under field conditions. In contrast, some researchers have reported increases in growth rate (Gilman et al., 2000), height (Gilman and Yeager, 1990; Gilman et al., 2000), and overall size (Lloyd et al., 2006; Neely, 1980; Schulte and Whitcomb, 1975) as a result of fertilizer applications. In addition, Rose and Biernacka (1999) found that N fertilization rate influenced tissue nutrient contents, dry weight, and shoot-to-root ratio of freeman maple (*Acer ×freemanii*). Tissue N, phosphorus (P), and potassium (K) accumulation during the growing season were correlated with dry weight accumulation and increased with time. However, rapid tree growth as a response to N fertilizer has also been associated with reduced drought tolerance and greater insect populations (Lloyd et al., 2006).

Several studies produced conflicting results on the benefit of applying fertilizer to woody ornamentals in the first years after planting. For example, van de Werken and Warmbrod (1969) determined that fertilizer had little effect on the growth rate of sugar maple (*Acer saccharum*), tulip tree (*Liriodendron tulipifera*), and pin oak (*Quercus palustris*) until the third year after planting. The authors found no differences in tree growth because of fertilizer treatments after 3 years for any species, but trees receiving N at an annual rate of 60 and 120 lb/acre had significantly greater growth (e.g., height, spread, and trunk diameter) than those receiving no N fertilizer after 8 years. Nitrogen fertilizer rate effects on sugar maple, tulip tree, and pin oak growth were even greater 11 years after planting, with trees receiving 120 lb/acre annual N producing the most growth (van de Werken, 1981). In contrast, total new growth of sugar maple planted in a clay loam soil increased as N increased in the first growing season (Schulte and Whitcomb, 1975). Similarly, Lloyd et al. (2006) reported that tree growth during the first year after planting into the landscape was positively correlated with N concentrations in plant tissue when they were treated in the nursery; however, the N fertilizer growth response did not

carry over into the following year of the study.

Though growth response of landscape-grown woody ornamentals to N fertilizers can be highly variable, a variety of sources provide generalized N rate recommendations for tree and shrub fertilization. For example, Rose (1999) summarized N fertilizer recommendations that were based on research conducted during the 1950s through the 1970s; N rate recommendations for fertilization of field-grown ornamentals ranged from 1 to 6 lb/1000 ft². The Florida Friendly™ Landscaping Program provides annual N fertilizer recommendations for ornamentals growing in low (0 to 2 lb/1000 ft²), medium (2 to 4 lb/1000 ft²), and high (4 to 6 lb/1000 ft²) maintenance landscapes (Florida Department of Environmental Protection, 2010); no guidance for selecting a maintenance level is provided. More broadly, the American National Standards Institute (ANSI) A300 Tree Fertilization Standards (ANSI, 2004) recommend using a slow-release fertilizer at N rates between 2 and 4 lb/1000 ft² per year, not to exceed 6 lb/1000 ft² per year or quick-release (soluble) fertilizer at N rates between 1 and 2 lb/1000 ft² per application, not to exceed 4 lb/1000 ft² per year. Additional research is needed to evaluate

these published fertilizer rate recommendations. The objective of this research was to evaluate the growth and quality response of three landscape-grown woody shrub species to N fertilizer applied at five rates. Nitrogen fertilizer response results will be used to develop N fertilization recommendations that reduce fertilizer applications to prevent N losses to groundwater without sacrificing plant growth and quality.

Materials and methods

PLANT MATERIALS AND EXPERIMENTAL DESIGN. Three ornamental shrub species ('Alba' indian hawthorn, sweet viburnum, and 'RADrazz' rose) were selected for evaluation across a range of N fertilization regimes in 2009. Shrubs were received from Harrell's Nursery (Plant City, FL) in 3-gal pots on 22 May 2009. Fifteen planting beds (4 × 54 ft) were established in central Florida [U.S. Department of Agriculture (USDA) hardiness zone 9a] at the University of Florida–Institute of Food and Agricultural Sciences Gulf Coast Research and Education Center in Wimauma, FL. Shrubs were planted in an existing field containing a mosaic of Zolfo fine sand (sandy, siliceous, hyperthermic Oxyaquic Alorthods) and Seffner fine sand [sandy, siliceous, hyperthermic Aquic Humic Dystrudepts (USDA, 2004)]. An initial composite soil sample was collected from the top 0 to 6 inches of the study area, air-dried, passed through a 2-mm screen, and analyzed for soil pH (1:2 soil to deionized water ratio), Mehlich 1 P, K, calcium (Ca), magnesium (Mg), zinc (Zn), copper (Cu), manganese (Mn), and iron (Fe) [1:4 ratio of soil to 0.0125 M sulfuric acid (H₂SO₄) +

0.05 M hydrochloric acid (HCl) (Mylavarapu, 2009)], and soil inorganic N (Mulvaney, 1996). Mehlich 1 nutrients were analyzed using inductively coupled plasma-atomic emission spectroscopy (Perkin Elmer, Waltham, MA). Colorimetric analysis of soil nitrate + nitrite (NO₃ + NO₂-N) [U.S. Environmental Protection Agency (USEPA), 1993a] and ammonium (NH₄-N) (USEPA, 1993b) was completed using a discrete analyzer (AQ2; Seal Analytical, Mequon, WI). The mean initial soil pH was 6.79 and Mehlich 1 P, K, Ca, Mg, Zn, Mn, and Cu were 239, 58.1, 1362, 87.8, 13.8, 8.28, and 18.0 mg·kg⁻¹, respectively; Mehlich 1 Fe concentrations were below the detection limit (<4.0 mg·kg⁻¹). Initial soil concentrations of NO₃ + NO₂-N and NH₄-N were 1.46 and 3.95 mg·kg⁻¹, respectively. Soil pH was adjusted to pH 6.5 before planting and annually using dolomitic lime (Lawn and Garden Lime; Sunniland Corp., Sanford, FL) at the recommended rate based on results of the Adams–Evans lime requirement test (Mylavarapu, 2009).

Plants were transplanted into each field plot with 6-ft spacing between plants and 12-ft spacing between rows on 15 to 17 June 2009. A total of three shrubs of each species were planted in each plot. Controlled-release fertilizer was broadcast applied to the shrub bed at annual N rates of 0, 2, 4, 6, and 12 lb/1000 ft² to correspond with the Florida Friendly Landscaping™ Program recommendations for landscape fertilization (Florida Department of Environmental Protection, 2010); double the highest recommended N rate (12 lb/1000 ft²) was included to represent overfertilization. Shrubs were fertilized every 12 weeks with a polymer-coated urea fertilizer (Polyon

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0283	ft ³	m ³	35.3147
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
48.8243	lb/1000 ft ²	kg·ha ⁻¹	0.0205
1.1209	lb/acre	kg·ha ⁻¹	0.8922
305.1517	oz/ft ²	g·m ⁻²	0.0033
1	ppm	mg·kg ⁻¹	1
(°F – 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

42N-0P-0K; Harrell's, Lakeland, FL) containing 33.6% slow-release N. The fertilization timing for the polymer-coated urea fertilizer was based on the release-rate curve supplied by the manufacturer. Other nutrients were applied to individual plots periodically at the University of Florida–Institute of Food and Agricultural Sciences recommended rates based on results of a routine soil test (Kidder et al., 2009). Triple superphosphate fertilizer (0N-20P-0K; manufacturer unknown) was applied at a P rate of 0.3 lb/1000 ft² per year to the plots receiving the 4 and 6 lb/1000 ft² N fertilizer treatment in block 1 on 26 Feb. 2010 and 20 Aug. 2010. A micronutrient fertilizer containing sulfur (S), boron (B), Cu, Fe, Mn, molybdenum (Mo), and Zn (Scotts MicroMax[®]; Scotts, Marysville, OH) was applied to at the label recommended rate to block 1 plots receiving the 4 and 6 lb/1000 ft² N fertilizer treatment on 26 Feb. 2010 and block 1 plots receiving the 4, 6, and 12 lb/1000 ft² N fertilizer treatment on 27 Jul. 2010. Potassium sulfate fertilizer (0N-0P-41.5K-17S; Great Salt Lake Minerals Corp., Overland Park, KS) was applied to all plots on 10 Sept. 2010 at a K rate of 1.2 lb/1000 ft². All roses received two foliar applications of liquid Fe [iron sulfate (Liquid Iron, Sunniland Corp.)] at a rate of 30 mL/gal (total of 2.5 gal applied) on 10 Mar. 2010 and 31 Mar. 2010 to correct an Fe deficiency. Plots were not mulched to minimize outside N contributions. Weeds were removed manually or spot treated with glyphosate (Round-Up[®]; Monsanto, Creve Coeur, MO).

Irrigation was applied to each individual plant through two spray stakes (Netafim USA, Fresno, CA) spaced 15 inches apart. Plants were irrigated four times per week, one row at a time, between 0000 and 0700 HR, to apply 3.8 gal of water per plant per irrigation event for a period of 3 months. Starting 5 Oct. 2009, irrigation was reduced to three times per week, with each plant receiving a total of 2.7 gal of water until 4 Jan. 2010 (28 WAP), at which time plants were considered established (Shober et al., 2009b). Once established, irrigation was then applied as needed during prolonged periods without significant rainfall. Cumulative rainfall was 86.5 inches from 18 June

2009 to 8 June 2011 (University of Florida, 2013).

PLANT SIZE INDEX AND BIOMASS.

Plant size measurements were taken at planting, monthly until 52 WAP, and every 3 months until 100 WAP. Size index (SI) was used as a quantitative indicator of plant growth. Size index was calculated as follows: SI (cubic meters) = $H \times W1 \times W2$, where H is the plant height (meters), W1 is the widest width of the plant (meters), and W2 is the width perpendicular to the widest width (meters). Shoot biomass was determined by harvesting all aboveground biomass (leaves and stems) at 100 WAP. Plant shoots were dried to a constant weight at 40.5 °C and weighed to determine shoot dry weight (grams).

PLANT SPAD VALUES. The reflective greenness of plant leaves was measured for all plants by averaging readings from three recently matured (midsection) leaves per plant using a portable SPAD-502 m (Minolta Corp., Ramsey, NJ). Plant SPAD readings were taken monthly for the first year and then every 3 months for the remainder of the study.

FOLIAR NUTRIENT ANALYSIS. The youngest fully expanded leaves were collected from all treatments every 3 months. Tissue samples from the three individual plants of each species were combined to create a single composite sample for each species in each plot, which generated three replicate composite samples for each species and N fertilizer treatment. Tissue samples were ground to pass a number 20 screen using a Wiley mill (Arthur H. Thomas Co. Scientific, Philadelphia, PA) and dried at 110 °C for 7 d. Digested tissue samples (Mylavarapu, 2009) were analyzed for TKN by EPA Method 351.2 (USEPA, 1993c) using an autoanalyzer (Alpkem Flow IV; Pulse Instrumentation, Saskatoon, SK, Canada).

PLANT QUALITY RATINGS. Visual quality ratings were assigned for each plant monthly through 54 WAP and every 3 months through 100 WAP. Canopy density, flower cover, chlorosis, and dieback were considered in assigning plants a quality rating of 0 to 5. Dead plants were assigned a rating of 0, average-quality plants with limited dieback or chlorosis were assigned a rating of 3, and outstanding quality plants with high canopy density, high-quality flowers, and no

nutrient deficiencies or dieback were assigned a rating of 5 (Shober et al., 2009a).

STATISTICAL ANALYSIS. The experiment was arranged in a randomized complete block design with 5 N fertilizer rates applied randomly over 15 landscape field plots. Nitrogen fertilizer treatments were replicated three times by randomly assigning each N rate to plots within each field block. Within each plot, three individual plants of each shrub species were planted. Plant growth parameter measurements (SI, SPAD, biomass, and tissue TKN) for all the three shrubs of each species planted were averaged to obtain a mean value for each species within each plot (replicate). Regression analysis was completed using PROC REG (SAS Version 9.3; SAS Institute, Cary, NC) to evaluate growth response of each species to N fertilization rate using the mean response data for plot at each collection date. First-order (linear) and second-order (polynomial) regression models were fit by species and WAP using N rate and N rate $\times$ N rate as the predictor variables. The regression model was considered significant at the $P < 0.05$ level. If the N rate $\times$ N rate term was significant (based on a t test with $P < 0.05$), then the second-order regression equation was selected in lieu of the first-order regression and the optimum N rate for each regression fit was determined by the maximum point on the regression curve, which was determined by solving the second-order derivative of the equation. The optimum N rate exceeded the 12 lb/1000 ft² if the first-order (linear) regression equation was significant. Plant quality data were analyzed by species and WAP using PROC GLIMMIX (SAS Version 9.3) with N rate included as a fixed effect. Normality of all data was validated using histogram and normality plots of the conditional residuals. All pairwise comparisons were conducted with the Tukey honestly significant difference test at a significance level of $\alpha = 0.05$.

Results

PLANT SIZE INDEX AND BIOMASS. Neither regression model (i.e., first- or second-order polynomial) adequately described the SI or biomass response of indian hawthorne or viburnum (data not shown). In contrast,

Fig. 1. Rose size index response to fertilizer-derived nitrogen (N) rate at 12, 16, 20, 27, and 39 weeks after planting (WAP) when planted in sandy field soil in central Florida; 1 lb/1000 ft² = 48.8243 kg·ha⁻¹, 1 m³ = 35.3147 ft³.

Table 1. Leaf greenness (SPAD) response of selected landscape-grown shrub species to fertilizer-derived nitrogen (N) rate when planted in St. Augustine fine sand subsoil fill in central Florida.

Species and time after planting (weeks)	Regression equation	P value	r ²
Indian hawthorne 88	SPAD = (0.406 × N rate) + 45.22	0.016	0.369
Rose 16	SPAD = (0.236 × N rate) + 45.22	0.035	0.236
88	SPAD = (0.330 × N rate) + 35.94	0.006	0.453
Viburnum 88	SPAD = (0.840 × N rate) + 35.45	0.006	0.449
100	SPAD = (0.778 × N rate) + 58.22	0.001	0.591

the effect of N rate on rose SI was best described by the first-order regression at 12, 16, 20, 27, and 39 WAP, indicating that maximum size was not achieved by N applications of up to 12 lb/1000 ft² (Fig. 1). However, the relationship between SI and fertilizer rate was weak ($r^2 \leq 0.40$), suggesting that other environmental factors contributed to the growth response of rose (Fig. 1). Neither the first- nor the second-order polynomial regression equations were significant for the SI or biomass response of roses from 48 WAP through the end of the study (data not shown).

PLANT SPAD VALUES AND FOLIAR NUTRIENT ANALYSIS. The first-order regression equation described plant SPAD values for indian hawthorne at 88 WAP, rose at 16 and 88 WAP, and viburnum at 88 and 100 WAP (Table 1). These results indicated that more than 12 lb/1000 ft² of N was needed annually to maximize greenness. Neither the first- nor second-order polynomial regression model significantly described the SPAD readings at any other time during the study (data not shown). Regression analysis did not reveal an N fertilizer effect on foliar TKN content at any

point during the study (data not shown).

PLANT QUALITY RATINGS. Plant quality response to N fertilization rate varied by species. No N rate effect on visual quality of viburnum was reported from 0 to 24 WAP. Beginning at 27 WAP, quality of viburnum receiving N at 0 or 2 lb/1000 ft² annual rates was usually lower than plants receiving 12 lb/1000 ft² (Table 2). Similarly, there was little N fertilizer effect on the quality of roses from 7 to 31 WAP. After 39 WAP (except 62 WAP), roses receiving 4 lb/1000 ft² of N annually exhibited higher quality than shrubs fertilized with 0 or 2 lb/1000 ft²; no additional quality improvement was reported for plants fertilized with N at 6 or 12 lb/1000 ft² per year (Table 1). However, visual quality of viburnum and roses was acceptable (quality ratings of 3) or greater during most weeks until 76 WAP, regardless of the amount of N applied (Table 2). From 76 to 100 WAP, the quality of viburnum was typically lower than 3 when plants received 0 (88 and 100 WAP) or 2 lb/1000 ft² (76 and 100 WAP) of N annually (Table 2). Rose quality also declined after 76 WAP, with most plants failing to rate higher than 3 when fertilized at the 0 or 2 lb/1000 ft² annual N rate; roses fertilized at the higher N rates maintained quality ratings of 3 or better during this period (Table 2). Nitrogen rate had little to no effect on visual quality of indian hawthorne from 7 to 12 WAP. After 16 WAP, the highest quality indian hawthorne was generally produced at the 12 lb/1000 ft² annual N rate when compared with other N rates (Table 2).

Discussion

Our results were similar to those presented in earlier studies evaluating growth response of woody ornamentals to applied N fertilizers (Broschat et al., 2008; Ferrini and Baietto, 2006; Gilman, 2011; Gilman and Yeager, 1990; Harris et al., 2008; Rose and Joyner, 2003), which suggested shrubs require little if any N for growth during the first years after planting. For example, Day and Harris (2007) found that N fertilizer applied at a rate of 3 or 6 lb/1000 ft² annually for 3 years after transplant did not affect growth parameters (trunk growth, shoot extension, or leaf N

Table 2. Visual quality of selected landscape-grown shrub species to fertilizer-derived nitrogen (N) rate when planted in St. Augustine fine sand subsoil fill in central Florida.

Time after planting (weeks) and fertilizer N rate (lb/1000 ft ²) ^z	Plant quality (0–5 scale) ^y		
	Indian hawthorne	Rose	Sweet viburnum
7 WAP ^x			
0	4.2	4.0	4.8
2	4.4	4.3	4.8
4	4.2	3.9	4.9
6	4.3	4.2	4.7
12	4.6	3.9	4.9
12 WAP			
0	3.7	3.4	4.2
2	3.8	3.6	4.0
4	3.7	3.3	3.9
6	3.8	3.7	4.2
12	4.1	3.6	4.2
16 WAP			
0	3.4 ab ^w	2.9	3.8
2	3.6 ab	3.0	3.8
4	3.4 ab	3.0	3.7
6	3.3 b	3.1	3.8
12	3.8 a	3.4	4.2
20 WAP			
0	3.4	3.2 b	3.3
2	3.5	3.4 ab	3.1
4	3.6	3.6 ab	3.3
6	3.4	3.7 ab	3.6
12	3.9	3.8 a	3.6
24 WAP			
0	3.4 b	3.4	3.5
2	3.4 b	3.2	3.2
4	3.7 ab	3.8	3.4
6	3.4 b	3.3	3.7
12	4.1 a	3.7	3.8
27 WAP			
0	3.4 ab	2.9	3.2 ab
2	3.4 ab	2.6	2.8 b
4	3.7 ab	2.9	3.3 ab
6	3.2 b	2.8	3.2 ab
12	3.8 a	3.1	3.6 a
31 WAP			
0	3.1 b	3.0	2.9 ab
2	3.3 b	2.9	2.6 b
4	3.3 ab	3.3	3.2 ab
6	3.0 b	3.1	3.6 a
12	3.9 a	3.6	3.5 a
39 WAP			
0	4.5 ab	3.1 b	3.2 c
2	4.6 ab	3.1 b	3.4 bc
4	4.7 ab	4.1 a	4.2 a
6	4.2 b	3.9 ab	4.0 ab
12	4.9 a	3.8 ab	4.4 a
48 WAP			
0	3.6	3.2 b	3.3 b
2	3.6	3.2 ab	3.3 b
4	3.4	3.8 ab	3.9 ab
6	3.3	3.7 ab	3.9 ab
12	3.9	4.0 a	4.3 a

(Continued on next page)

content) of red maple (*Acer rubrum*) and littleleaf linden (*Tilia cordata*) trees. Similarly, Harris et al. (2008) reported no effect of N fertilization on posttransplant growth or rate of establishment of 10 shade tree species, even when grown in poor-quality urban soils. Perry and Hickman (1992) also found no increase in growth of valley oak (*Quercus lobata*) when fertilized with N at planting and at 1 year after planting into a Bear Creek clay loam soil (fine-loamy, mixed, superactive, thermic Typic Endoaqualfs). The authors suggested that soil fertility was adequate to sustain adequate growth during this period.

In contrast, some researchers have reported increases in growth parameters of woody ornamentals with the addition of fertilizer (Gilman and Yeager, 1990; Gilman et al., 2000; Lloyd et al., 2006; Neely, 1980; Schulte and Whitcomb, 1975). For example, seedling southern magnolia (*Magnolia grandiflora*) and field-grown live oak (*Quercus virginiana*) trees grew faster when fertilized with N on sandy, low fertility, central Florida soils (Gilman et al., 2000). Likewise, Rose and Joyner (2003) and Neely (1980) reported greater increases in growth of fertilized woody landscape plants on lower fertility soils. Broschat et al. (2008) reported the appearance of nutrient deficiency symptoms in areca palm (*Dypsis lutescens*) $\approx$ 6 to 8 months after transplant. Because roots of container-grown shrubs are confined to the planting hole for several months after planting (Shober et al., 2009b; Wiese et al., 2009), fertilizers applied to plants in the potting substrate are likely depleted quickly during establishment. Therefore, based on the results of our work and other studies, it appears that the fertility of our field soils (rather than the potting substrate) was adequate to support the establishment growth of the woody ornamental species. However, it is possible that a growth response of evaluated shrubs to N fertilizer would be observed if shrubs were transplanted into lower fertility soils or subsoil fill material instead of field soils.

We reported little to no growth response of shrub species to N in year 1 or 2 of the study; however, some researchers reported increases in growth when N inputs are supplied in the first year (Ferrini and Baietto,

Table 2. (Continued) Visual quality of selected landscape-grown shrub species to fertilizer-derived nitrogen (N) rate when planted in St. Augustine fine sand subsoil fill in central Florida.

Time after planting (weeks) and fertilizer N rate (lb/1000 ft ²) ^z	Plant quality (0–5 scale) ^y		
	Indian hawthorne	Rose	Sweet viburnum
62 WAP			
0	3.9 ab	3.4	3.4 b
2	3.8 b	3.4	3.7 ab
4	3.6 b	3.7	4.1 ab
6	3.6 b	3.8	4.0 ab
12	4.5 a	3.9	4.3 a
76 WAP			
0	4.1 ab	2.6 b	3.1 ab
2	4.1 ab	2.4 b	2.8 b
4	3.4 b	3.6 a	3.6 a
6	3.4 b	3.1 ab	3.1 ab
12	4.3 a	3.2 ab	3.7 a
88 WAP			
0	4.4 ab	2.9 b	2.9 b
2	4.5 ab	2.8 b	3.1 ab
4	3.9 b	4.5 a	3.5 ab
6	4.2 ab	3.9 a	3.5 ab
12	4.7 a	4.1 a	3.7 a
100 WAP			
0	3.8 a	2.6 b	2.9 b
2	3.7 ab	2.7 b	2.8 b
4	3.2 ab	3.7 a	3.3 ab
6	3.1 b	3.3 ab	3.6 a
12	3.7 a	3.6 a	3.8 a

^z1 lb/1000 ft² = 48.8243 kg·ha⁻¹.

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

^zWAP = weeks after planting.

^wMean separation within columns for each species and WAP by Tukey's honestly significant difference test at $P < 0.05$.

2006; Schulte and Whitcomb, 1975). In contrast, other researchers saw increases in growth only when fertilizer was supplied in later years. For example, Gilman et al. (2000) reported that N fertilizer applied at 4.2, 8.3, 12.4, 16.5, or 20.6 lb/1000 ft² per year did not influence height or trunk diameter of southern magnolia in years 1 or 2. However, trees receiving N fertilizer at an annual rate of 8.3 lb/1000 ft² grew taller than plants receiving 4.2 lb/1000 ft² of N annually. Therefore, it is also possible that the shrub species evaluated in our study could exhibit a growth response to added N fertilizer in later years.

Although we reported limited growth response of shrubs to added N, visual quality increased late in year 2 (after 76 WAP) when rose and sweet viburnum were fertilized with a minimum of 4 or 6 lb/1000 ft² per year, respectively (Table 2). Broschat and Moore (2010) reported that unfertilized hibiscus (*Hibiscus rosa-sinensis*) had poor quality (as measured

by plant color) and reported increased growth and darker color when hibiscus received high rates of N (75 g·m⁻² of 18N–0.6P–6.7K–2.6 Mg compared with 75 g·m⁻² of 8N–0.9P–10K–4Mg); however, high rates of N induced magnesium deficiency, which eventually affected plant quality. In contrast, Broschat et al. (2008) found that quality of fertilized dwarf allamanda (*Allamanda cathartica* ‘Hendersoni’) fertilized with N at 8, 12, or 24 lb/1000 ft² per year and nandina (*Nandina domestica*) fertilized with N at 8, 12, or 16 lb/1000 ft² per year was not different from unfertilized plants. Similarly, the quality of all species evaluated here was acceptable or better regardless of N fertilizer rate before 76 WAP.

Our results suggest that shrub species may need little to no supplemental N fertilizer during the establishment period (year 1) to produce high-quality plants. However, shrub quality may benefit from a low level of N fertilizer during the second year

(Table 2). Yet, Broschat and Moore (2010) reported that N fertilizer applied at 6 months after planting continued to affect plant quality at 12 and 24 months after transplant. Werner and Jull (2013) suggested that young trees rely more heavily on fertilizer-derived N than mature trees, which used previously assimilated N to meet the requirements. As such, fertilizer-derived N applied in the early years after planting may provide the woody ornamentals the N needed to meet the demand in later years. Therefore, we cannot discount the benefits of N applications during establishment, although we reported little to no quality response of shrubs to fertilizer.

Struve (2002) recommends that fertilizer rates should correspond to the particular goal in the landscape (e.g., correcting a nutrient deficiency, increasing plant growth, or maintaining plant quality). Therefore, we suggest that the visual quality of some shrub species would benefit from annual applications of N fertilizer at 2 to 4 lb/1000 ft²; lower rates could support adequate growth and quality for some shrub species. Our recommended rate corresponds with published annual N fertilizer recommendations for woody ornamentals in the landscape [2 to 4 lb/1000 ft² (Smiley et al., 2002); 0 to 1 lb/1000 ft² (Gill et al., 2001); and 0.5 to 3 lb/1000 ft² (Rose and Joyner, 2003)]. These N fertilization recommendations suggest applying only small amounts of N fertilizer, which will prevent N losses to groundwater without sacrificing plant growth and quality.

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