Nitrogen and Flowering Dogwood. II. Impact of Nitrogen Fertilization Rate on Flower Bud Set and Tree Growth[1]

A.K. Hagan[2], J.R. Akridge[3], K.L. Bowen[4], and C.H. Gilliam[5]
Department of Entomology and Plant Pathology
Department of Horticulture
Auburn University, AL 36849

Abstract

Impact of nitrogen (N) fertilization rate on the growth of 'Cloud 9' and 'Cherokee Chief' flowering dogwood was assessed in a field planting from February 2001 until January 2006 in southwest Alabama (USDA Zone 8a). Starting at planting in 2001 and ending in 2005, ammonium nitrate was broadcast in a 0.3 m^2 circle around the base of each tree at 4.1, 8.3, 16.5, 33.0 and 66.0 g $N{\cdot}m^{-2}$ (37.5, 75, 150, 300, 600 lb $N{\cdot}A^{-1}$) with the application of half of each N-rate in April and June of each year. In each year, disease control was maintained with approximately six applications of Heritage 50W fungicide made at 2-week intervals. Trunk diameter and tree height were recorded in early-winter from 2001 through 2006; flower bud counts were taken annually from 2003 to 2006. With the exception of 2004 when N rate had not influence on bud formation, highest flower bud counts were associated with elevated rates of 33 and 66 g $N{\cdot}m^{-2}$ (300 and 600 lb$\cdot N^{-2}$). Nitrogen rate had no influence on the height or trunk diameter of flowering dogwood until three and four years, respectively, after planting. Impact of N rates below 66.0 g $N{\cdot}m^{-2}$ (600 lb$\cdot A^{-1}$) per year on tree height was minimal. In 2005 and 2006, trunk diameter was greater for trees receiving the two highest than the two lowest N rates. Regression analysis was used to calculate optimum N rate for flower bud set, as well as change in trunk diameter and tree height.

Index words: shoot elongation, trunk diameter, tree height, fall color, fungicide-stimulated growth response.

Species used in this study: *Cornus florida* 'Cherokee Chief' and *C. florida* 'Cloud 9'.

Significance to the Nursery Industry

Beginning in 2001, ammonium nitrate was applied at rates of 4.1, 8.3, 16.5, 33.0, and 66.0 g actual nitrogen$\cdot m^2$ (g $N{\cdot}m^{-2}$) (37.5, 75, 150, 300, 600 lb $N{\cdot}A^{-1}$) per year to 'Cloud 9' and 'Cherokee Chief' flowering dogwoods established in full sun in a well drained sandy loam soil in southwest Alabama. In years when N rate had a significant impact on flower bud formation, bud counts rose with increasing N rates. Averaged across both cultivars, tree height and trunk diameter was not influenced by N rate until three and four years, respectively after planting. In 2005 and 2006, trunk diameter was larger for trees receiving the two higher compared with two lowest N rates. Impact of N rates below 66.0 g $N{\cdot}m^{-2}$ (600 lb$\cdot A^{-1}$) per year on tree height between the 2001 planting and final January 2006 rating date was minimal. While the recommended 4.9 to 14.4 g $N{\cdot}m^{-2}$ (44 to 130 lb $N{\cdot}A^{-1}$) for landscape plantings was sufficient for tree maintenance, enhanced flower bud set and accelerated growth of flowering dogwood would require at least a doubling of N rates, which would not be economically feasible. From the standpoint of a field production nursery, flowering dogwoods probably would have to be held in the field for a minimum three years before any enhancement in tree growth if fertilized above the recommended N rate of 27.5 g $N{\cdot}m^{-2}$ (250 lb $N{\cdot}A^{-1}$). Due to the negligible growth response of flowering dogwood to a wide range of N rates over a period of several years, the Field Nursery Best Management Practices for fertilization guidelines, where per-tree N rates increase over time, may be the preferred fertilization program for field-grown flowering dogwood.

Introduction

Despite the popularity of flowering dogwood (*Cornus florida* L.), the impact of N rate on tree growth and health is not well documented. In a forest setting, Curlin (2) reported that increasing N rates from 0 to 32 g $N{\cdot}m^{-2}$ (293 lb $N{\cdot}A^{-1}$) were accompanied by a corresponding increase in trunk diameter of flowering dogwood. With southern magnolia and live oak, no increase in growth was observed at rates above 40 g $N{\cdot}m^{-2}$ (360 lb $N{\cdot}A^{-1}$) in a fine sandy soil (7). Over a three year study, caliper and height of field-grown 'Red Sunset' maple, 'China Girl' holly, Douglas fir, Norway spruce, 'Compactus' euonymus often were not greatly influenced by N rates ranging from 11 to 44 g $N{\cdot}m^{-2}$ (100 to 400 lb $N{\cdot}A^{-1}$) (11). Within three years of planting, the growth rate for bare-root pin oak, sugar maple, and yellow popular receiving 6.6 and 13.2 g $N{\cdot}m^{-2}$ (60 and 120 lb $N{\cdot}A^{-1}$) was similar (19). Only in the fourth year following transplanting did van der Werken (19) note any N-related growth response. Smith and Gilliam (17) reported that 14.4 g $N{\cdot}m^{-2}$ (130 lb$\cdot A^{-1}$) per year was sufficient for maintaining the health and beauty of most landscape trees and shrubs. Currently, 4.9 to 14.4 g $N{\cdot}m^{-2}$ (44 to 130 lb $N{\cdot}A^{-1}$) for mineral and 9.9 to 19.3 g $N{\cdot}m^{-2}$ (87 to 174 lb $N{\cdot}A^{-1}$) for slow-release nitrogen forms are recommended for established landscape trees (16). For field-grown nursery stock including flowering dogwood, optimum annual N rate is approximately 27.5 g $N{\cdot}m^{-2}$ (250 lb $N{\cdot}A^{-1}$) (17). According to Field Nursery Best Management Practices (BMPs), surface side dress applications of nitrogen fertilizers within the root zone of field-grown trees and shrubs of 7.0 to 14.1 g N (0.25–0.5 oz N) in the first, 14.1 to 28.4 g N (0.5–1.0 oz N) in the second, and 28.4 to 56.8 g N (1.0 to 2.0 oz N) per plant in the third year after establishment are recommended (22). In addition, 2/3rd of the total amount of fertilizer should be applied at bud break followed by the remainder in mid-June

[1]Received for publication December 1, 2007; in revised form May 9, 2008.

[2]Professor, Department of Entomology and Plant Pathology. haganak@auburn.edu

[3]Superintendent, Brewton Agricultural Research Unit.

[4]Professor, Department of Entomology and Plant Pathology.

[5]Professor, Department of Horticulture.

(22). An extensive review of shade tree nitrogen fertility research was recently published by Struve (18) who noted that results of many studies are compromised by inter-plot interference, soils with high background fertility, and turfgrass competition. The objective of this study was to evaluate the long term impact of N rates on the growth of flowering dogwood in a simulated landscape planting.

Materials and Methods

Bare-root 'Cherokee Chief' and 'Cloud 9' flowering dogwoods were potted in January 2000 into #5 containers filled with a pine bark:peat moss medium (3:1 by vol) amended with 4.9 kg (14 lb) of Osmocote 17–7–12, 2.1 kg (6 lb) of dolomitic limestone, 0.7 kg (2 lb) of gypsum, and 0.5 kg (1.5 lb) of Micromax per m^3 (yd^3). In February 2001, trees were transplanted into a Benndale (A) fine sandy loam (coarse-loamy, siliceous, semiactive, thermic Typic Paleudults) (< 1% organic matter) with a pH of 6.1 at the Brewton Agricultural Research Unit in Brewton, AL, where winter rye (*Secale cereale*) had previously been killed with Roundup® (glyphosate, Monsanto Co., St. Louis, MO). According to the results of a pre-plant soil fertility assay, Mehlich 1 extractable concentrations of phosphorus, potassium, magnesium and calcium were 29, 41, 56, and 360 $mg \cdot kg^{-1}$ of soil (58, 82, 113, 720 $lb \cdot A^{-1}$), respectively (3). A drip irrigation system with a single emitter per tree was installed before tree establishment and the trees were watered as needed. Centipedegrass (*Eremochloa ophiuroides*) alleys, which were established after transplanting, were mowed but not fertilized. After planting, 2.5 cm (1 in) of aged pine bark was evenly distributed in a 0.3 m^2 (8.6 ft^2) circle around the base of each tree. The pine bark mulch was periodically freshened. Murate of potash (0–0–60 K_2O) at 85 g (3.6 oz) per tree was evenly distributed over the mulched area on February 26, 2003 and March 9, 2004. A separate application of super phosphate (0–0–46 P_20_5) at 85 g (3.6 oz) per tree was made on March 9, 2004. Directed applications of 0.68 kg $a.i. \cdot ha^{-1}$ (1 $lb \cdot A^{-1}$) of Gallery® DF (isoxaben, Dow AgroSciences LLC, Indianapolis, IN) plus 2.2 kg $a.i. \cdot ha^{-1}$ (2 $qt \cdot A^{-1}$) of Surflan® T/O (oryzalin, United Phosphorus, Trenton, NJ) were made to the mulched area once or twice each year for pre-emergent weed control. Escaped weeds were controlled by hand and spot applications of Finale® 1E (glufosinate-ammonium, Bayer Environmental Science, Kansas City, MO) at 1.9 g $a.i. \cdot liter^{-1}$ (2 fl $oz \cdot gal^{-1}$). Trunk sprays of Dursban® 2E (chlorpyrifos, Dow AgroSciences LLC, Indianapolis, IN) were made on May 14, 2002, as well as in 2004 on March 24 and April 27 to protect trees from the dogwood borer *Synanthedon scitula* (Harris).

A split plot design consisting of 120 trees arranged in 6 replications with nitrogen (N) rate as the main plot and dogwood cultivar as the sub plot was used. At planting, the average height for both flowering dogwood cultivars was between 1.5 and 1.6 m (4.9 to 5.2 ft). Ammonium nitrate ($33N–0P_2O_5–0K_2O$) was surface applied at 4.1, 8.3, 16.5, 33.0 and 66.0 $g\ N \cdot m^{-2}$ (37.5, 75, 150, 300, 600 $lb\ N \cdot A^{-1}$), which corresponds to 10.4, 20.7, 41.4, 82.9, and 165.5 g (0.37, 0.73, 1.46, 2.92, and 5.8 oz) of ammonium nitrate evenly distributed each year over the 0.3 m^2 (8.6 ft^2) mulched area around each tree. From 2001 through 2005, half of each rate of ammonium nitrate was distributed in April and the remainder in June. Each main plot included two 'Cherokee Chief' and 'Cloud 9' flowering dogwoods planted on 5.0 m (16 ft) centers. Heritage 50W fungicide (azoxystrobin, Syngenta Professional Products, Greensboro, NC) was applied at a rate of 1.6 g $a.i. \cdot liter^{-1}$ (4 $oz \cdot 100\ gal^{-1}$) of spray volume. Fungicide applications, which were made with a CO_2-pressurized sprayer, were scheduled at two-week intervals from April 20 to July 27, 2001; April 10 to July 10, 2002; March 21 to July 10, 2003; April 1 to July 7, 2004; and April 19 to July 27, 2005. Tree height and trunk diameter measurements were made 10 cm (4 in) above the soil line on February 13, 2001; December 3, 2001; February 17, 2003; January 13, 2004; January 8, 2005, and January 10, 2006. Flower buds counts on each tree were recorded on February 17, 2003; January 13, 2004; January 31, 2005; and January 18, 2006.

Significance of N rate effects on flower bud set, trunk diameter (caliper) tree height, and cultivar × N rate interactions for trunk diameter and tree height in each year were tested by analysis of variance (15). Means for trunk diameter and tree height were compared with Fisher's protected least significant difference (LSD) test with a level of significance of $P \leq 0.05$. In addition, change in tree height or trunk diameter over time (i.e. growth) were determined by subtracting initial measurement for each parameter at establishment in February 2001 from the measurement taken on the 2003, 2004, 2005, and 2006 rating dates (e.g. 2001 height was subtracted from the 2003 height, etc.). For each flowering dogwood cultivar, tree height and trunk diameter data from each year were fit to linear and quadratic models with N rate as the independent variable. Linear models usually did not provide a better fit to the data than did the quadratic models. Optimum N rate was determined from the differential of the quadratic models.

Results and Discussion

Flower bud counts were higher for 'Cloud 9' compared with 'Cherokee Chief' in 2003, 2004, and 2005 but not in 2006 (Table 1). When differences were noted, flower bud counts for 'Cloud 9' were two to three times higher than for 'Cherokee Chief'.

Since the N rate × cultivar interaction for flower bud set in 2003, 2004, 2005, and 2006 was not significant; flower bud counts for each N rate in each of the above years were averaged across flowering dogwood cultivars (Table 2). In three of four years, flower bud numbers rose significantly as N rate increased (Table 2). In 2003, bud counts were higher on trees receiving 66.0 $g\ N \cdot m^{-2}$ (600 $lb \cdot A^{-1}$) compared with all lower N rates except for 33.0 $g\ N \cdot m^{-2}$ (300 $lb \cdot A^{-1}$). While a similar response to increasing N rates was seen in 2005, fewest buds formed on the trees receiving 4.1 $g\ N \cdot m^{-2}$ (37.5 $lb \cdot A^{-1}$). Bud counts rose significantly when N rates increased from 8.3 to 66 $g\ N \cdot m^{-2}$ (75 to 600 $lb \cdot A^{-1}$). As was noted in

Table 1. Flower bud counts for each flowering dogwood cultivar averaged across N rates by year.

	Number of flower buds per tree			
Cultivar	**2003**	**2004**	**2005**	**2006**
Cherokee Chief	38b[z]	118b	139b	193a
Cloud 9	105a	282a	335a	238a

[z]Means in each column that are followed by the same letter are not significantly different according to Fisher's least significant difference test (P = 0.05).

Table 2. **Flower bud counts on flowering dogwood as influenced by nitrogen fertilization rate.**

Nitrogen rate g N·m⁻²	Number of flower buds per tree[z]			
	2003	2004	2005	2006
4.1	30[y]	188	35	149
8.3	54	193	178	123
16.5	36	188	225	177
33.0	93	209	342	294
66.0	135	245	435	352
LSD ($P \leq 0.05$)	74	NS	133	109
ANOVA Source				
Nitrogen rate	**0.0314**[x]	0.8262	**<0.0001**	**0.0008**
Cultivar	**0.0099**	**<0.0001**	**0.0002**	**0.0124**
Nitrogen rate × Cultivar	0.7052	0.4680	0.0621	0.9005

[z]Represents the average number of flower buds on the fungicide-treated 'Cherokee Chief' and 'Cloud 9' flowering dogwoods.

[y]Mean separation was according to Fisher's least significant difference (LSD) test ($P \leq 0.05$).

[x]P values in **bold** are significant at least at $P \leq 0.05$.

2003, trees receiving 66 g $N{\cdot}m^{-2}$ (600 $lb{\cdot}A^{-1}$) had higher flower bud counts compared with lower N rates except for 33 g $N{\cdot}m^{-2}$ (300 $lb{\cdot}A^{-1}$). For 2006, flower bud counts were significantly higher for trees receiving 33.0 and 66.0 g $N{\cdot}m^{-2}$ (300 and 600 $lb{\cdot}A^{-1}$) than the three lower nitrogen fertilization rates. In contrast to the other trees years of this study, flower bud counts were similar for all N rates in 2004.

For 'Cloud 9', significant N rate optima of 78.0 g $N{\cdot}m^{-2}$ (709 $lb{\cdot}A^{-1}$) and 84.2 g $N{\cdot}m^{-2}$ (765 $lb{\cdot}A^{-1}$) were calculated in 2005 and 2006, respectively. In 2005 and 2006, 'Cherokee Chief' had optima of 50.8 and 53.4 g $N{\cdot}m^{-2}$ (462 and 487 $lb{\cdot}A^{-1}$), respectively for flower bud formation (Table 3). Since the increase in flower bud counts in 2003 on 'Cherokee Chief' was linear, no N rate optimum was calculated. No linear and quadratic relationship between flower bud counts and N rate were noted for 'Cloud 9' in 2003 and 2004 as well as 'Cherokee Chief' in 2004.

Applying excessive nitrogen to flowering dogwood was thought to favor shoot growth over flower bud set (20), however in our study flower bud counts rose in three of four years with increasing N rates. With the exception of 2004 when bud counts were similar across all N rates, flower bud counts were significantly higher on trees receiving 66.0 g $N{\cdot}m^{-2}$ (60 $lb{\cdot}A^{-1}$) compared with the 4.1 to 16.5 g $N{\cdot}m^{-2}$ (37.5 to 150 $lb{\cdot}A^{-1}$) rates. At 33.0 and 66.0 g $N{\cdot}m^{-2}$ (300 and 600 $lb{\cdot}A^{-1}$), similar flower bud counts were recorded in 2003, 2005, and 2006. In addition, trees receiving 4.1 to 16.5 g $N{\cdot}m^{-2}$ (37.5 to 150 $lb{\cdot}A^{-1}$) had similar flower bud counts in two of three years. Previously, increasing numbers of flower buds on 'English Roseum' but not 'Catawbiense Boursault' rhododendron were associated with the highest N rates (21). In 2005 and 2006, calculated N rate optima for flower bud formation on 'Cloud 9' and 'Cherokee Chief' greatly exceeded the recommended 4.9 to 14.4 g $N{\cdot}m^{-2}$ (44 to 130 lb $N{\cdot}A^{-1}$) and 27.5 g $N{\cdot}m^{-2}$ (250 $lb{\cdot}A^{-1}$) respectively, for landscape (16) and field production nursery (17) plantings of shrubs and trees. Also, 'Cloud 9' had a higher N rate optimum than 'Cherokee Chief'.

At planting in February 2001, 'Cloud 9' had greater trunk diameter than 'Cherokee Chief' (Fig. 1A). Differences in trunk diameter between the two flowering dogwood cultivars persisted into 2004. At the 2005 and 2006 rating dates, trunk diameter of the two flowering dogwood cultivars was similar.

Although trunk diameter of the two cultivars differed at four of six rating periods, ranking of N rate treatments on the 'Cherokee Chief' and 'Cloud 9' flowering dogwoods, as indicated by non-significant N rate × cultivar interactions in 2002, 2003, 2004, 2005, and 2006, was similar (Table 4). Therefore, trunk diameter data for the two flowering dogwood cultivars at each of the above annual rating periods were averaged. Between the January 2001 planting and January 2004 rating date, N rate had no influence on trunk diameter (Fig. 2A). In 2005, trunk diameter was significantly

Table 3. **Calculated N rate optima, coefficient of determination, and probability that quadratic model reflects data.**

	Cloud 9			Cherokee Chief		
	Optimum*	R^2	P value	Optimum*	R^2	P value
Flower buds						
2003	Linear	0.151	0.130	**Linear****	0.535	<0.0001
2004	41.6	0.0609	0.456	31.4	0.158	0.117
2005	**78.0**	0.407	0.0019	**50.8**	0.655	<0.0001
2006	**84.2**	0.224	0.0473	**53.4**	0.203	0.050
Height						
2003	31.6	0.183	0.080	59.4	0.016	0.866
2004	77.3	0.076	0.372	**34.9**	0.276	0.0177
2005	45.7	0.144	0.142	29.3	0.0934	0.2937
2006	Linear	0.128	0.191	25.8	0.0794	0.355
Trunk diameter						
2003	114.3	0.0978	0.276	16.4	0.0624	0.419
2004	61.7	0.137	0.157	6.9	0.0267	0.71
2005	26.7	0.163	0.108	52.2	0.0689	0.41
2006	41.9	0.105	0.263	**109.7**	0.293	0.016

*Optima N rate in **bold** are significant at $P \leq 0.05$.

**Linear relationship between increased flower bud counts or growth parameters with increasing N rates such that no optimum N rate could be determined.

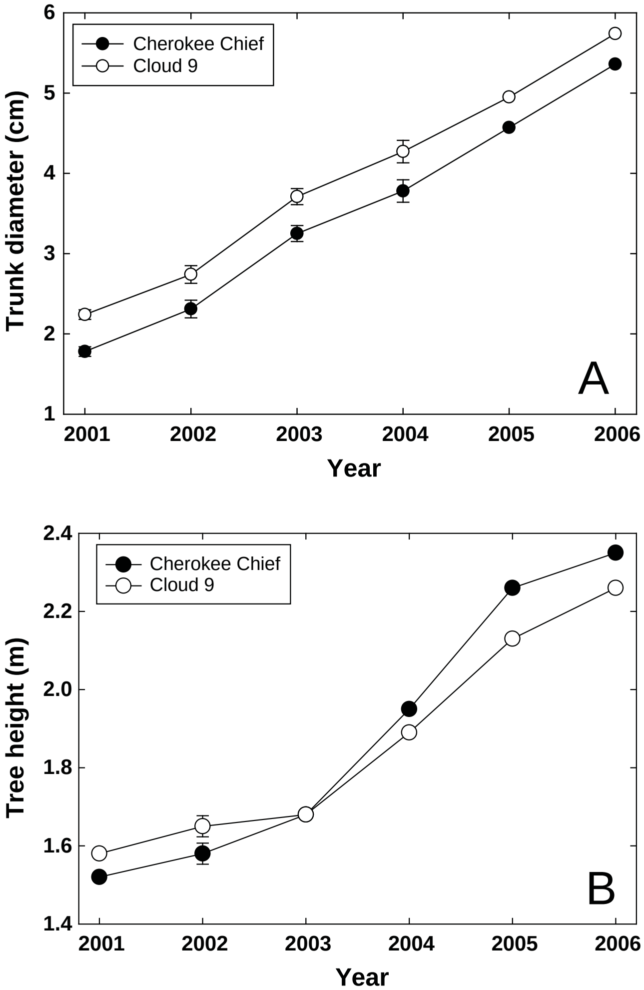

Fig. 1. Increase in trunk diameter (A) and tree height (B) of fungicide-treated 'Cherokee Chief' and 'Cloud 9' flowering dogwood between planting in 2001 and 2006.

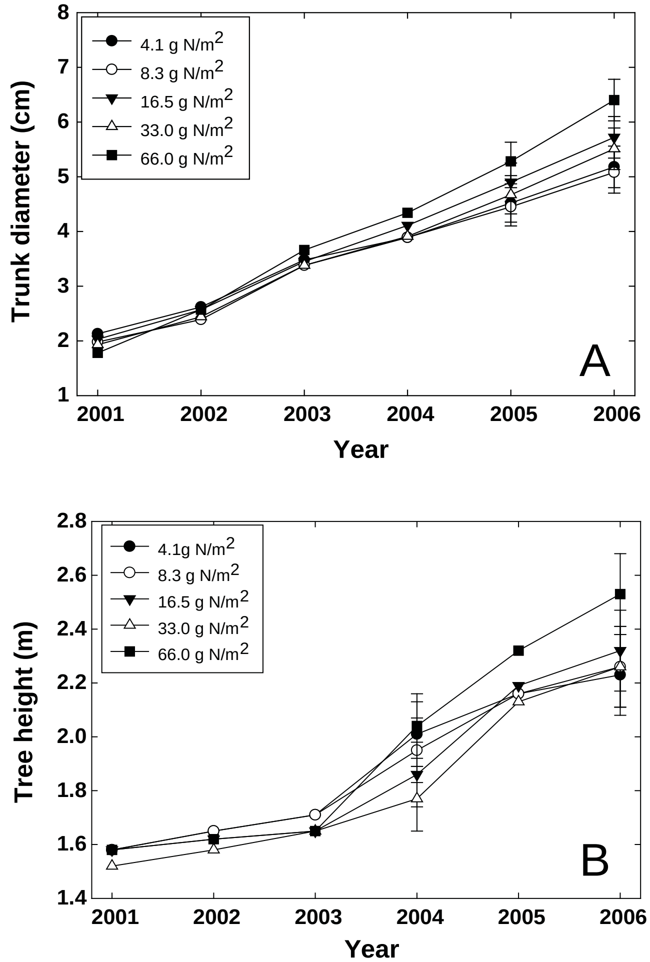

Fig. 2. Impact of nitrogen fertilization rate on the trunk diameter (A) and height (B) of flowering dogwood from 2001 to 2006.

higher for trees receiving 66.0 g N·m^{-2} (600 lb·A^{-1}) than the two lowest N rates, while those recorded at 16.5 and 33.0 g N·m^{-2} (150 and 300 lb·A^{-1}) were intermediate. For 2006, trees receiving 66.0 g N·m^{-2} (600 lb·A^{-1}) had a higher trunk diameter compared with all lower N rates except 16.5 g N·m^{-2} (150 lb·A^{-1}).

The quadratic model that described the relationship between N rate and change in trunk diameter of 'Cherokee Chief' between the February 2001 planting and January 2006 rating date had a calculated optimum of 109.7 g N·m^{-2} (1000 lb N·A^{-1}) (Table 3), which greatly exceeded the N rate where no further enhancement of trunk diameter of several shrubs and trees occurred (7, 11). Coefficients of determination for change in trunk diameter of 'Cherokee Chief' between the 2001 planting and 2003, 2004, and 2005 rating dates were not significant as well as for 'Cloud 9' between the 2001 planting date and the 2003, 2004, 2005 and 2006 rating dates (Table 3) were not significant.

Table 4. Summary of analysis of variance for interaction of N rate × flowering dogwood cultivar.

	P value for nitrogen rate × cultivar interaction	
Year	Trunk diameter	Tree height
2001	0.7965	0.9573
2002	0.1184	0.8213
2003	0.7736	0.7776
2004	0.4986	0.2296
2005	0.6751	0.5532
2006	0.7905	0.5255

With the exception of 2002, average height of 'Cloud 9' and 'Cherokee Chief' flowering dogwoods was similar over the study period (Fig. 1B). In 2002, 'Cloud 9' was taller than 'Cherokee Chief'.

Since N treatment rank on both cultivars with respect to tree height as indicated by non-significant P values for N rate × cultivar interaction in 2002, 2003, 2004, 2005, and 2006 did not significantly differ, data for 'Cloud 9' and 'Cherokee Chief' were pooled for each of the above years (Table 4). Tree height was not significantly impacted by N rate at the 2002, 2003, and 2005 but was at the 2004 and 2006 rating dates. While trees receiving 66.0 g N·m^{-2} (600 lb·A^{-1}) compared 33.0 g N·m^{-2} (300 lb·A^{-1}) were significantly taller in 2004, tree height at the three lowest N rates was similar to those recorded at 33.0 and 66.0 g N·m^{-2} (300 and 600 lb·A^{-1}) (Fig. 2B). For 2006, height of trees receiving 66 g N·m^{-2} (600 lb·A^{-1}) was significantly higher than at 4.1 g N·m^{-2} (37.5 lb·A^{-1}) while those at the remaining N rates was intermediate (Fig. 2B).

Change in the height of 'Cherokee Chief' flowering dogwood was influenced by N rate between the 2001 planting date and 2004 but not 2003, 2005, and 2006 rating dates (Table 3). In 2004, data fit a quadratic model with a calculated optimum of 34.9 g N·m^{-2} (320 lb N·A^{-1}). The relationship between change in the height of 'Cloud 9' flowering dogwood over time and N rate was not described by a linear or quadratic model (Table 3).

In 2005 and 2006, trunk diameter was greater at the highest compared with the two lowest N rates (Fig. 2). In addition, trees receiving 16.5 and 66 g N·m^{-2} (150 and 600 lb·A^{-1}) had similar trunk diameters in 2005 and 2006 compared with 33.0 g N·m^{-2} in 2005. While Curlin (2) also saw an expansion in trunk diameter of flowering dogwood with increasing N rates, that growth response was seen in the first and, to a lesser extent, the second year but not the third and fourth years after application. Tallest flowering dogwoods were seen in 2004 and 2006 at 66 g N·m^{-2} (600 lb·A^{-1}). Otherwise, N rates ranging from 4.1 to 33.0 g N·m^{-2} (37.5 to 300 lb·A^{-1}) had little influence on tree height. Ingram et al. (11) also reported no sizable differences in the dimensions of field-grown Douglas fir, Norway spruce, 'Compactus' euonymus, 'Red Sunset' maple, and 'China Girl' holly at 11, 27.5, and 44 g N·m^{-2} (100, 250, and 400 lb N·A^{-1}) per year. Response of southern magnolia to increasing N rates differs somewhat from that of flowering dogwood. While greater height and trunk diameter for southern magnolia were obtained with 40 g N·m^{-2} (360 lb N·A^{-1}) compared with 0 and 20 g N·m^{-2} (160 lb·A^{-1}) after four years, neither of the above parameters were enhanced at N rates of 40 to 100 g N·m^{-2} (360 to 900 lb·A^{-1}) (7).

An immediate growth response of flowering dogwoods in a full-sun, simulated landscape setting to increasing N rates was not observed. Trunk diameter and tree height was not impacted by N rate until three and four years, respectively, after planting and initial N application. A delay in the response of recently transplanted shrubs and trees to N inputs has been noted in many (4, 6, 14, 19) but not all (2, 9) field studies. Such delays have been reported for newly planted bare-root (19), container (7), and B&B stock (4, 7) as well as established trees (14). When planted in a fine sandy soil in central Florida, 10 to 13 cm (4–5 in) caliper tree spade-transplanted live oak and container grown southern magnolia did not respond to N inputs until 18 and 24 months, respectively, after transplanting (7). A growth response to N on bare-root sugar maple, yellow poplar, and pin oak were not seen until the fourth growing season in Tennessee (19). In an urban setting, Ferrini and Baietto (4) reported that nitrogen fertilization over a three year period often did little to enhance the shoot growth and leaf dry weight of B&B sweetgum, Japanese pagoda tree, and European ash. Trunk diameter of established valley oak and Chinese pistache in a non-turf park setting in California also was not increased over that of the non-treated control by applications of ammonium nitrate (14). In contrast, increases in trunk diameter of established flowering dogwoods in a forest setting were noted the year following the application of nitrogen (2). At plant N applications resulted in significant increases in tree height and shoot length within 6 months following the establishment of container-grown southern magnolia (9). Fertilization practices for container-grown trees may also influence post-transplant growth (1, 13). Struve (18) noted that the failure to discern differences in growth response to N inputs by shade trees may be attributed to treatment interference (shared root zones) as well as high fertility of the native soil or competition with sod. Here, young trees were planted on 5 m (16 ft) centers in a well-drained sandy loam soil with low organic matter content and non-fertilized centipedegrass alleys, so treatment interference due to 'shared root zones' is unlikely. While the deep green ring of turf bordering the mulched area surrounding each tree illustrated that the centipedegrass captured some N, enhanced flower bud set noted within two years after planting at higher N rates highlights tree response to N inputs.

Production method can influence root and shoot growth of recently transplanted shrubs and trees. Establishment and growth of container-grown East Palatka holly and to a lesser extent laurel oak was delayed in field grown or fabric container grown compatriots (5, 6). Gilman and Beeson (6) suggest that production methods that favor the retention of medium and larger roots compared with shorter-lived, fine fibrous roots (8), which dominate the root system of container-grown shrubs and trees. An enhanced growth response to increasing N inputs might have been observed earlier had field-grown (B&B) rather than container-grown trees been used.

Recommended N rates for small flowering trees and shrubs in the landscape (16) and field nursery (17) are 4.9 to 14.4 g N·m^{-2} (44 to 130 lb N·A^{-1}) and approximately 27.5 g N·m^{-2} (250 lb·A^{-1}), respectively. For flowering dogwoods in the landscape, maintaining the 14.4 g N·m^{-2} (130 lb·A^{-1}) rather than lower 4.9 g N·m^{-2} (44 lb·A^{-1}) fertilization rate may occasionally enhance flower bud set but would not accelerate tree growth. Unless the production cycle for field-grown flowering dogwoods exceeds three years or elevated flower bud counts are desired, little increase in the rate of tree growth but higher flower bud counts might seen by increasing rates above N rates recommended for the landscape plantings. Field Nursery Best Management Practices (BMPs) fertilization program (22) for field-grown shrubs and trees specifies a gradual increase in N rates per-tree over a two-year period after planting that would fall within the range of the N rate optimum identified here for bud formation and in tree height on 'Cherokee Chief'. Maintaining N rates at the recommended 27.5 g N·m^{-2} (250 lb·A^{-1}) on field-grown flowering dogwood may help suppress the diseases Cercospora leaf spot and spot anthracnose but may enhance powdery mildew (10).

Literature Cited

1. Cabrera, R.I. and D.R. Devereaux. 1999. Crape myrtle post-transplant growth as affected by nitrogen nutrition during nursery production. J. Amer. Soc. Hort. Sci. 124:94–98.

2. Curlin, J.W. 1962. Dogwood responds to nitrogen fertilization. J. For. 60:718–719.

3. Donohue, S.J. 1992. Reference soil test methods for the southern region of the United States. Univ. of Georgia. Sou. Coop. Ser. Bull. 374.

4. Ferrini, F. and M. Baietto. 2006. Response to fertilization of different tree species in the urban environment. Arboriculture & Urban Forestry 32:93–99.

5. Gilman, E.F. and R.C. Beeson, Jr. 1996. Production method affects tree establishment in the landscape. J. Environ. Hort. 14:81–87.

6. Gilman, E.F. and R.C. Beeson, Jr. 1996. Nursery production method affects root growth. J. Environ. Hort. 14:88–91.

7. Gilman, E.F., T.H. Yeager, and D. Kent. 2000. Fertilizer rate and type impacts magnolia and oak growth in a sandy landscape soil. J. Arboriculture 26:177–182.

8. Hedrick, R.L. and K.S. Pregitzer. 1992. The demography of fine roots in a northern hardwood forest. Ecology 73:1094–1104.

9. Hensley, D.L., R.E. McNeil, and R. Sundheim. 1988. Management influences on growth of transplanted *Magnolia grandiflora*. J. Arboriculture 14:204–207.

10. Hagan, A.K., J.R. Akridge, and K. Bowen. 2008. Nitrogen and flowering dogwood. I. Impact of nitrogen fertilization rate on the occurrence of spot anthracnose, powdery mildew, and Cercospora leaf spot and their effect on tree growth. J. Environ. Hort. 26:197–203.

11. Ingram, D.L., B. Roach, and M. Klahr. 1998. Effects of controlled-release fertilizers on growth and nutrient content of field-grown nursery crops. Proc. Southern Nur. Assoc. Res. Conf. 43:124–127.

12. Klein, I., I. Levin, B. Bar-Yosef, R. Assaf, and A. Berkovitz. 1989. Drip nitrogen fertigation of 'Starkling Delicious' apple trees. Plant and Soil 119:305–314.

13. Lloyd, J.E., D.A. Herms, M.A. Rose, and J. Van Wagoner. 2006. Fertilization rate and irrigation scheduling in the nursery influence growth, insect performance, and stress tolerance of 'Sutyzam' crabapple in the landscape. HortScience 41:442–445.

14. Perry, E. and G.W. Hickman. 1998. Correlating foliar nitrogen levels with growth of two landscape tree species. J. Arboriculture 24:149–153.

15. SAS Institute. 2006. SAS/SAST User's Guide, Vers. 9.1. SAS Institute Inc. Cary, NC.

16. Smiley, E.T., S.J. Lily, and P. Kelsey. 2002. Best Management Practices: Trees and Shrub Fertilization. International Society of Arboriculture, Champaign, IL.

17. Smith, E.M. and C.H. Gilliam. 1979. Fertilizing landscape and field grown nursery crops. OSU Coop. Ext. Ser. Bull. 650.

18. Struve, D.K. 2002. A review of shade tree nitrogen fertilization research in the United States. J. Arboriculture 28:252–263.

19. Van der Werken, H. 1981. Fertilization and other factors enhancing the growth rate of young shade trees. J. Arboriculture 7:33–37.

20. Witte, W.T, M.T. Windham, A.S. Windham, F.A. Hale, D.C. Fare, and W.K. Clatterbuck. 2000. Dogwoods for American Gardens. University of Tennessee Ag. Ext. Serv. PB1670.

21. Wright, R.D. 1992. Influence of nitrogen nutrition on flower bud initiation of rhododendron. J. Amer. Rhodo. Soc. 46:99–100.

22. Yeager, T.H., T.E. Bilderback, D.C.Fare, C.H. Gilliam, J.D. Lea-Cox, A.X. Niemiera, J.M. Ruter, K. Tilt., S.L. Warren, T. Whitwell, and R.D. Wright. 2007. Best Management Practices: Guide for Producing Nursery Crops. The Southern Nursery Association, Atlanta, GA.