Container Grown Plant Production

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Section Editor

Reducing Fertilizer Needs for Nursery Plant Production: From Poo to Profit

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Index Words Substrate, swine lagoon waste, compost, shoot dry weights, substrate solution

Significance to the Industry Quality pine bark is becoming more difficult for growers to source due to timber processing mills moving overseas (2). Alternative products are being researched as possible amendments to extend pine bark supplies (3) and growers welcome a local amendment that could potentially reduce the quantity of chemical fertilizer needed. The farms with the later life stage pigs are shown to have desirable concentrations of NPK nutrients (3). Results from this study suggest that nitrogen additions can be cut in half and no additional P, K, Ca, Mg, or micronutrients are needed with nursery plants are grown in substrates with swine lagoon wastes.

Nature of Work North Carolina is one of the top hog producing states in the U.S., with nearly a million more pigs than people, generating as much untreated waste as New York City metro area (1). This abundance of manure is generally spread as slurry on fallow agricultural fields within a narrow radius from the hog farms as a necessary practice to reduce the solids in the lagoons.

Materials and Methods A study was designed in a randomized complete block design with six replications to evaluate the treatment impacts of four nitrogen (N) rates on plant growth in a substrate composed of pine bark (PB) amended with swine lagoon solids (SLS) (9:1 v/v) and an industry control substrate (9:1 PB:sand v/v) amended with 1.8 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) dolomitic limestone and 0.9 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) micronutrients (Parker Bark Company, Rose Hill, NC). Swine lagoon solids were dredged from a lagoon in Garland, NC (Murphy Brown, LLC, Warsaw, NC) using a tiller attachment to cut the solids off the lagoon bottom and pumped to a holding tank where a polymer (PT1051, PolyTec Inc., Mooresville, NC) was added and thoroughly mixed with the solids. The solids and polymer mix was pumped into a geotextile bag (TITANTube OS425/OS425A, Flint Industries, Metter, GA) situated on a plastic lined, recessed reservoir with a slight slope to one side. The water filtered out of the bag and was pumped from the reservoir back into the lagoon. The waste/polymer mix in the bag was allowed to drain for two years before use. Once removed from the bag, the SLS were spread on plastic and allowed to air dry in a plastic covered hoop house for a week with heat and forced air, and then ground to 2 mm (0.1 in) using a grist mill (Molino Corona, Landers, Mora & Cia, LTDA, Medellin, Colombia).

On May 21, 2015 liners of *Buddleia davidii* ‘Potter’s Purple’, *Forsythia* x *intermedia* ‘Courdijau’, *Gardenia radicans*, and *Rhaphiolepis indica* ‘Conia’ were potted into 3.8 L (1 gal) (Classic 500, Nursery Supplies, Inc., Chambersburg, PA) containers filled with either the 9:1 PB:SLS or the industry control substrate. The plants were grown on a gravel pad at the NCSU Horticulture Field Lab in Raleigh, NC. Slow release N (43-0-0) (Harrell’s LLC, Lakeland, FL) was applied in the rates 0, 1, 2, or 3 g N/3.8 L container to the 9:1 PB:SLS substrate. A complete fertilizer (17-5-10) (Harrell’s LLC, Lakeland, FL) was applied to the control substrate and supplied 3.5 g N/3.8 L container.

Additionally, substrate solution was collected (June 4, 18 and 30, July 20, 2015) using the pour-through nutrient extraction method (5). Substrate solution pH was measured using a combination EC/pH meter (HI 8424, Hannah Instruments, Ann Arbor, MI). Substrate solution samples collected on June 4 and 30, 2015 were submitted to the NCDA&CS (North Carolina Department of Agriculture and Consumer Services, Agronomic Division Raleigh, NC) for ammonium (NH-N), nitrate (NO-N), phosphorus (P), and potassium (K). On August 13, 2015, shoots were harvested and dried at 62C/144F for 4 days and used for growth comparisons.

All variables were subjected to analysis of variance (ANOVA), linear contrasts, and regression analyses where appropriate in SAS version 9.4 (4) and *P* was considered significant at $\leq$ 0.05.

Results and Discussion Shoot dry weights had a significant species by treatment interaction. Treatment significantly impacted shoot dry weights for all species except *Rhaphiolepis*. The control treatment produced significantly larger shoot dry weights for *Buddleia* compared to the SLC treatments (0, 1, 2, and 3 g of N) (Table 1). However, there were no significant linear or quadratic trends for increasing N rates on shoot dry weights of *Buddleia* grown in the SLC treatments. *Forsythia* shoot dry weights were significantly larger for the SLC treatment with 2 g of N added compared to the control treatment, while the remaining SLC treatments were not significantly different from the control treatment. However, the SLC treatments for *Forsythia and Gardenia* shoot dry weights had a quadratic trend, increasing from 0 to 2 g of N and then decreasing after 2 g of N. *Gardenia* shoot dry weights were also all similar to the control treatment, with the exception of the SLC treatment with 0 g of N added, which was significantly smaller than the control.

The pH for all SLC treatments remained within the recommended range of 4.5 to 6.5 for the duration of the study (6). However, the control treatment tended to be slightly lower or higher than the recommended range; for example, the lowest pH of control plants was *Buddleia* with a pH of 4.7 on June 19, 2015, while, the highest pH was *Gardenia* with a pH of 6.6 on June 30, 2015.

There were not a significant species by treatment by sample time interactions for all nutrients [ammonium (NH-N), nitrate (NO-N), phosphorus (P), and potassium (K)] in the substrate solution. However, the two-way treatment by sample time interactions were significant for all nutrients (NH-N: *P*=<0.0001, NO-N: *P*=<0.0001, P: *P*=<0.0001, K:

P=<0.0001). Also, the main effect of treatment was significant for all nutrients for June 4, 2015. However, for June 30, 2015 the main effect of treatment was only significant for NO-N and P. As shown in Table 2, when comparing the control treatment to all SLC treatments, the control treatment resulted in significantly less NH-N, NO-N, P, and K present in the substrate solution. However, by June 30, 2015 all of the SLC treatments were similar to the control for most nutrients with the exception of P, where SLC treatments maintained higher amounts in the substrate solution compared to the control. For NH-N, the SLC treatments had larger amounts present in the substrate solution for SLC treatments with 1 and 2 g of N added (Table 2). For NO-N, the SLC treatments were significantly higher than the control with 2 and 3 g of N added. Although, when the SLC treatments (0, 1, 2, and 3 g of N) were analyzed for linear and quadratic trends there were no significant differences (data not shown).

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Table 1. Shoot dry weight, treatment by species.

Treatment	*Buddleia*	Linear Contrast[z]	*Forsythia*	Linear Contrast[z]	*Gardenia*	Linear Contrast[z]	*Rhaphiolepis*	Linear Contrast[z]
0 g N	11.4	<0.0001	10.0	NS	3.3	0.0063	2.4	NS
1 g N	18.5	0.001	20.1	NS	6.2	NS	2.5	NS
2 g N	11.5	<0.0001	25.8	0.0004	8.1	NS	2.4	NS
3 g N	23.7	0.0065	19.5	NS	7.5	NS	2.5	NS
Control[y]	43.1		15.1		6.2		2.7	
Linear[x]	NS		0.0045		0.0002		NS	
Quadratic[w]	NS		<0.0001		0.0105		NS	

[z]Linear contrast compared all N treatments to control treatment. NS=not significant, *P*-value given otherwise.
[y]Control Treatment supplied 3.5 g N.
[x]Analysis of Linear regression. NS=not significant, *P*-value given otherwise.
[w]Analysis of Quadratic regression. NS=not significant, *P*-value given otherwise.

Table 2. Nutrient concentration.

Sample time 4 June 2015								
	NHN[z]		NON[y]		Phos[x]		K[w]	
Control[v]	0.1	Linear Contrast[u]	0.2	Linear Contrast[u]	1.6	Linear Contrast[u]	15.5	Linear Contrast[u]
0 g N	151.9	<0.0001	257.0	<0.0001	404.9	<0.0001	113.2	<0.0001
1 g N	135.5	<0.0001	261.0	<0.0001	397.2	<0.0001	100.3	<0.0001
2 g N	146.3	<0.0001	251.3	<0.0001	421.7	<0.0001	109.9	<0.0001
3 g N	141.1	<0.0001	271.0	<0.0001	418.7	<0.0001	104.4	<0.0001
Sample time 30 June 2015								
	NHN[z]		NON[y]		Phos[x]		K[w]	
Control[v]	3.0	Linear Contrast[u]	23.3	Linear Contrast[u]	3.1	Linear Contrast[u]	17.3	Linear Contrast[u]
0 g N	5.5	NS	21.5	NS	234.1	<0.0001	16.6	NS
1 g N	9.1	0.0255	35.2	NS	232.5	<0.0001	19.8	NS
2 g N	10.2	0.0097	92.9	<0.0001	216.8	<0.0001	20.9	NS
3 g N	6.8	NS	63.6	0.0016	221.8	<0.0001	16.6	NS

[z]NHN = ammonium.
[y]NON = nitrate.
[x]Phos = phosphorus.
[w]K = potassium
[v]Control Treatment supplied 3.5 g N.
[u]Linear contrast compared all N treatments to control treatment. NS=not significant, *P*-value given otherwise.

Shade Periodicity Affects Growth of Container Grown Dogwoods

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Index words *Cornus florida* L. 'Comco No.1' Cherokee Brave™, *C. f*. 'Cherokee Princess', container production, nursery production, native tree

Significance to the Industry Container grown dogwoods are an important product in the nursery and landscape industry. Dogwoods are a challenging crop to produce in container culture, especially when bare root liners are used as the initial transplant into containers, and have resulted in unacceptable levels of mortality and poor growth. This research shows the benefit of growing Cherokee Brave™ and 'Cherokee Princess' under shade especially during the hottest months, July and August, to produce quality container-grown dogwoods. Both cultivars exhibited more than 20 percent height growth when grown under shade for the entire growing season or grown under shade from July through October compared to plants grown entirely in full sun. In this test, trunk diameter growth was similar among sun, shade or combinations of sun and shade plants with both cultivars.

Nature of Work Flowering dogwood is one of the most beautiful and important small flowering trees used in the nursery and landscape industry and ranks third in the U.S. in nursery sales of ornamental trees (6). It is considered an aristocrat of native flowering trees of the U.S. and has a broad geographical range extending through most of the eastern states and westerly through Iowa and south to Texas (2). Flowering dogwood has been in nursery cultivation a long time, however, as the demand for containerized trees has increased in the last 20 years, so has the demand for container-grown dogwoods. However, dogwoods are a challenging crop to produce in container culture, especially when bare root liners are used as the initial transplant into containers, and have resulted in unacceptable levels of mortality and poor growth. Anecdotal comments from nursery producers include overwatering, underwatering, over fertilization, poor root structure, environmental stress, or transplanting delay from the bare root harvest as reasons for poor dogwood growth during the first growing season.

Flowering dogwoods are considered an understory tree, but most producers grow container-grown dogwoods in full sun. Substrate temperatures in black plastic containers can exceed 43.3C (110 F) in full sun (3). Shade treatments were used to reduce root zone temperatures after transplanting dogwoods into containers and resulted in larger plants compared to plants grown in full sun (4). Research has shown that native understory species are successfully grown under shade cloth (5) and dogwood growth was greater when plants were grown under white or black shade compared to full sun (1).

The objective of this research was to evaluate growth of two cultivars of bare root dogwood liners after transplanting into nursery containers with periods of shade exposure during the growing season.

Nature of Work On March 10, 2015, uniform bare root flowering dogwood liners of *Cornus florida* L. 'Cherokee Princess' and *C.f.* 'Comco No.1' Cherokee Brave™, were obtained from a commercial nursery in Winchester, TN. Liners, 45.7-60.9 cm (18-24 in) tall, were potted into a #7 nursery container (C2800, Nursery Supplies, Chambersburg, PA) with pine bark substrate amended with 6.6 kg (11.0 lbs.) 19-5-9 (19N-2.2P-7.5K) Osmocote Pro 12 to 14 month controlled release fertilizer (Everris, Dublin, OH), 0.7 kg (1.2 lbs.) Micromax (Everris, Dublin, OH) and 0.6 kg (1 lbs.) of AquaGro (Aquatrols, Paulsboro, NJ) per m^3 (yd^3) and placed on outdoor growing facility at the TSU Nursery Research Center in McMinnville, TN. On April 20, plant height and trunk diameter [15.2 cm above top of substrate (6 in)] were measured on plants that had begun to leaf out and measured again at termination. Plants were assigned to four treatments: 1) full sun exposure during growing season, 2) full sun exposure until July 13, then placed under 53% black shade, 3) full sun exposure until August 13, then placed under 53% black shade, or 4) full shade exposure (53%) during growing season. On July 13 and August 11, plant height and trunk caliper were recorded and plants in treatment 2 and 3, respectively, were moved from full sun and placed under shade. Shoots from four randomly selected plants were severed from the roots at the substrate surface and the pine bark substrate was gently blown from the root mass using a compress air system. Both roots and shoots were dried in a forced-air oven at 56C for ten days.

Cyclic irrigation was applied daily using micro-spray emitter [160° Spot-Spitter fan emitter (Roberts Irrigation Company, Inc., San Marcos, CA)]. Weed control and powdery mildew control measures followed normal nursery practices.

The experimental design was a completely randomized design with four replications of ten plants per cultivar per experimental unit (n=40). All data were subjected to analysis of variance with the GLM procedure of SAS (SAS for Windows Version 9.1, SAS Institute, Cary, NC) and differences among treatments were separated by a Fisher's least significant difference, $P \leq 0.05$.

Results and Discussion Up until July, Cherokee Brave™ and 'Cherokee Princess' grown in full sun (trt 1, 2, 3) were similar in height but had less height growth compared to plants grown in shade (trt 4) (Figure 1). A similar trend was observed in August for Cherokee Brave™, even though trt 2 had been under shade for about 30 days. In contrast, 'Cherokee Princess' grown in shade (trt 4) were taller than other plants in August, however, plants placed in shade in July (trt 2) had more height growth than plants in full sun (trt 1 and 3). By mid-October, both Cherokee Brave™ and 'Cherokee Princess' grown in shade from March through October were similar in size to plants that were placed in shade in July (trt 2). Cherokee Brave™ and 'Cherokee Princess' grown in shade either from July or from March until October were about 26% and 23% larger, respectively than plants grown in full sun.

Trunk diameter growth of Cherokee Brave™ was similar in July, August and October among treatments and similar in July and August with 'Cherokee Princess'. However, by October, 'Cherokee Princess' plants grown in full sun were larger than plants grown in shade from August to October, but were similar to plants grown in shade from March or July until October. This is in contrast to findings by Burrows et al. (1) that reported dogwoods grown in sun had less trunk diameter growth than plants grown in white or black shade treatments.

Shoot dry weight was greatest with Cherokee Brave™ dogwoods grown under shade from March to October compared to plants grown in full sun during the same period, 111.7 g vs 84 g, respectively. 'Cherokee Princess' grown in full sun had the least biomass with 89.4 g and plants grown under shade from March to October had similar shoot dry weight to plants grown under shade from July to October, 118.4 vs 114.7 g, respectively.

This research shows that periods of shade resulted in increased plant growth of Cherokee Brave™ and 'Cherokee Princess' during one growing season; however, the authors realize that providing shade would require an investment in the infrastructure of nursery facilities.

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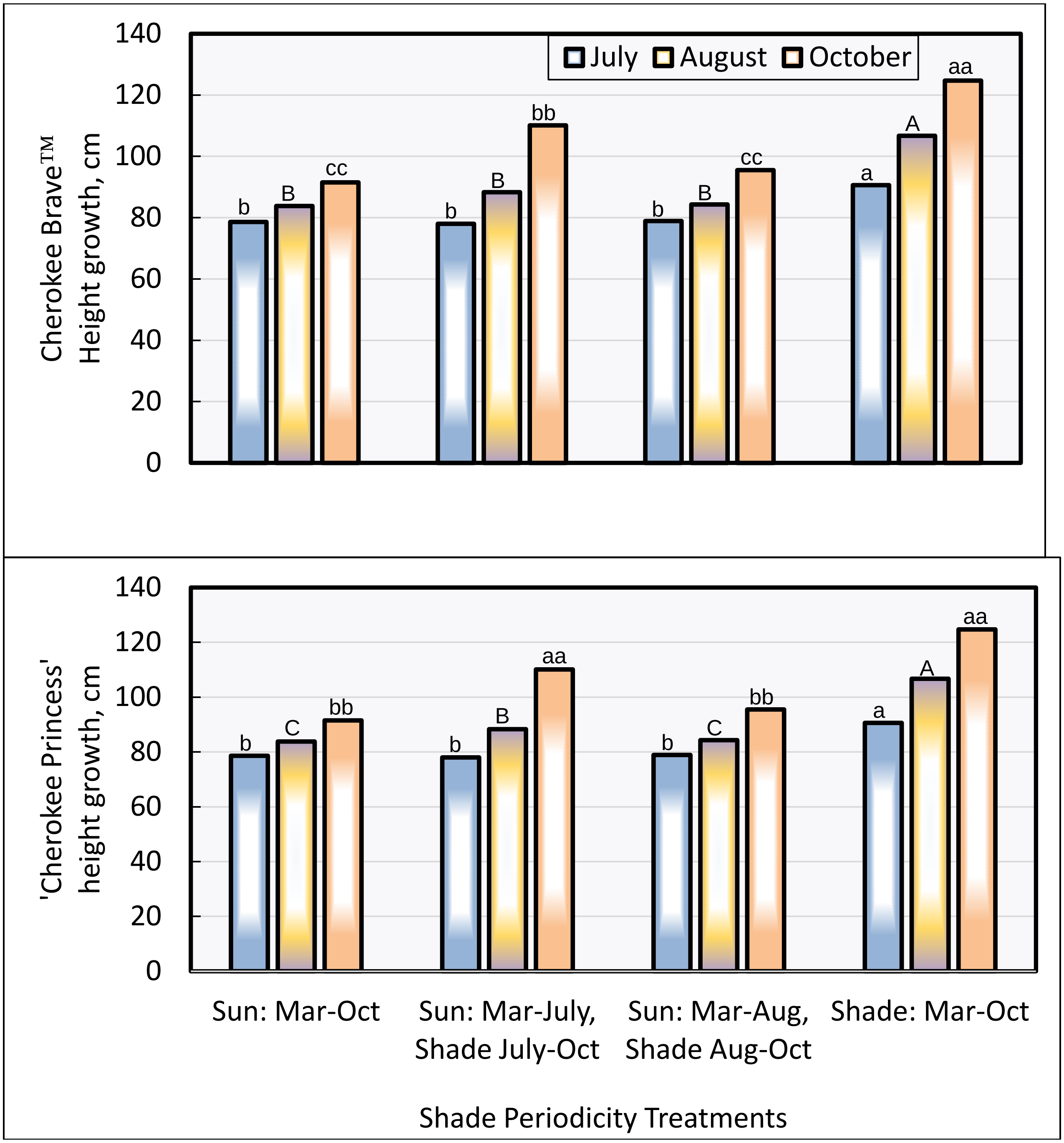

Figure 1. Influence of shade periodicity on height growth of *Cornus florida* L. 'Comco No.1' Cherokee Brave™ and *C.f.* 'Cherokee Princess' grown in #7 nursery containers during 2015. Significant and non-significant differences, separated by Fisher's least significant difference at P≤0.05, compare height growth across treatments at July, August and October.

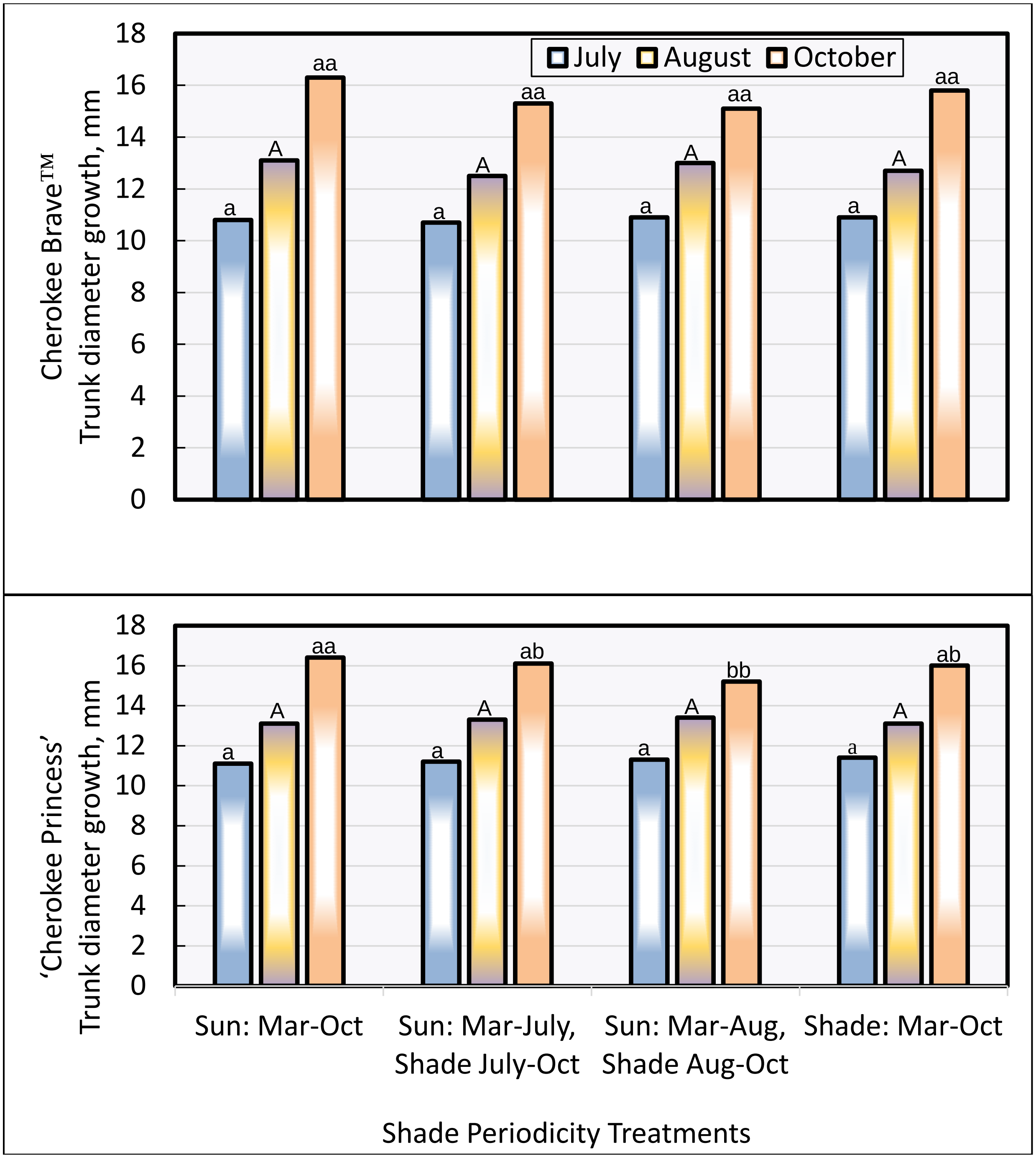

Figure 2. Influence of shade periodicity on trunk diameter growth of *Cornus florida* L. 'Comco No.1' Cherokee Brave™ and *C.f.* 'Cherokee Princess' grown in #7 nursery containers during 2015. Significant and nonsignificant differences, separated by Fisher's least significant difference at P≤0.05, compare trunk diameter growth across treatments at July, August and October.

Production of Herbaceous Perennials with Varied N:P:K Ratios and Nitrogen Rates

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Index Words Substrate solution, shoot dry weights, overhead irrigation

Significance to the Industry The P_2O_5 and K_2O supplies in control release fertilizers for the production of herbaceous perennials could be reduced by 0.67% per pound by utilizing a 16:2:4 instead of a 17:6:12 N:P:K ratio and produce equivalent shoot growth. Additionally, a 16:2:4 N:P:K ratio maintained lower NO_3-N and K concentrations in the substrate solution which would result in less environmental pollution. However, nutrient uptake by the plant must be considered before a fertilizer formulation change should be adopted.

Nature of Work Currently, fertilization of herbaceous perennials is not well defined. Appropriate recommendations for herbaceous perennial fertilization with controlled release fertilizers would reduce costs, increase plant uptake and reduce leaching of nutrients and treatment requirements of captured and re-used runoff water from production of a popular green industry crop. Current guidelines for fertilization of herbaceous perennials have been based on either woody plants (for production in nurseries) or annual plants (for production in greenhouses). Thus, recommendations are based on 50-100 ppm nitrogen (N), 10-20 ppm P and 25-50 ppm K (which are known to be able to support growth of woody, perennial plants) (5) and 90-225 ppm N with a 2:1:2 N:P:K ratio (which are appropriate for herbaceous annual plants) (1). While many herbaceous perennials have the same accelerated growth rate as annual plants, they also store nutrients in roots for re-growth following a dormant season like a woody plant. No research addresses controlled release fertilizer rates for herbaceous perennials. The objective of this research was to determine the effect of varying the N:P:K ratio and N rate of controlled release fertilizers on the growth of six herbaceous perennials under overhead irrigation.

Materials and Methods The experiment was arranged as a factorial treatment with three N:P:K ratios (17:6:12, 16:2:4, and 24:2:4), four N rates (1, 2, 3, and 4g), and six species [*Rudbeckia fulgida* var. *sullivantii* 'Goldsturm' (*Rudbeckia*), *Hibiscus moscheutos (Hibiscus)*, *Pennisetum alopecuroides* ‘Hameln’ (*Pennisetum*), *Coreopsis* ‘Full Moon’ (*Coreopsis*), *Phlox paniculata* ‘Jeana’ (*Phlox*), and *Veronica spicata* ‘Royal Candles’ (*Veronica*)]. There were 4 replications arranged in a randomized complete block design.

On June 28, 2012, all species were planted into 4.6 L (1.2 gal) containers (Classic 500, Nursery Supplies Inc., Chambersburg, PA) filled with an 8:1 pine bark:sand (v/v) substrate amended with 5 $kg \cdot m^{-3}$ (10 $lb \cdot yd^{-3}$) of dolomitic limestone (Rockydale Quarries Corporation, Roanoke, VA). Irrigation was supplied cyclically at 8:00 am, 12:00 pm, and 4:00 pm each day using sprinklers (R13-18, Rainbird, Tucson, AZ) that applied 6.1 $L \cdot min^{-1}$ (1.6 $gal \cdot min^{-1}$). On July 10, 2012 fertilizer was top-dressed to all species for each N:P:K ratio x N rate.

Irrigation volume was monitored every two weeks to maintain a 0.2 leaching fraction (LF = volume leached ÷ volume applied). Nutrient concentration in the substrate solution was measured by collecting leachate samples using the Virginia Tech Pour Through Extraction Method (4). Substrate solution samples were collected on August 31, 2012 (for *Phlox*, *Rudbeckia*, and *Veronica* only) and were submitted to the North Carolina Department of Agriculture and Consumer Services, Agronomic Division (Raleigh, NC) for ammonium (NH_4-N), nitrate (NO_3-N), phosphorus (P), and potassium (K) analyses. On September 5-7, 2012, *Coreopsis*, *Hibiscus, and Pennisetum* and on September 18-20, 2012, *Phlox*, *Rudbeckia,* and *Veronica* shoots (stems and leaves) were harvested. Shoots were dried at 62C (144F) for 5 days for dry weight determination.

This study was conducted at the North Carolina State University Horticultural Field Laboratories (Raleigh, NC). All variables were subjected to analysis of variance (ANOVA) and regression analyses, where appropriate, using PROC GLM and PROC REG in SAS version 9.4 (3) and where P was considered significant at $\leq$ 0.05.

Results and Discussion The N:P:K ratio by N rate by species interaction was non-significant for shoot dry weights; however, all two-way interactions were significant (N rate by species: P=<.0001, N:P:K ratio by species: P=<.0001, N:P:K ratio by N rate: P=0.0002). When analyzed by species, the N rate, regardless of N:P:K ratio, had increasing linear trends in shoot dry weights from 1 to 4g for all species (data not shown). Also, when analyzed by species, N:P:K ratio only had a significant impact on shoot dry weights for *Coreopsis, Hibiscus, and Rudbeckia* regardless of N rate (Figure 1). Generally, for all of these species, 17:6:12 produced the largest shoot dry weights and was similar to 16:2:4. However, 24:2:4 produced significantly smaller shoot dry weights compared to 17:6:12 for *Coreopsis, Hibiscus, and Rudbeckia* but was generally similar to 16:2:4. These data suggest that both the P_2O_5 and K_2O supplies in controlled release fertilizers for the production of herbaceous perennials could be reduced by 0.67% per pound by utilizing a 16:2:4 instead of a 17:6:12 N:P:K ratio. Similarly, when using daily fertigation, Kraus and Warren (2) found that *Rudbeckia* and *Hibiscus* were best grown with an 8:1:2 N:P:K ratio and 200 $mg \cdot L\ N^{-1}$, 25 $mg \cdot L\ P^{-1}$, 50 $mg \cdot L\ K^{-1}$. However, a 17:1:2 N:P:K ratio and lower P and K rates (17 $mg \cdot L\ P^{-1}$ and 33 $mg \cdot L\ K^{-1}$) produced similar growth in *Rudbeckia*.

Substrate solution nutrient concentrations had a significant N:P:K ratio by N rate interaction for NO_3-N and K. However, only the main effects of N rate and N:P:K ratio were significant for NH_4-N, while the main effects of species, N rate, and N:P:K ratio were significant for P. For NO_3-N and K, when analyzed by N:P:K ratio and averaged over species, concentrations increased linearly with increasing N rates from 1 to 4g for both 16:2:4 and 17:6:12 (Figure 2A, 2B). However, the concentrations in the substrate solution for 16:2:4 and 24:2:4 remained lower than 17:6:12 regardless of N rate and would result in less nutrient in runoff. Additionally, there was a larger concentration of NH-N in the substrate solution with 17:6:12 compared to 16:2:4 and 24:2:4 regardless of N rate and there were larger concentrations of P in the substrate solution for 16:2:4 compared to 24:2:4, while, the concentrations were similar to 17:6:12 (data not shown).

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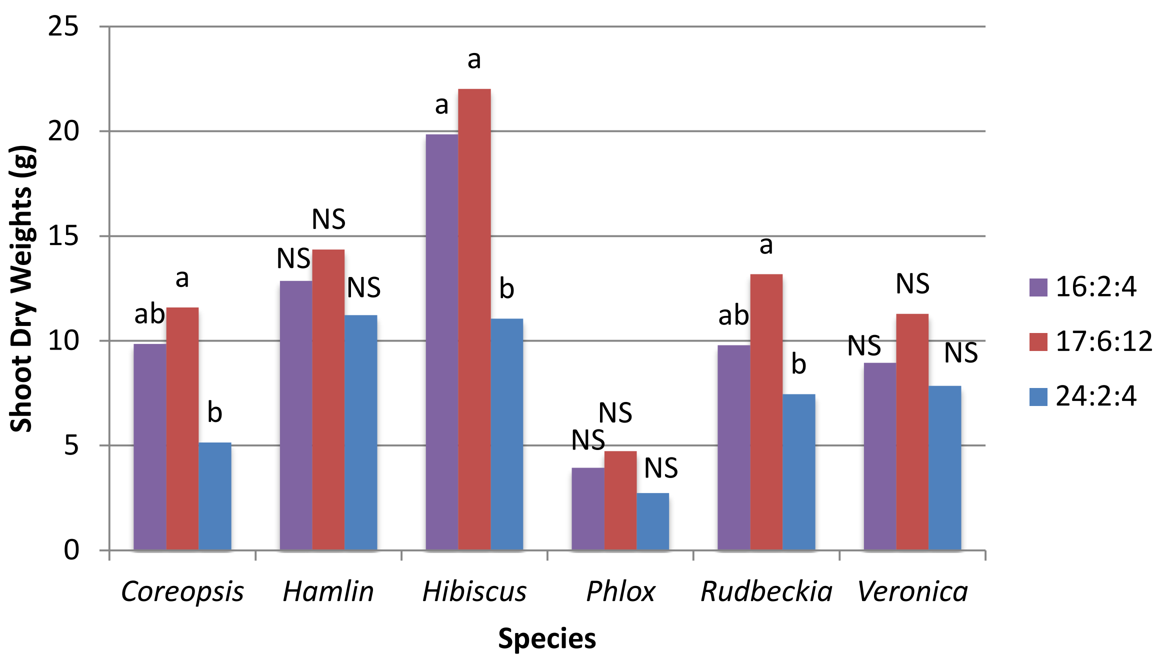

Figure 1. Effect of nitrogen:phosphorus:potassium ratio (16:2:4, 17:6:12, or 24:2:4), averaged over all nitrogen rates, on shoot dry weights for *Rudbeckia fulgida* var. *sullivantii* 'Goldsturm' (*Rudbeckia*), *Hibiscus moscheutos (Hibiscus)*, *Pennisetum alopecuroides* 'Hameln' (*Pennisetum*), *Coreopsis* 'Full Moon' (*Coreopsis*), *Phlox paniculata* 'Jeana' (*Phlox*), and *Veronica spicata* 'Royal Candles' (*Veronica*). For each species, means between nitrogen:phosphorus:potassium ratios are significantly different from each other based on Tukey's honestly significant differences means separation procedures ($P \leq 0.05$).

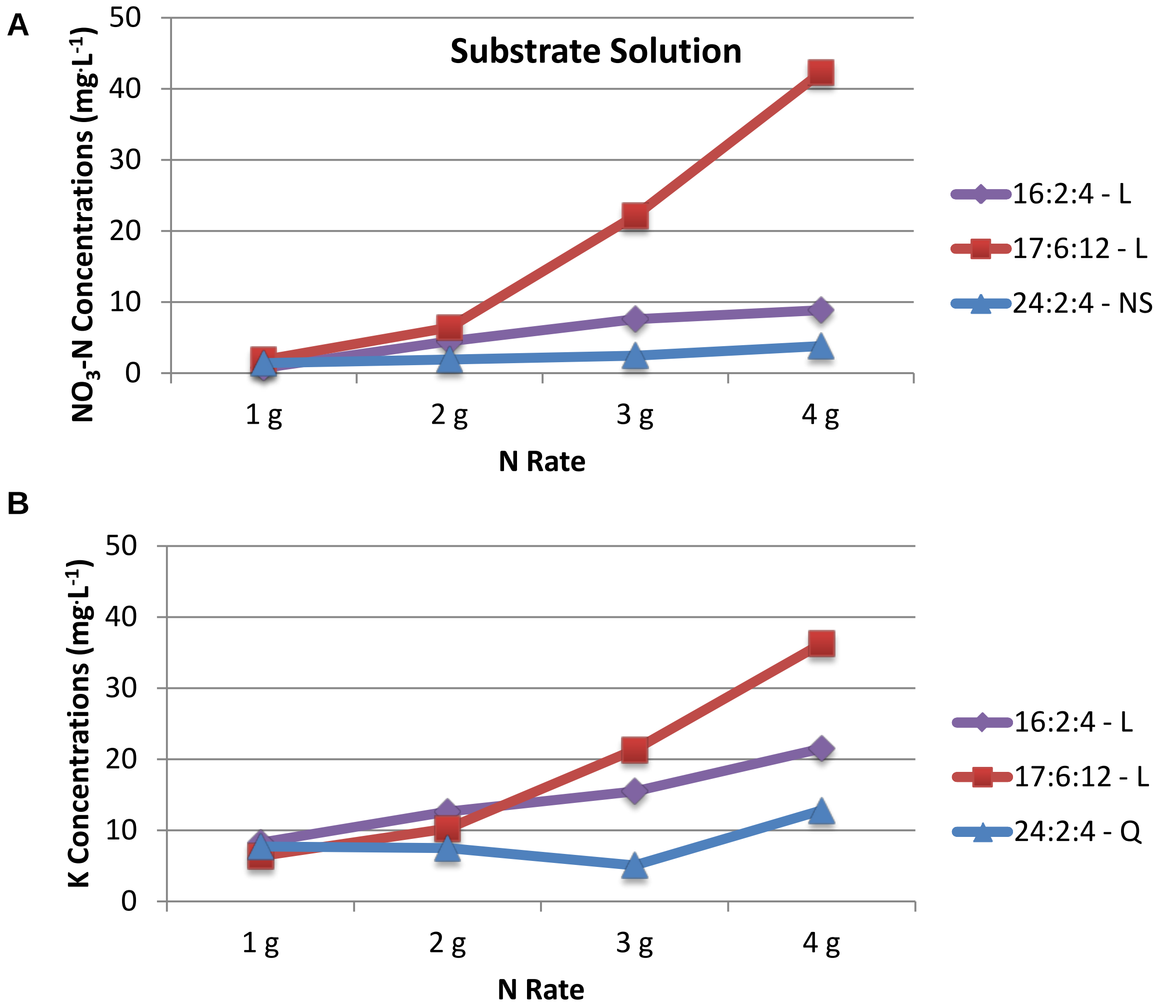

Figure 2. Effect of nitrogen rate (N rate) on nitrate (NO_3-N) concentrations (A) and potassium (K) concentrations (B) for each nitrogen:phosphorus:potassium ratio (16:2:4, 17:6:12, or 24:2:4) averaged over species (*Rudbeckia fulgida* var. *sullivantii* 'Goldsturm', *Hibiscus moscheutos*, *Pennisetum alopecuroides* ‘Hameln’, *Coreopsis* ‘Full Moon’, *Phlox paniculata* ‘Jeana’, and *Veronica spicata* ‘Royal Candles’). Regression analyses were utilized for linear (L), quadratic (Q), and non-significant (NS) responses ($P \leq 0.05$).

Effect of Volumetric Water Content on the Growth of *Anisacanthus quadrifidu*, *Caryopteris* x *clandonensis*, and *Cuphea hyssopifolia*

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Index Words Dry weight, growth index, visual score, volumetric water content

Significance to the Industry Drought tolerant ornamental plants are needed to meet the demands of the green industry for sustainability and low maintenance landscapes as drought events are often unpredictable. *Anisacanthus quadrifidus* (Vahi) Nees var. *Wrightii* (Torr.) Henrickson (flame acanthus), *Caryopteris* × *clandonensis* 'Dark Knight' ('Dark Knight' bluebeard), and *Cuphea hyssopifolia* Kunth (mexican false heather) are popular ornamental plants. Yet little research-based information is available about their tolerance to drought conditions. A greenhouse experiment was conducted to determine their relative drought tolerance by maintaining a constant substrate volumetric water content (volume of water/volume of substrate, VWC) of 25, 30, 35, 40, or 45% for 10 weeks. Results showed that as VWC decreased, leaf area, number of flowers, and dry weight (DW) of all plant species decreased linearly with variation among species. As VWC decreased from 45% to 25%, flame acanthus, 'Dark Knight' bluebeard, and mexican false heather plants exhibited reductions in leaf area by 49, 81, and 80%; in number of flowers by 33, 27, and 71%; and in whole plant DW by 58, 68, and 76%, respectively. Among the three plants evaluated, flame acanthus displayed better drought tolerance with less growth reduction in comparison with 'Dark Knight' bluebeard and mexican false heather. Such information may help growers and homeowners make informed decisions regarding plant selection and irrigation management.

Nature of Work *Anisacanthus quadrifidus* var. Wrightii (flame acanthus), *Caryopteris* × *clandonensis* 'Dark Knight' ('Dark Knight' bluebeard), and *Cuphea hyssopifolia* (mexican false heather) are widely used landscape plants. Flame acanthus is a small shrub native to Texas and Mexico (1). From midsummer through frost, flame acanthus is covered with long, slender, red or orange flowers. It adapts to well-drained soil and sunny exposures (1). 'Dark Knight' bluebeard is a soft rounded shrub native to eastern and southern Asia (2). It has an upright habit with dark green foliage and lovely bright blue flowers. It prefers a loose, loamy soil and full sun (2). Mexican false heather is a small evergreen shrub native to Mexico, Guatemala, and Honduras (3). It has fine foliage and beautiful eye-catching purple flowers. It can be grown in a range of soils in a sunny or partially shaded spot with good drainage (3). All three species are attractive to beneficial insects such as bees and butterflies. They are heat tolerant and require low maintenance. However, little research-based information is available on their drought tolerance.

Field trials or well controlled greenhouse experiments are needed to determine plant drought tolerance instead of anecdotal observations. Field trials are a standard and reliable method of evaluating plant response to drought conditions. However, these trials often require years to get accurate results and need a great quantity of plant materials. Furthermore, the occurrence of drought conditions in the field is unpredictable and rainfall can complicate drought treatments. A sensor-based irrigation system as described by Nemali and van Iersel (4) allows irrigating plants to a desired level at which drought stress is imposed on plants. Such sensor-based irrigation system accurately control the desired drought stress levels and thus provide an effective approach to determine plant drought tolerance by examining the growth and physiological responses of plants to drought stress within a relatively short period of time.

The objective of this study was to evaluate the relative drought tolerance of flame acanthus, 'Dark Knight' bluebeard and mexican false heather in a greenhouse. The growth response to five substrate volumetric water contents (volume of water/volume of substrate, VWC, $L \cdot L^{-1}$) controlled by a sensor-based automatic irrigation system was investigated.

Rooted cuttings of flame acanthus, 'Dark Knight' bluebeard and mexican false heather were received from Southwest Perennials (Dallas, TX) on 9 Apr. 2015. Uniform plants were selected and transplanted into 5.8-L black poly-tainer containers (22.5 × 19.5 cm) containing commercial substrate Metro-Mix 902 [50%-60% composted bark, Canadian sphagnum peat moss, vermiculite and coarse perlite, starter nutrient charge with Gypsum and slow release nitrogen and dolomitic limestone (SunGro®, Agawam, MA)]. The medium was incorporated with 25 g Scotts® Osmocote® Plus Controlled Release Fertilizer 15-9-12 Osmocote with 5 to 6 months longevity (The Scotts Company, Marysville, OH). Plants were watered with reverse osmosis (RO) water throughout the experiment.

Containers were then irrigated at one of the five substrate VWC set points: 0.25 $L \cdot L^{-1}$ (25%), 0.30 $L \cdot L^{-1}$ (30%), 0.35 $L \cdot L^{-1}$ (35%), 0.40 $L \cdot L^{-1}$ (40%), and 0.45 $L \cdot L^{-1}$ (45%), using a sensor-based automated irrigation system similar to that described by Nemali and van Iersel (4). One 10HS capacitance sensor (Decagon, Pullman, WA) was inserted vertically into the substrate in a randomly selected container in each treatment. The sensors were connected to a CR10 datalogger (Campbell Scientific, Logan, UT) through an AM416 multiplexer (Campbell Scientific), and the voltage output was measured every 5 min. The datalogger was programmed to convert voltage to substrate VWC using a substrate-specific calibration equation ($VWC = -75.146 + 198.344 \times voltage - 69.747 \times voltage^2$, $R^2 = 0.996^{***}$). The datalogger compared the VWC in each treatment with the VWC set point for that particular treatment. As soon as the VWC in a container dropped below the set point for irrigation, the datalogger sent a signal to the 16-channel SDM-CD16AC relay controller (Campbell Scientific), which opened the solenoid valve (X-13551-72; Dayton Electric Co., Niles, IL) corresponding to that treatment for 40 seconds. Each container was watered with one dribble ring (Dramm, Manitowoc, WI) at a diameter of 15 cm with five emitter holes per ring. The dribble ring was connected to a pressure-compensated drip emitter (8 LPH; Netafim USA, Fresno, CA) with an average flow rate of 2.1 gallon per

hour. The temperatures in the greenhouse were maintained at 29.0 ± 1.8 °C (mean ± standard deviation) during the day and 24.3 ± 2.6 °C at night. The daily light integral (photosynthetically active radiation) was 11.1 ± 1.5 $mol{\cdot}m^{-2}{\cdot}d^{-1}$.
Plant height (cm) from pot rim to the tallest point of the plant was recorded every two weeks. On 21 July 2015 (69 days after treatment), the shoots of all plants were severed at the substrate surface. Leaf area was determined using LI-3100C area meter (LI-COR® Biosciences, Lincoln, NE). Number of inflorescences (including flower buds, open flowers, or faded flowers) was counted. Thereafter, the above-ground parts (including stems, leaves, and flowers) were oven-dried at 70 ℃ for four days and dry weight (DW, g) was determined.

The study was designed as a randomized complete block design with two blocks, five VWC thresholds as treatments, and four plants per treatment. Analysis of variance (ANOVA) was performed using PROC GLM. Means separation among treatments was conducted using Tukey's HSD multiple comparison. All statistical analyses were performed using JMP 11 (SAS Institute Inc., Cary, NC).

Results and Discussion The daily average substrate VWCs were 1 to 3% higher than their respective set points over the course of the experiment (Fig. 1). Although daily variations in VWCs were observed, especially at the lower set points, distinguished differences in the average VWCs among the treatments were maintained throughout the experiment. From 10 to 70 days after treatment, the averaged VWCs were 28%, 32%, 37%, 41%, and 46% in treatments with irrigation set points of 25%, 30%, 35%, 40%, and 45%, respectively.

Plant height and leaf area of three species decreased linearly with decreasing VWC set points (Fig. 2 and 3). When VWC set points decreased from 45 to 25%, the slope of the regression curve of mexican false heather was less steep than that of 'Dark Knight' bluebeard and flame acanthus. As VWC decreased from 45 to 25%, flame acanthus, 'Dark Knight' bluebeard, and mexican false heather plants showed reductions in plant height of 29%, 34%, and 20%, respectively, and a reduction in leaf area of 49%, 81%, and 80%, respectively.

The number of inflorescences and total dry weight of three species were reduced as VWC decreased. Linear regression relations of the number of inflorescences and total dry weight with VWC were observed for three species (Fig. 4 and 5). As VWC set points decreased from 45 to 25%, the slope of the regression curve of mexican false heather and 'Dark Knight' bluebeard were less steep than that of flame acanthus. A reduction of 33%, 27%, and 71% in number of inflorescences and 58%, 68%, and 76% in total dry weight was recorded for mexican false heather, 'Dark Knight' bluebeard, and flame acanthus, respectively, as VWC decreased from 45% to 25%.

In conclusion, drought stress provided in this study significantly reduced the growth of flame acanthus, 'Dark Knight' bluebeard and mexican false heather. The responses varied with species. The flame acanthus displayed better drought tolerance with less growth reduction in comparison with 'Dark Knight' bluebeard and mexican false heather.

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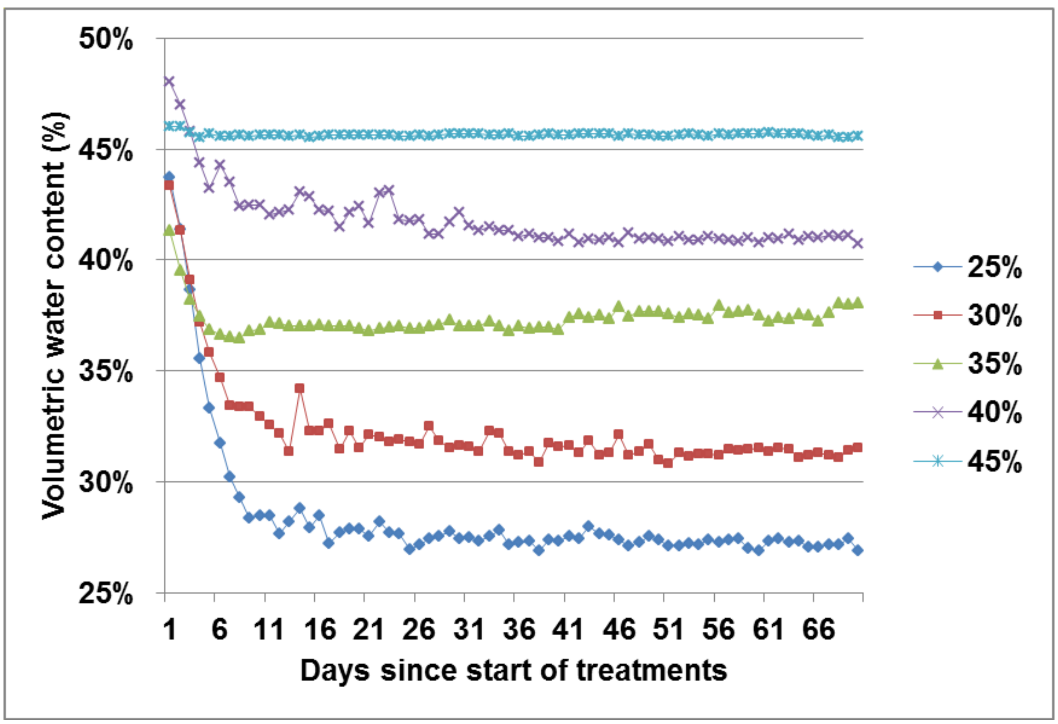

Figure 1. Daily average substrate volumetric water content maintained by a soil moisture sensor-controlled automatic irrigation system.

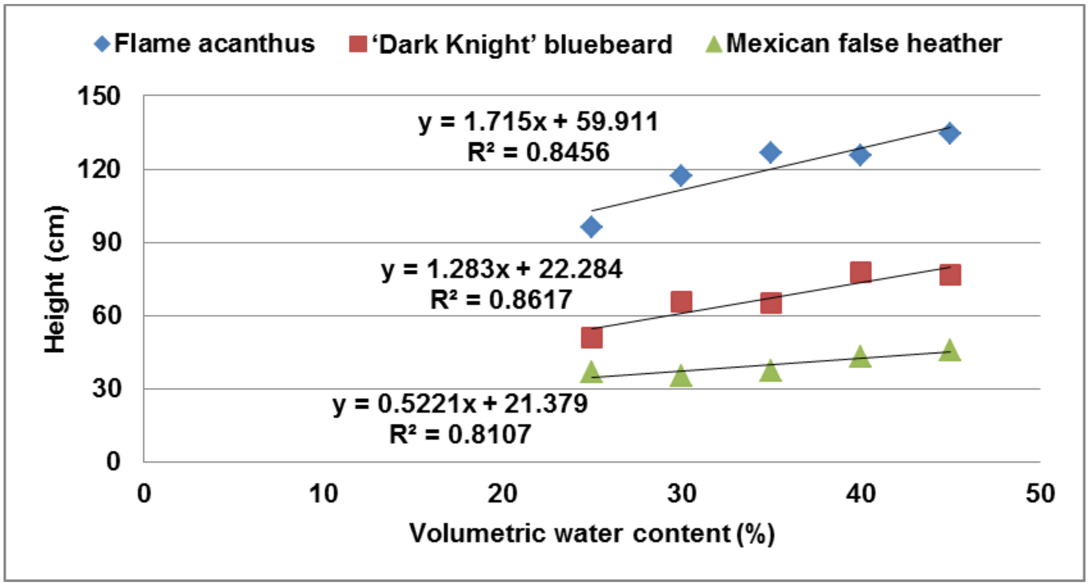

Figure 2. Plant height of *Anisacanthus quadrifidus* var. *Wrightii* (flame acanthus), *Caryopteris* × *clandonensis* 'Dark Knight' ('Dark Knight' bluebeard), and *Cuphea hyssopifolia*' (mexican false heather) irrigated with a constant substrate volumetric water content maintained by a soil moisture sensor-controlled automatic irrigation system.

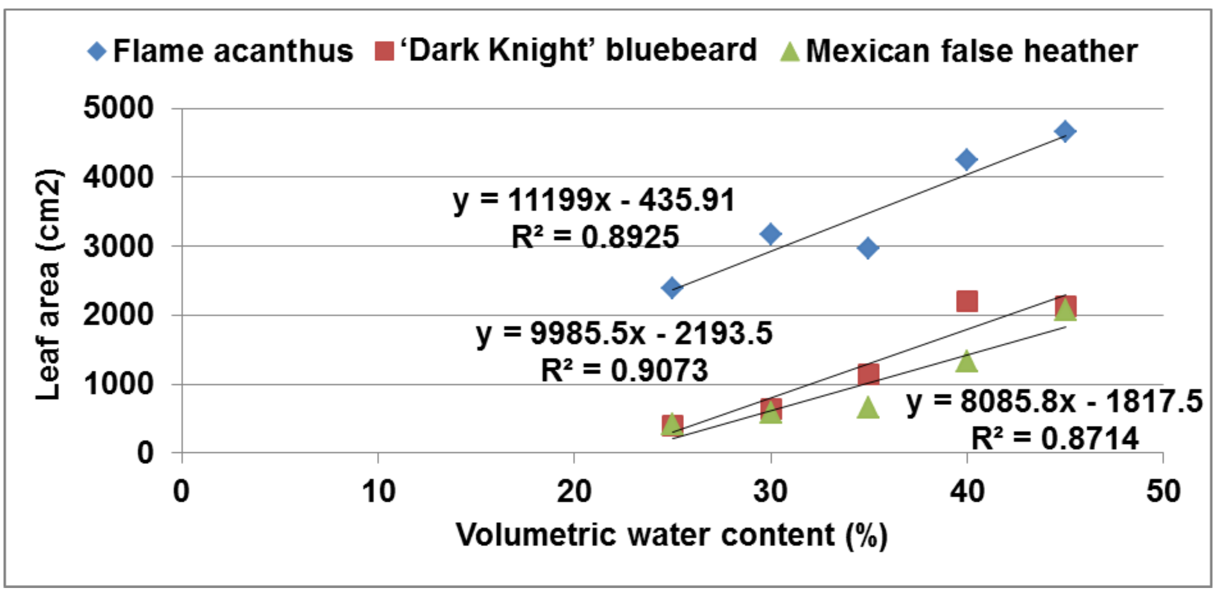

Figure 3. Leaf area of *Anisacanthus quadrifidus* var. *Wrightii* (flame acanthus), *Caryopteris* × *clandonensis* 'Dark Knight' ('Dark Knight' bluebeard), and *Cuphea hyssopifolia*' (mexican false heather) irrigated with a constant substrate volumetric water content maintained by a soil moisture sensor-controlled automatic irrigation system.

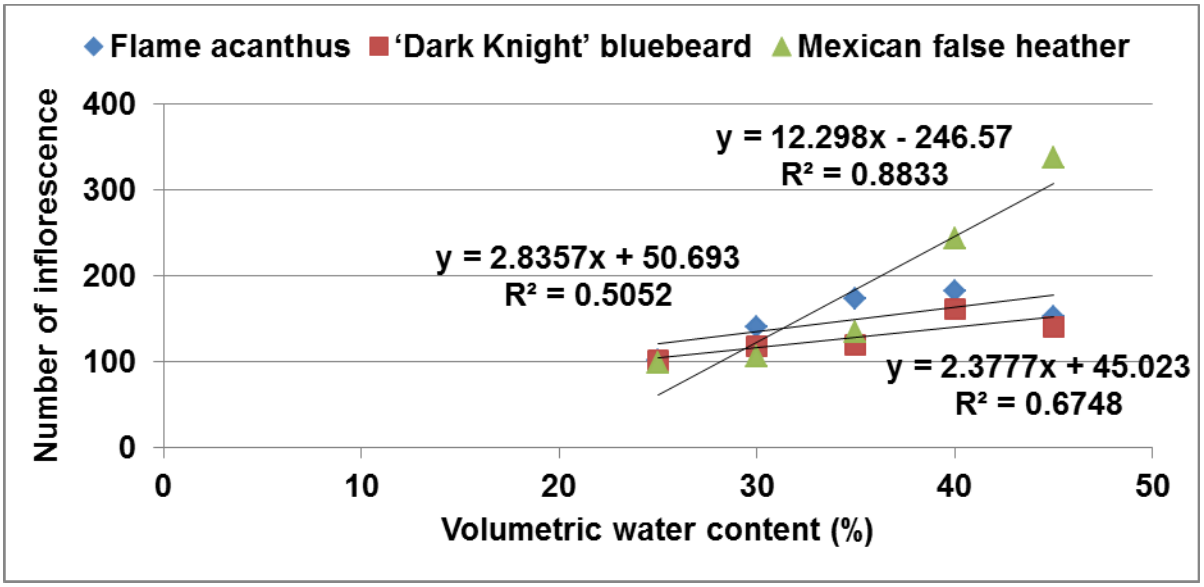

Figure 4. Number of inflorescence of *Anisacanthus quadrifidus* var. *Wrightii* (flame acanthus), *Caryopteris* × *clandonensis* 'Dark Knight' ('Dark Knight' bluebeard), and *Cuphea hyssopifolia*' (mexican false heather) irrigated with a constant substrate volumetric water content maintained by a soil moisture sensor-controlled automatic irrigation system.

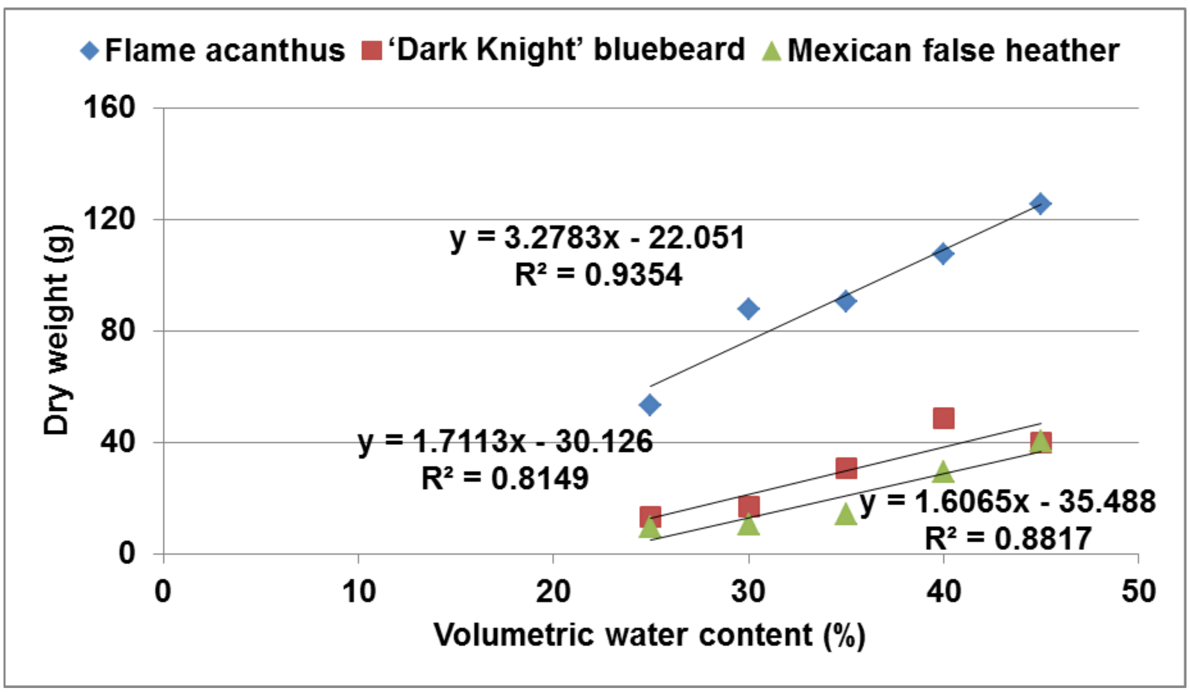

Figure 5. Dry weight of *Anisacanthus quadrifidus* var. *Wrightii* (flame acanthus), *Caryopteris* × *clandonensis* 'Dark Knight' ('Dark Knight' bluebeard), and *Cuphea hyssopifolia*' (mexican false heather) irrigated with a constant substrate volumetric water content maintained by a soil moisture sensor-controlled automatic irrigation system.