Response of Landscape-grown Warm- and Cool-season Annuals to Nitrogen Fertilization at Five Rates

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SUMMARY. Current nitrogen (N) fertilizer recommendations for landscape-grown ornamentals are based on limited research. The objective of this research was to evaluate plant response of selected warm- and cool-season annuals to N fertilizer applied at five rates in the landscape. Three warm-season annual species [‘Profusion Cherry’ zinnia (*Zinnia elegans* ×*angustifolia*), ‘Cora White’ vinca (*Catharanthus roseus*), and ‘Golden Globe’ melampodium (*Melampodium divaricatum*)] and three cool-season annual species [‘Telstar Crimson’ dianthus (*Dianthus chinensis*), ‘Delta Pure Violet’ pansy (*Viola wittrockiana*), and ‘Montego Yellow’ snapdragon (*Antirrhinum majus*)] were transplanted into raised beds containing subsoil fill in U.S. Department of Agriculture (USDA) hardiness zone 9a. Slow-release N fertilizer was applied over an 18-week period at an annual N rate of 0, 2, 4, 6, and 12 lb/1000 ft^2. Trials were replicated a second year. Plant size index (SI), tissue chlorophyll (SPAD), and plant quality were determined every 6 weeks. Shoot biomass and tissue total Kjeldahl N (TKN) were determined at 18 weeks. Regression analysis indicated that all species required N inputs at annual rates exceeding 8 lb/1000 ft^2 to achieve maximum size, shoot biomass, or SPAD. However, acceptable quality plants were produced at much lower N rates. We suggest application of N fertilizer at a rate of 4 to 6 lb/1000 ft^2 per year to landscape-grown annuals to maintain acceptable plant quality and growth. We expect fertilization at lower rates (based on aesthetics) can reduce the amount of fertilizer applied and the potential for nutrient losses in runoff or leachate. Future research should address N fertilization needs in higher fertility soils as well as the response of other plant species.

Rapid population growth continues to generate non-point source (e.g., runoff, leaching, and volatilization) pollution, including plant nutrients (Tang et al., 2005). This non-point source nutrient pollution is in part attributed to homeowners who may over apply fertilizers in an attempt to attain aesthetically pleasing landscapes (Israel and Knox, 2001). Targeted fertilization of urban landscape plants based on plant nitrogen requirements could reduce the likelihood of over fertilization and reduce the potential for nutrient losses from urban landscapes.

Most of the research on fertilization of landscape annuals has focused on nutrient requirements of containerized plants during production in greenhouses and nurseries. For example, van Iersel et al. (1998a, 1998b, 1999) reported that growth of impatiens (*Impatiens walleriana*), salvia (*Salvia splendens*), vinca (*Catharanthus roseus*), and petunia (*Petunia* ×*hybrida*) in the nursery generally increased with increasing N fertilizer rate (8–32 mM or 50–150 mg·L^{-1}), but that optimal N rates varied with species and plant growth stage (pretransplant plugs vs. posttransplant seedlings). However, the results of N fertilizer requirement studies conducted with containerized annual bedding plant species do not translate well into a landscape setting, where plant roots are no longer confined to a container and environmental conditions are more variable. Few studies have evaluated plant response of annual bedding species to N fertilizer when grown in the landscape. Wright et al. (2009) determined the growth response and quality of annual bedding plants [‘Cocktail Vodka’ begonia (*Begonia* ×*semperflorens-cultorum*), ‘Red Hot Sally’ salvia, ‘Bonanza Yellow’ marigold (*Tagetes erecta*), and ‘Cooler Pink’ vinca] grown in the landscape that received N at 0, 1, or 2 lb/1000 ft^2 per year. The authors reported a significant increase in dry weight and plant growth (plant size) for all species as fertilizer rates increased, but N rate did not affect the aesthetic quality of plants.

Despite the limited amount of research on annual bedding plant response to N fertilization in the landscape, general N rate recommendations for field-grown ornamentals exist in the literature. For example,

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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
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
16.3871	inch^3	cm^3	0.0610
488.2430	lb/100 ft^2	kg·ha^{-1}	0.0020
48.8243	lb/1000 ft^2	kg·ha^{-1}	0.0205
1.1209	lb/acre	kg·ha^{-1}	0.8922
33.9057	oz/yard^2	g·m^{-2}	0.0295
1	ppm	mg·kg^{-1}	1
1	ppm	mg·L^{-1}	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Rose (1999) reported that various states (based on published extension bulletins) recommended N rates for field-grown woody landscape ornamentals ranging from 44 to 261 lb/acre; however, there were few guidelines for selecting a rate within the range for a particular species. Tjia and Black (2003) recommended a biweekly application of fertilizer containing 10% N at a rate of 1 lb/100 ft^2 for begonia planted in a landscape in Florida. Currently, the Florida Friendly^{TM} Landscaping (FFL) program, under the auspices of the University of Florida—Institute of Food and Agricultural Sciences (UF-IFAS), provides fertilizer recommendations for ornamentals growing in the landscape. Annual FFL N fertilizer recommendations are divided into low maintenance (0–2 lb/1000 ft^2), medium maintenance (2–4 lb/1000 ft^2), and high maintenance (4–6 lb/1000 ft^2) categories (Florida Department of Environmental Protection, 2010). However, the basis for the FFL N fertilizer recommendations for landscape-grown ornamentals is unclear.

Because of the limited amount of research related to fertilizer N response of landscape-grown annual bedding species, there is a need to validate existing N rate recommendations for these types of plants. The objective of this research was to evaluate plant response of selected warm- and cool-season annuals to N fertilizer applied at five rates in the landscape. The overall goal was to validate or, if necessary, update current N fertilizer recommendations for annual plants grown in the landscape. Nitrogen fertilizer rate information will be used to provide recommendations for N fertilization that will provide acceptable quality plants while minimizing the potential for excessive fertilizer inputs that could be subject to leaching and runoff losses.

Materials and methods

Plant material. Three warm-season annual species ('Profusion Cherry' zinnia, 'Cora White' vinca, and 'Golden Globe' melampodium) and three cool-season annual species ('Telstar Crimson' dianthus, 'Delta Pure Violet' pansy, and 'Montego Yellow' snapdragon) were selected for evaluation across a range of N fertilization regimes based on anecdotal evidence of high, moderate, and low fertilization needs, respectively. 'Golden Globe' melampodium, 'Montego Yellow' snapdragon, 'Telstar Crimson' dianthus, and 'Delta Pure Violet' pansy were received as plugs from Knox Nursery (Winter Garden, FL). 'Cora White' vinca and 'Profusion Cherry' zinnia were received as plugs from Speedling, Inc. (Sun City, FL).

Experimental design. To control and document N application during rearing, plugs for both warm- and cool-season annual species were grown in 4-inch azalea pots (Reb Plastic, Orlando, FL) for ≈7 weeks before transplanting into field plots. The experiment was replicated for both warm-season (June to October) and cool-season (November to February) annuals over two growing seasons (2008–09). Warm-season annuals were transplanted into the field on 11 June 2008 (year 1) and 30 June 2009 (year 2), and cool-season annuals were transplanted on 10 Nov. 2008 (year 1) and 16 Nov. 2009 (year 2). Fifteen raised beds (10 × 40 × 0.5 ft) were established at the UF-IFAS Gulf Coast Research and Education Center in Wimauma, FL (USDA hardiness zone 9a). The raised beds were filled with St. Johns fine sand (Sandy, siliceous, hyperthermic Typic Alaquods) (USDA, 2004) subsoil collected from a local borrow pit. This soil was representative of material commonly used as "topsoil fill" in new residential landscape construction areas in west-central Florida. Before construction of the landscape beds, an initial composite soil sample was air-dried, passed through a 2-mm screen, and analyzed for soil pH (1:2 soil to deionized water ratio), Mehlich 1 soil nutrients [1:4 ratio of soil to 0.0125 M sulfuric acid + 0.05 M hydrochloric acid (Mylavarapu, 2009)], and soil inorganic N (Mulvaney, 1996) using standard methods. Mehlich 1 nutrients were analyzed using inductively coupled plasma-atomic emission spectroscopy (Perkin Elmer, Waltham, MA). Soil nitrate + nitrite (NO_3–N + NO_2–N) and ammonium (NH_4–N) were analyzed colorimetrically on a discrete analyzer (AQ2; Seal Analytical, Burgess Hill, UK). The initial soil pH was 4.77 and Mehlich 1 phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn), and iron (Fe) were 250, 5.30, 434, 28.7, 0.52, and 4.08 mg·kg^{-1}, respectively. Soil test (Mehlich 1) copper (Cu) and manganese (Mn) concentrations were below the detection limit (<4 mg·kg^{-1}). Initial soil NO_3–N + NO_2–N and NH_4–N were 1.22 and 2.69 mg·kg^{-1}, respectively. Soil pH was adjusted to pH 6.5 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, 2009).

Twelve plants of each species were transplanted from 4-inch pots into clusters within each raised landscape bed. Each plant cluster contained three plants of the same species forming a triangle with individual plants spaced 1 ft apart, for a total of four clusters per species per bed. A polymer-coated ammonium sulfate fertilizer (20N–0P–0K–23S; Honeywell nylon, Seffner, FL) was applied at the following annual N rates: 0, 2, 4, 6, and 12 lb/1000 ft^2 per year. Nitrogen fertilizer was applied every 6 weeks over the 18-week study period for a total of 0.00, 0.69, 1.38, 2.10, and 4.20 lb/1000 ft^2 N applied. Timing of fertilizer application was based on results of 1- and 7-d dissolution tests that were conducted on 10% weight/volume at 74 to 76 °F (Thornton Laboratories Testing and Inspection Services, Tampa, FL), which estimated the release rate of the polymer-coated ammonium sulfate was 3.8 to 4.5 weeks. In 2009, production of the polymer-coated ammonium sulfate was discontinued. Therefore, cool-season annuals (planted 16 Nov. 2009) were fertilized every 12 weeks (based on the release curve rate of the fertilizer) with a polymer-coated urea fertilizer (42N–0P–0K, Polyon; Harrell's, Lakeland, FL) containing 33.6% slow-release N at the same N rates for a total of 0.00, 0.92, 1.85, 2.77, and 5.54 lb/1000 ft^2 N applied over the 18-week period. A single composite soil sample was collected from each bed before the 10 Nov. 2008, 20 Apr. 2008, and 16 Nov. 2009 plantings by collecting several soil cores from the top 0 to 4 inches to determine residual concentrations of inorganic N. Soil samples were air-dried at room temperature, sieved to pass a 2-mm screen, extracted with 2 M potassium chloride [1:25 soil to solution ratio (Mulvaney, 1996)], and analyzed colorimetrically for NO_3–N + NO_2–N [U.S. Environmental Protection Agency

(USEPA), 1993a] and NH_4–N (USEPA, 1993b). Total soil inorganic N was determined by summing the soil concentrations of NO_3–N + NO_2–N and NH_4–N. Total inorganic N concentrations were converted to an N rate (pounds per 1000 ft²) assuming soil weight of 30,609 lb/1000 ft² in 4 inches of soil (based on the concept of an acre furrow slice); soil N concentrations were then added to the total fertilizer N rate to determine the effective N rate (Table 1). Statistical analysis indicated no significant difference between soil inorganic N concentrations among replicate beds.

Beds were not mulched to minimize outside N contributions. All other nutrients (excluding N) were applied to all plots at the same rate based on soil test and plant requirements according to UF-IFAS recommendations (Kidder et al., 2009). No P fertilizer was applied because soil test P concentrations were considered to be excessive. Potassium sulfate fertilizer (0N–0P–41.5K; Great Salt Lake Minerals Corp., Overland Park, KS) was applied every 4 months at an annual rate of 4.6 lb/1000 ft² (1.59 lb/1000 ft² total). A micronutrient fertilizer containing S, boron (B), Cu, Fe, Mn, molybdenum (Mo), and Zn (MicroMax®; Scotts, Marysville, OH) was applied to all plots on 23 July 2009 at 45 $g \cdot m^{-2}$ to prevent micronutrient deficiencies based on the soil test results.

Irrigation was applied through nine drip lines (Jain Irrigation, Winter Haven, FL) that were spaced 1 ft apart with 8-inch spacing between emitters and a flow rate of 1 $L \cdot min^{-1}$ per bed. Plants were irrigated three times per week at 0830 HR for 25 min to apply a total of 1.80 cm of water. Cumulative rainfall and irrigation was 30.5 inches from June 2008 to Oct. 2008, 30.4 inches from Nov. 2008 to Mar. 2009, 31.8 inches from Apr. 2009 to Aug. 2009, and 31.75 inches from Nov. 2009 to Mar. 2010 (University of Florida, 2010). Weeds were removed manually or spot treated as needed with glyphosate (Round-Up®; Monsanto, Creve Coeur, MO).

Table 1. Fertilizer and soil inorganic nitrogen (N) available to landscape-grown warm- and cool-season annuals species planted in St. Augustine fine sand subsoil fill in U.S. Department of Agriculture hardiness zone 9a.

Date of planting and annual N fertilizer rate (lb/1000 ft²)[z]	Total fertilizer N applied (lb/1000 ft²)[y]	Mean (SD) soil inorganic N ($mg \cdot kg^{-1}$)[x]	Mean effective N rate (lb/1000 ft²)[w]
30 June 2008			
0	0.00	0.12	0.12
2	0.69	0.12	0.81
4	1.38	0.12	1.50
6	2.10	0.12	2.22
12	4.20	0.12	4.32
10 Nov. 2008			
0	0.00	0.11 (0.02)	0.11
2	0.69	0.11 (0.02)	0.80
4	1.38	0.17 (0.08)	1.55
6	2.10	0.17 (0.05)	2.27
12	4.20	0.77 (0.31)	4.97
20 Apr. 2009			
0	0.00	0.14 (0.02)	0.14
2	0.69	0.20 (0.06)	0.89
4	1.38	0.38 (0.05)	1.76
6	2.10	0.83 (0.37)	2.93
12	4.20	1.73 (0.31)	5.93
16 Nov. 2009			
0	0.00	0.13 (0.02)	0.13
2	0.92	0.25 (0.06)	1.17
4	1.85	0.20 (0.03)	2.05
6	2.77	0.30 (0.05)	3.07
12	5.54	0.41 (0.04)	5.95

[z]1 lb/1000 ft² = 48.8243 $kg \cdot ha^{-1}$.
[y]Total N fertilizer rate indicates the amount of controlled-release N fertilizer applied to plants over the 18-week study period.
[x]SD are not reported for soil N or effective N rates for the 30 June 2008 planting date because one bulk sample of soil fill was analyzed (in duplicate) for soil inorganic N before construction of the planting beds; 1 $mg \cdot kg^{-1}$ = 1 ppm.
[w]Mean effective N rate = fertilizer N + mean soil inorganic N.

PLANT SI AND SHOOT BIOMASS. Plant size measurements were taken at planting and then every 6 weeks until 18 weeks after planting (WAP). SI was used as a quantitative indicator of plant growth. SI was calculated as follows: SI (cubic meters) = H × W1 × 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). With the exception of warm-season species in year 1, plant shoots were cut at the soil surface at 18 WAP. Plant tissue (leaves and stems) was dried to a constant weight at 40.5 °C and weighed to determine dry shoot biomass (grams).

PLANT CHLOROPHYLL CONTENT. Chlorophyll content (SPAD) was estimated every 6 weeks using a portable chlorophyll meter (SPAD-502; Minolta Corp., Ramsey, NJ). Six readings were taken per plant cluster (two readings per plant) and averaged. Fisher et al. (2003) reported that SPAD is an indirect, non-destructive measurement of chlorophyll content; the authors reported a linear relationship between SPAD and chlorophyll content (0.2128 + 0.0295 × SPAD; r^2 = 0.86).

FOLIAR NUTRIENT ANALYSIS. Composite samples of foliar tissue from each plant cluster were collected from the harvested plants (18 WAP) following determination of shoot biomass. All healthy, mature leaves were sampled because collection of the youngest, fully expanded leaves did not produce samples of adequate weight for nutrient analysis. Dry tissue samples were ground to pass a number 20 screen using a Wiley mill (Arthur H. Thomas Scientific, Philadelphia). Tissue digestions were completed using the standard methods of the UF-IFAS Extension Soil Testing Laboratory (Mylavarapu, 2009). Digested samples were analyzed for TKN using USEPA Method 351.2 (USEPA, 1993c) on an Alpkem Technicon autoanalyzer (Pulse Instrumentation, Saskatoon, SK, Canada).

FLOWER COVER. Overhead photographs of each plant cluster were taken every 6 weeks in year 2 only. Color contrasts in the photographs were enhanced by altering the brightness using Adobe Photoshop Elements 6.0 (Adobe Systems, San Jose, CA). The non-plant background was removed using the cropping function. The photographs were then analyzed using a computer image analysis system (WinFOLIA 2007b for leaf analysis; Regent Instruments, Quebec, QC, Canada). Color groups were created for flowers, foliage, and the background. Pixels in each image were manually assigned to one of three color groups to represent leaves (green), flowers (color based on species), or background (brown to represent soil). WinFOLIA software then calculated the percent area covered by each color group based on pixel color. Flower cover was calculated as: flower cover (percent) = flower area/(flower area + canopy area) × 100, where flower area is the area (square centimeters) of the plant covered by flowers and canopy area is the area (square centimeters) of the plant covered by canopy.

Plant quality ratings. Quality ratings considered canopy density, flowers, chlorosis, and dieback based for each individual plant on the following scale: 0 indicated a dead plant; 1 indicated a poor quality plant (low canopy density, few to no flowers, and chlorosis); 2 indicated a below average quality plant (significant dieback or pest damage); 3 indicated an average quality plant (moderate dieback or pest damage); 4 indicated an above average quality plant (minimal dieback or pest damage); and a quality rating of 5 indicated an outstanding plant (dense leaf canopy, high quality flowers, and no nutrient deficiencies or dieback) (Shober et al., 2009).

Statistical analysis. The experiment was designed as a completely randomized design with five N fertilizer rates randomly applied over 15 landscape beds containing four clusters of three species per landscape bed. Plant SI, SPAD, harvest biomass, and tissue TKN measurements were averaged for all plant clusters in each plot. Mean values were then used in regression analysis using PROC REG (SAS version 9.2; SAS Institute, Cary, NC) to determine the effect of effective N rate on each plant response indicator. Linear and polynomial regression models were fitted by species and WAP with N rate and N rate × N rate as the predictor variables. Regression analysis was considered to be significant if the whole model and the predictor variables had a $P \leq 0.05$. The second-order equation was chosen over the linear equation only when the *t* test indicted significance of the N rate × N rate term ($P \leq 0.05$). The maximum N rate was determined for each regression fit by solving the second-order derivative of the equation to determine the maximum point on the regression curve. This point corresponds to the "optimum" N rate for the specific plant response (i.e., application of N above that rate is not expected to result in a plant response). For linear (first order) fits, the "optimum" N rate exceeded our maximum annual effective N rate and is reported as such. Flower cover was analyzed by species and WAP (year 2 only) using PROC MIXED (SAS version 9.2) with fertilizer N rate as a fixed effect and plant cluster × treatment as a random effect. Plant quality data were analyzed by species, WAP, and year using PROC GLIMMIX (SAS version 9.2) with N rate as a fixed effect and plant cluster × treatment as a random effect using a normal distribution and an identity link function. Pairwise comparisons for flower cover and quality were completed using the Tukey's honestly significant difference test with a significance level of $\alpha = 0.05$. All data were checked for normality by examining histogram and normality plots of the conditional residuals.

Results and discussion

Plant SI and harvest biomass. For most species at most dates, there was a positive plant SI response to N fertilizer applications. Most relationships were best fit with a second-order polynomial regression (Fig. 1); a similar approach was used to determine plant yield response of agronomic crops to N fertilizers application (Fletcher and Chakwizira, 2012; Sheehy et al., 1998). Therefore, we were able to determine the rate at which application of additional N would not be expected to increase the size of the plants (Fig. 1). For example, at 18 WAP, the SI of dianthus increased with increasing effective N rate until the amount of fertilizer and soil N applied exceeded 3.65 and 5.63 lb/1000 ft^2 over the 18-week growing period in year 1 and 2, respectively (Fig. 1). The SI of the other cool- and warm-season annuals we evaluated exhibited similar trends at most data collection points (Table 2). Based on regression analysis, we suggest that zinnia required N at a rate that exceeded 8 lb/1000 ft^2 per year to optimize plant size throughout the growing season. Similarly, melampodium required more than 9 lb/1000 ft^2 per year N, while dianthus, pansy, and snapdragon required more than 10 lb/1000 ft^2 per year to maximize SI response. Vinca required N at a rate that exceeded

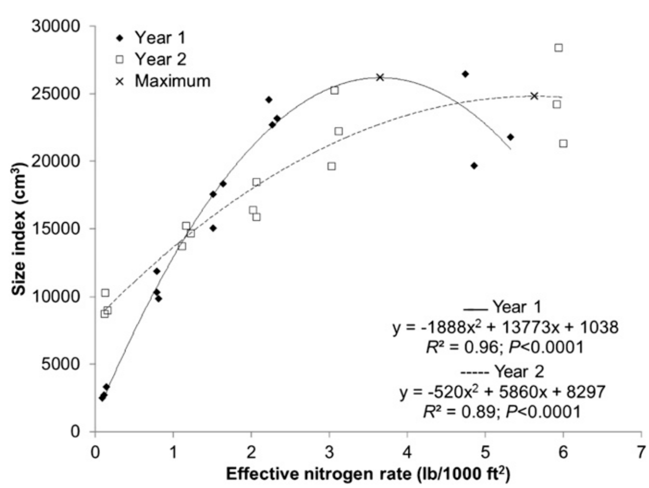

Fig. 1. Dianthus size index response to effective nitrogen (N) rate (fertilizer N + soil N) at 18 weeks after planting (WAP) when planted in St. Augustine fine sand subsoil fill in U.S. Department of Agriculture hardiness zone 9a. Regression analysis indicated second-order polynomial response with a maximum size at 18 WAP achieved when effective N rate was 4.02 and 5.63 lb/1000 ft^2 in years 1 and 2, respectively; 1 lb/1000 ft^2 = 48.8243 kg·ha^{-1}, 1 cm^3 = 0.0610 inch^3.

Table 2. Regression derived optimum and annual nitrogen (N) rates for size index (SI) and SPAD for selected landscape-grown cool- and warm-season annual species based on plant response to effective N rate (fertilizer N + soil inorganic N) when planted in St. Augustine fine sand subsoil fill in U.S. Department of Agriculture hardiness zone 9a.

Species and yr	WAP[z]	SI[y] Optimum N rate (lb/1000 ft²)[x]	SI[y] Annual rate (lb/1000 ft²)[w]	SPAD Optimum N rate (lb/1000 ft²)	SPAD Annual rate (lb/1000 ft²)
Dianthus					
1	6	3.69	10.7	3.74	10.8
1	12	4.02	11.6	3.94	11.4
1	18	3.65	10.6	3.78	10.9
2	6	NS[v]	NS	>5.95	>12.9
2	12	>5.95	>12.8	3.91	11.3
2	18	5.63	16.3	4.23	12.2
Pansy					
1	6	>4.97	>14.4	>4.97	>15.0
1	12	3.96	11.4	3.88	11.2
1	18	3.48	10.1	3.58	10.4
2	6	NS	NS	>5.95	>12.9
2	12	4.43	12.8	4.87	14.1
2	18	4.34	12.6	5.15	14.9
Snapdragon					
1	6	>4.97	>14.4	>4.97	>14.4
1	12	>4.97	>14.4	>4.97	>14.4
1	18	3.51	10.1	4.27	12.3
2	6	>5.95	>12.8	4.58	13.2
2	12	7.5	21.7	5.00	14.5
2	18	5.26	15.2	4.53	13.1
Melampodium					
1	6	3.01	8.70	3.17	9.16
1	12	NS	NS	>4.32	>12.5
1	18	NS	NS	—[u]	—
2	6	5.69	16.4	>5.93	>17.1
2	12	4.34	12.6	3.68	10.6
2	18	—	—	—	—
Vinca					
1	6	>4.32	>12.5	4.03	11.6
1	12	>4.32	>12.5	>4.32	>12.5
1	18	4.1	11.8	3.57	10.3
2	6	>5.93	>17.1	7.19	20.8
2	12	>5.93	>17.1	>5.98	>17.1
2	18	>5.93	>17.1	1.58	4.6
Zinnia					
1	6	NS	NS	—	—
1	12	2.67	7.71	—	—
1	18	2.64	7.64	—	—
2	6	>5.93	>17.1	>5.93	>17.1
2	12	>5.93	>17.1	NS	NS
2	18	>5.93	>17.1	NS	NS

[z]WAP = weeks after planting.
[y]SI was calculated as follows: SI (cubic meters) = H × W1 × 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).
[x]Optimum N rate for the 18-week study period was determined for each regression fit by solving the second-order derivative of the equation to determine the maximum point on the regression curve. For linear (first order) fits, the "optimum" N rate exceeded our maximum annual effective N rate and is reported as such; 1 lb/1000 ft² = 48.8243 $kg \cdot ha^{-1}$.
[w]Annual N rate was determined by multiplying the optimum N rate established for the 18-week period by 2.89 to calculate the optimum N input needed for 1 year.
[v]Regression analysis was not significant.
[u]Data not available.

12 lb/1000 ft² per year to achieve maximum size. Trends were similar for production of plant harvest biomass, with biomass response of most species following a second-order polynomial relationship with effective annual N rate (data not shown). In general, plants produced the most shoot biomass when N was available at rates that exceeded 10 lb/1000 ft² per year (Table 3). In both years, most melampodium plants had reached the end of their life cycle by 18 WAP, regardless of the N fertilizer treatment. Therefore, no melampodium shoot biomass data were available for analysis (Table 3).

Plant chlorophyll content. As was reported for SI and harvest biomass, the SPAD response of cool-season species to effective N rate

Table 3. Regression derived optimum and annual nitrogen (N) rates for shoot biomass and tissue total Kjeldahl N concentration for selected landscape-grown cool- and warm-season annual species based on plant response to effective N rate (fertilizer N + soil inorganic N) at 18 weeks after planting in St. Augustine fine sand subsoil fill in U.S. Department of Agriculture hardiness zone 9a.

Species and yr	Shoot biomass		Total Kjeldahl N	
	Optimum N rate (lb/1000 ft²)[z]	Annual rate (lb/1000 ft²)[y]	Optimum N rate (lb/1000 ft²)	Annual rate (lb/1000 ft²)
Dianthus				
1	3.54	10.2	4.31	12.5
2	5.49	15.7	5.51	15.9
Pansy				
1	3.38	9.8	4.18	12.1
2	>5.95	>12.8	7.54	21.8
Snapdragon				
1	3.62	10.5	4.22	12.2
2	6.67	19.3	7.74	22.4
Vinca				
1	—[x]	—	—	—
2	10.9	31.6	2.89	8.34
Zinnia				
1	—	—	—	—
2	>5.46	>15.8	0.75	2.18

[z]Optimum N rate was determined for each regression fit by solving the second-order derivative of the equation to determine the maximum point on the regression curve. For linear (first order) fits, the "optimum" N rate exceeded our maximum annual effective N rate and is reported as such; 1 lb/1000 ft² = 48.8243 kg·ha⁻¹.
[y]Annual N rate was determined by multiplying the optimum N rate established for the 18-week period by 2.89 to calculate the optimum N input needed for 1 year.
[x]Data not available.

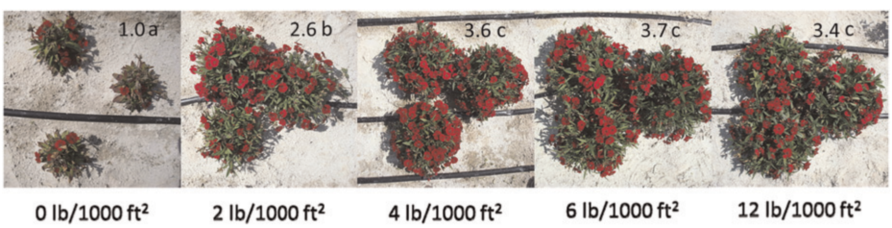

Fig. 2. Aesthetic quality response of dianthus to fertilizer nitrogen (N) rate at 18 weeks after planting when planted in St. Augustine fine sand subsoil fill in U.S. Department of Agriculture hardiness zone 9a. Mean separation species and WAP by Tukey's honestly significant difference test at $P \leq 0.05$; 1 lb/1000 ft² = 48.8243 kg·ha⁻¹.

tended to follow a second-order polynomial relationship (data not shown). Both dianthus and pansy required >10 lb/1000 ft² of available N on an annual basis to achieve maximum tissue SPAD readings, while snapdragon required >12 lb/1000 ft² (Table 2). The SPAD response of warm-season species was less clear. At most sampling dates, vinca and melampodium SPAD readings increased as effective N rates increased (Table 2). However, in year 2, we determined a decrease in tissue SPAD for plants receiving N at the middle rates (≈2, 4, and 6 lb/1000 ft² per year) at 12 WAP for melampodium and 18 WAP for zinnia (data not shown). In both cases, tissue SPAD reached a minimum (3.68 and 1.58 lb/1000 ft² of N for melampodium and vinca, respectively) and then began to increase again with increasing available N. There was no relationship between effective N rate and SPAD for zinnia at most sampling dates (Table 2). The exception was at the 6 WAP collection date in year 2 when a first-order linear relationship was noted. As such, we suggest that zinnia required >17.1 lb/1000 ft² available N to achieve maximum SPAD levels (Table 2).

Foliar nutrient analysis. As reported for SPAD, cool-season annual species again exhibited a second-order relationship of tissue TKN with effective N rate (data not shown). Inputs of N exceeded 12 lb/1000 ft² N before dianthus, pansy, and snapdragon tissue TKN concentrations reached a maximum (Table 3). For warm-season species (when data were available), the response of tissue TKN to increasing effective N rate followed a second-order polynomial curve with the concentration decreasing to a minimum, followed by an increase as effective N rate increased. In year 2, the minimum tissue TKN concentration was reached at 2.89 and 0.75 lb /1000 ft² effective N (over the 18-week growing season) for vinca and zinnia, respectively. Because melampodium had reached the end of their life cycle before 18 WAP, tissue TKN for this species was not available for analysis (Table 3).

Flower cover. Flower cover response to N fertilizer at 6 WAP (year 2 only) was only observed for melampodium, where plants receiving N fertilizer at a rate equivalent to 4, 6, or 12 lb/1000 ft² had the highest proportion of the plant canopy covered with flowers (Table 4). At 12 WAP, flower cover was affected by N fertilizer rate for all annual species we evaluated. In general, flower cover was highest when N fertilizer was applied at the 2, 4, 6, or 12 lb/1000 ft² annual rates for pansy, vinca, and zinnia, the 4, 6, or 12 lb/1000 ft² annual rate for melampodium, the 6 or 12 lb/1000 ft² annual rate for snapdragon, and the 12 lb/1000 ft² annual rate for dianthus (Table 4). By 18 WAP, N fertilizer applications did not affect flower cover for pansy or zinnia (Table 4). However, application of N fertilizer at 4, 6, or 12 lb/1000 ft² resulted in higher flower coverage for dianthus, snapdragon, and vinca at 18 WAP (Table 4). All melampodium plants had died by 18 WAP (year 2); therefore, we could not evaluate the effect of N rate on flower cover at 18 WAP. Overall, fertilizing annual species with 4 or 6 lb/1000 ft² N (on an annual basis) will produce plants with more flower coverage than at the lower N rates (Table 4). We did not see evidence for increasing annual N application rate to 12 lb/1000 ft² based on flower coverage.

Plant quality ratings. Visual quality ratings suggest that acceptable quality plants can be produced in the landscape at lower fertilizer N rates than needed to maximize other

Table 4. Flower cover response of selected landscape-grown cool- and warm-season annual species to effective nitrogen (N) rate (fertilizer N + soil inorganic N) when planted in St. Augustine fine sand subsoil fill in U.S. Department of Agriculture hardiness zone 9a.

Species and fertilizer N rate ($lb/1000 ft^2$)[z]	Flower cover (%)[y]		
	6 WAP[x]	12 WAP	18 WAP
Dianthus			
0	51.2 a[w]	7.0 d	24.0 d
2	49.6 a	16.9 c	39.4 c
4	47.5 a	23.0 b	47.1 bc
6	50.3 a	22.8 b	59.2 a
12	36.6 a	29.6 a	56.6 ab
Pansy			
0	35.6 a	35.4 b	58.6 a
2	36.1 a	42.9 ab	63.9 a
4	34.2 a	44.8 a	62.6 a
6	32.5 a	52.2 a	58.7 a
12	25.2 a	51.0 a	63.2 a
Snapdragon			
0	20.6 a	29.0 d	14.6 c
2	14.8 a	34.1 cd	30.3 b
4	13.0 a	38.7 bc	39.0 ab
6	17.1 a	44.5 ab	40.2 a
12	21.2 a	47.5 a	41.5 a
Melampodium			
0	17.6 c	20.6 c	—[v]
2	19.6 bc	22.9 bc	—
4	20.7 abc	29.0 a	—
6	23.4 a	30.2 a	—
12	22.9 ab	27.6 ab	—
Vinca			
0	36.7 a	26.0 a	11.8 ab
2	37.5 a	25.1 ab	9.2 b
4	38.0 a	25.1 ab	12.4 a
6	40.1 a	20.7 bc	10.7 ab
12	39.1 a	17.7 c	12.2 a
Zinnia			
0	52.9 a	34.2 b	27.9 a
2	55.4 a	40.4 ab	37.8 a
4	56.0 a	40.7 a	38.3 a
6	55.3 a	40.7 a	32.9 a
12	52.9 a	38.7 ab	39.8 a

[z]$1 lb/1000 ft^2 = 48.8243 kg\cdot ha^{-1}$.
[y]Flower cover = flower area/(flower area + canopy area) × 100.
[x]WAP = weeks after planting.
[w]Mean separation for each species and WAP by Tukey's honestly significant difference test at $P \leq 0.05$.
[v]Data not available.

measured plant responses (Fig. 2). Analysis of variance results indicated that, in general, dianthus (Fig. 2), pansy, and vinca achieved acceptable plant quality when they received fertilizer at the 4 to 6 lb/1000 ft² annual application rate, while the quality of snapdragon, melampodium, and zinnia was acceptable when fertilized with N at the ≤2 lb/1000 ft² annual application rate. There were no differences in visual quality of dianthus (Fig. 2) or pansy when plants received 4 or 6 lb/1000 ft² annual N application at any point. Quality of vinca plants was lower when fertilized with 0, 2, or 4 lb/1000 ft² annual application than when fertilized with 6 or 12 lb/1000 ft² annual N rate in most weeks. However, no differences in quality of vinca plants were reported at any time during the study when fertilized at the 6 or 12 lb/1000 ft² annual N rate. Differences in visual quality of snapdragon were only reported at 18 WAP in year 1, when quality of plants receiving 12 lb/1000 ft² annual N application exhibited slightly higher quality than plants receiving N at the 2 lb/1000 ft² annual application rate. Application of N at the annual fertilizer rate of 12 lb/1000 ft² produced higher quality melampodium plants at 6 WAP in year 2 only. But, no differences in quality of melampodium plant receiving 2, 4, or 6 lb/1000 ft² N per year were reported at any time during year 1 or at 12 or 18 WAP in year 2. Similarly, an annual N fertilizer rate of 6 or 12 lb/1000 ft² increased zinnia quality at 6 WAP in year 1; however, no differences in quality of zinnia plants were noted when plants received 2, 4, 6, or 12 lb/1000 ft² N per year at 12 or 18 WAP in year 1 or at any time in year 2.

We did not see evidence of improved plant quality when plants were fertilized at higher rates. In fact, quality of pansy and melampodium plants receiving fertilizer at the 12 lb/1000 ft² annual application rate began to decline over time. By 18 WAP in both years, pansy quality declined when the 12 lb/1000 ft² annual application fertilizer rate was applied compared with plants supplied with 4 or 6 lb/1000 ft² annual application rate. No quality differences were observed among melampodium plants receiving 2, 4, or 6 lb/1000 ft² N per year at 12 WAP (in both years) or 18 WAP (year 1 only); however, plants receiving fertilizer at the 12 lb/1000 ft² N per year rate began to decline by 12 WAP.

Discussion

Plant response to N fertilizer was species dependent; however, regression analysis indicated that most of the landscape-grown annual species we evaluated require high rates of available N to achieve maximum size, biomass, SPAD, or tissue TKN. Landscape applications of fertilizer would be recommended at rates that exceed the current high maintenance (4 to 6 lb/1000 ft² per year) recommendations for landscape fertilization by the FFL program (Florida Department of Environmental Protection, 2010) to maximize growth response. However, most of the landscape annuals we evaluated maintained acceptable plant quality and had a higher proportion of the canopy covered with flowers when fertilizer N rates were 4 or 6 lb/1000 ft² per year. Some species, like zinnia or snapdragon, performed well aesthetically when fertilized with

N at 0 or 2 lb/1000 ft^2 per year. Similarly, Wright et al. (2009) reported a plant size and dry weight response to increasing N fertilizer rate (0, 1, and 2 lb/1000 ft^2 per year) for 'Cocktail Vodka' begonia, 'Red Hot Sally' salvia, 'Bonanza Yellow' marigold, and 'Cooler Pink' vinca grown in the landscape (fertilizer N applied at 0, 1, or 2); however, fertilizer N rate did not affect the aesthetic quality of the plants.

We believe that the average property owner is much more concerned with maintaining annual landscape plants that are aesthetically pleasing than maximizing plant growth response of annuals grown in residential or commercial landscapes. Therefore, we suggest that basing landscape fertilizer recommendations for landscape ornamentals on plant visual quality or flower coverage is appropriate. Based on the results of this preliminary research, we suggest application of N fertilizer at a rate of 4 to 6 lb/1000 ft^2 per year to landscape-grown annuals to maintain acceptable plant quality and growth. Fertilization at lower rates is suggested where species-specific data indicates that the lower N-inputs will still provide acceptable plant quality and growth. Fertilization at rates based on aesthetics allows us to recommend lower N fertilization rates (20% to 100% lower than rates based on plant growth at 18 WAP), which can reduce the use of excess fertilizer that is subject to leaching or runoff losses from residential and commercial landscapes.

This research was the first part of a study designed to validate and broaden N recommendations for Florida landscape plants. We recognize that soil fertility will play a role in plant response to N and should be accounted for when making general recommendations for the application of fertilizer N. Unfortunately, the lack of a reliable N soil test makes it more difficult to make recommendations based on soil fertility status. To build on these preliminary recommendations, we are currently evaluating N fertilizer response of additional plant species in fill and field (higher fertility) soils. This work should identify broader plant N response patterns allowing us to fine tune N fertilization recommendations.

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