Container Grown Plant Production

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Section Editor

Diagnosing Aesthetic and Growth Disorders in Hydrangea Plants under Commercial Nursery Production

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Index Words Controlled-release fertilizers, fertigation, growth and quality, leaf tissue analyses, fertilization management, shading

Significance to Industry Hydrangeas are a popular and significant component of nursery crops production in the U.S. Stunted growth and foliage chlorosis and reddening were reported in hydrangea cultivars in nurseries in New Jersey. The severity of chlorosis symptoms and growth reductions were associated with reduced nutrient levels and substrate pH levels approaching 6.0. Reduced leaf iron and manganese concentrations were related to the increasing severity of the chlorosis symptoms. Over-applications of liming amendments when mixing some substrate batches was a likely cause for the observed chlorosis, along with irrigation management practices that affected root growth. Unsightly leaf tissue reddening, accompanied by mild growth reductions, were also observed in some cultivars growing under full sun, but these symptoms were not evident when growing under 30% shade fabric.

Nature of Work Hydrangeas accounted for $91.3 million dollars in US nursery sales in 2014, equivalent to 13.5% of the total sales in the deciduous shrubs grouping category (8). Bigleaf hydrangea [*Hydrangea macrophylla* (Thunb.) Ser.] is likely the most popular nursery-grown species. Cultivars of serrated [*H. serrata* Thunb.) Ser.], panicle (*H. paniculata* Sieb.), and other hydrangea species are also found in nursery, greenhouse and landscape cultivation (1, 2, 3, 4).

The soil/substrate pH, as it pertains to the concentration/availability of aluminum ions, is often a major consideration for flower color development in hydrangeas (1, 2, 7). However, there is only generic information regarding the most suitable soil/substrate pH range for hydrangeas with respect to the availability and uptake of mineral nutrients, their assimilation in plant tissues and aesthetic quality, e.g. development of nutrient-related disorders (2, 7). Yellow foliage and chlorosis in nursery-grown bigleaf hydrangea have been reported to occur in the middle of summer, attributed to overwatering, root rot and low iron uptake (2, 6). Although bigleaf hydrangeas grow normally in full sun, it is reported that shading is favorable to their growth, and it is imperative in the U.S. hardiness zones 7 to 9 (1). Higher (>60%) shading densities can significantly reduce the incidence of the common cercospora leaf spot (*Cercospora hydrangeae* Ellis & Everh)

afflicting this species (5). Some commercial nurseries are now adopting the practice to grow hydrangeas, at least some cultivars and selections, under shade.

A large commercial nursery in our area reported a serious problem with stunted growth and foliage chlorosis and reddening in several hydrangea cultivars. Despite attempts to correct these issues with changes in their fertilization program, these persisted. The nursery was visited to collect information and plant/substrate samples for analyses to help diagnose this production problem. Rooted cuttings of hydrangeas had been transplanted in early spring of 2016 into #3 containers filled with a bark-peat-rice hulls-coarse sand (40-40-15-5 by volume) substrate amended with dolomitic limestone, gypsum and hydrated calcium lime (6, 2 and 2 lb/yd^3, respectively [3.56, 1.19, and 1.19 Kg/m^3]). The substrate also had incorporated the controlled-release fertilizer Harrell's 17-6-12 Plus [5-6 month] (Harrell's LLC, Lakeland, FL) at 6 lb/yd^3 (3.56 Kg/m^3). The plants were also fertigated with Helena CoRoN 28-0-0 (Helena Chem. Co., Collierville, TN) and Soilless Special 10-4-6 (Oakland Farms Crop Services, Bridgeton, NJ) adjusted to deliver 100 ppm of N at every irrigation.

Hydrangea production blocks affected by stunted growth, chlorosis and leaf reddening (Figure 1) were evaluated on 1 September 2016. Data were collected from randomly selected normal-looking and symptomatic plants: height, width in two perpendicular axes, the fraction (%) of leaves afflicted by chlorosis or reddening (Figure 2), and chlorophyll index (SPAD 502 meter, Minolta, Japan). Recently-matured leaves collected from these plants were subjected to mineral analyses (J.R. Peters Lab., Allentown, PA). Collected substrate samples were subjected to routine soilless media analyses at the Rutgers Soil Testing Laboratory (New Brunswick, NJ).

Results and Discussion Inspection of the hydrangea production areas (Figure 1) showing stunted growth and chlorotic (Figure 2A) and reddened (Figure 2B) foliage suggested these were largely related to specific plant blocks and species. Most afflicted by these symptoms were two bigleaf hydrangea cultivars (*H. macrophylla* Firefly™ ['Horcos' PP27110] and Everlasting® Garnet ['Kolmgarip' PPAF]) and one cultivar of mountain hydrangea (*H. serrata* x *macrophylla* 'Preziosa'). Some blocks of 'Preziosa' and Firefly™ plants were growing under shade (30% shade fabric) and others under full sun (uncovered). The uncovered plants were clearly smaller in height and size/volume (i.e. plant growth index) compared to those growing under shade (Table 1). The higher radiation, and concomitant heat load, in sun-grown plants of these cultivars likely reduced their photosynthesis and increased their transpiration, resulting in the observed smaller plant sizes compared to plants growing under shade. This observation lends support to the almost imperative recommendation of shading hydrangeas in sunnier/hotter environments (1), particularly for *H. macrophylla* cultivars (7).

Plants of 'Preziosa' and Firefly™ showed an unsightly interveinal reddish tint on the younger upper foliage when grown under full sun, and some of the Firefly™ plants also had mild symptoms of interveinal chlorosis which were associated with lower chlorophyll index readings compared to shaded plants (Table 1). No differences in chlorophyll index

readings where observed between shade- and sun-grown 'Preziosa' plants. It is hypothesized that the reddish coloration in sun-grown plants is likely an overproduction of anthocyanin pigments in young leaves as a photoprotective response to a higher UV-radiation incidence compared to the plants growing under shade (9). Low temperatures and nutrient deficiencies (3, 4, 9) can also result in an enhanced foliar anthocyanin production, but the former was ruled out as these hydrangea crops were still growing in the hot days of summer. The mineral nutrient profile in leaves of sun- and shade-grown 'Preziosa' plants was similar (Table 2). On the other hand, while the Firefly™ plants had similar foliar concentrations of most mineral elements under shade and sun, there were distinctive 8% and 28% reductions in iron (Fe) and manganese (Mn), respectively, in leaves of sun-grown plants (Table 2). These reduced foliar levels of Fe and Mn in sun-grown Firefly™ plants certainly correlate with their lower chlorophyll indexes (Table 1), and the observed mild chlorosis in some of these plants. Iron foliar concentrations lower than 50 mg/kg have been previously reported to be associated with mild chlorosis symptoms in florist hydrangeas (3). Unfortunately substrate samples were not collected for this cultivar, whose chemical analyses might have yielded clues as to the concentration and/or availability of these Fe and Mn micronutrients in relation to the sun and shade production environments.

A range of chlorosis symptoms was prevalent in a shaded production block of Garnet® hydrangeas (Figure 2A). The increased severity (none, mild, severe) of the chlorosis symptoms was reflected in significant reductions in foliage chlorophyll levels and growth parameters (Table 1). The reductions in plant size were inversely related to increases in the foliar concentration of all macronutrients and most micronutrients (Table 2), a common observation in stressed plants. However, foliage Fe and Mn concentrations decreased along with the reductions in chlorophyll levels and plant growth (Table 1). The substrate of the most chlorotic Garnet® plants showed pH levels approaching or exceeding 6 (Table 3). The concentration of substrate macronutrient ions showed an increasing trend with the severity of chlorosis symptoms, but with the exception of phosphorous (P), their overall values, along with the overall fertility of the substrate assessed by electrical conductivity (EC), were below the suggested optimum ranges (Table 3). Among the micronutrients, the substrate concentrations of Fe, Mn and Zn were diagnosed as below their suggested ranges in the plants showing the most severe chlorosis symptoms. An accidental over-application of liming amendments in some substrate batches was the likely causal agent for the higher substrate pH levels (≥ 6), significantly reduced concentrations of Fe, Mn and Zn in the substrate, and reduced assimilation of Fe and Mn in the foliage of the most chlorotic Garnet® plants. An informal, non-destructive assessment of root vigor and condition in “normal” and symptomatic plants, showed significantly smaller root systems in the chlorotic plants, along with a larger volume of substrate showing wetter (saturated/waterlogged) conditions. Excessive irrigation has been previously reported as a causal agent to the incidence of root rot, reduced micronutrient (mainly Fe) uptake and the development of significant yellowing and chlorosis in nursery-grown bigleaf hydrangeas (2, 6).

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Table 1. Growth measurement and foliage quality assessments in hydrangea cultivars growing in a commercial nursery. Data are means of three plants (*n*=3) for each cultivar and production area (shaded or full sun).

Cultivar	Cover [x]	% Leaves with symptoms [y]	Chlorophyll Index (SPAD)	Height (cm)	Plant Growth Index [z]	Notes
'Preziosa'	Shade	2	63.7	39	53	Foliage reddening
	Sun	63	63.5	30	40	
Firefly™	Shade	6	47.1	25	34	Foliage reddening and mild chlorosis in some
	Sun	68	29.5	18	22	
Garnet ®	Shade	0	64.0	22	38	Varying degrees of chlorosis
	Shade	55	35.5	18	29	
	Shade	90	19.0	15	21	

[x] Some of the production beds had 30% shade (black) fabric overlaid on top of the Quonset structures. The rest were uncovered (i.e. full sun).
[y] The predominantly observed aesthetic symptoms are listed in the last column (Notes).
[z] Calculated as (height + width 1 + width 2) / 3, with measurements taken in cm.

Table 2. Nutrient concentrations in leaf tissues of commercially-grown hydrangea cultivars showing varying degrees of chlorosis and reddening. Data are means of three plants (*n*=3) for each cultivar and production area (shaded or full sun).

Shade (% leaves w/symptoms) [x]	N	P	K	Ca	Mg	Fe	Mn	B	Zn	Cu
	(% dry wt.)					(mg/kg dry wt.)				
'Preziosa'										
Shade (2)	2.9	0.2	1.5	0.8	0.3	67	67	27	17	3
Sun (63)	2.5	0.2	1.6	0.9	0.4	67	57	31	20	3
Firefly™										
Shade (6)	2.8	0.2	1.9	0.9	0.4	48	39	34	20	5
Sun (68)	3.0	0.3	2.0	1.1	0.4	44	28	32	20	4
Garnet®										
Shade (0)	2.6	0.2	1.2	1.1	0.3	74	62	34	30	2
Shade (55)	2.7	0.3	1.4	1.2	0.4	59	51	41	32	3
Shade (90)	3.4	0.4	2.0	1.6	0.6	48	27	56	33	3

[x] Some of production beds had 30% shade cover; the rest were in full sun. The numbers in parentheses denote the % of leaves observed with reddening and/or chlorosis symptoms (see text and Table 1 for more details).

Table 3. Chemical properties of substrate collected from the center core of commercially-grown Garnet® hydrangea plants showing varying degrees of chlorosis. Data are means of three plants (*n*=3).

% Leaves with chlorosis [x]	pH	EC (dS/m)	N [y]	P	K	Ca	Mg	Fe	Mn	Zn	Cu
0	4.8	0.35	23	7	27	17	11	0.33	0.10	0.07	0.04
55	4.9	0.43	33	7	31	23	14	0.34	0.17	0.08	0.06
90	6.1	0.69	47	11	46	41	27	0.11	0	0.07	0.02
Optimum Range [z]	5.2 -5.8	2.0 – 3.5	100 - 200	6 - 9	150 -250	> 200	> 70	0.3 - 3	0.02 - 3	0.3 - 3	0.005 - 0.5

[x] The severity of the chlorosis symptoms can be appreciated in Figs. 1 and 2. All plants from the cultivar Garnet® were growing under 30% shade cover.

[y] All ion concentrations in mg/L. Nitrogen as nitrate-N.

[z] Optimum values for peat-based substrates (Guidelines from Rutgers Soil Testing Laboratory).

Figure 1. Overview of a hydrangea crop at a commercial nursery production with plants showing varying degrees of chlorosis.

Figure 2. Hydrangea plants displaying increasing levels of leaf tissue chlorosis (**A**; cultivar Garnet® growing in 30% shade) and reddening (**B**; cultivar 'Preziosa' growing in full sun [left] and 30% shade [right]).

Effects of Lime and Fertilizer Rate on Growth of Citrus Rootstock, *Poncirus trifoliata* var. *monstrosa* 'Flying Dragon'

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Index Words Controlled release fertilizer, nursery production, substrate amendments

Significance to the Industry Combinations of three top dress rates of Osmocote 18-5-8 (12-14 months) and three rates of dolomitic limestone were evaluated over 55 weeks of production. Results indicate no difference in stem diameter for rates over the medium labeled rate (21 g). A decrease in stem diameter was observed as lime rate increased. Six $lb \cdot yd^{-3}$ (3.5 $kg \cdot m^{-3}$) of pulverized dolomitic lime produced the largest stem diameters. More work is needed to determine if budded plants would perform similarly.

Nature of Work The primary citrus for both commercial and yard trees for the northern Gulf Coast is the satsuma (*Citrus unshiu* Marcovitch). Satsumas are typically budded onto trifoliate rootstock *Poncirus trifoliata*, with 'Rubidoux' as the most popular rootstock; however high density plantings favor the dwarf rootstock 'Flying Dragon' (1). Trifoliate rootstocks offer increased cold hardiness, and Phytophthora and nematode resistance. Many citrus nurseries utilize fertigation; however, the small citrus nurseries in Alabama solely utilize controlled release fertilizer (CRF). Through extension contacts and farm visits, a need was recognized for recommendations for fertilizer and lime rates for 'Flying Dragon' rootstock. Work on budded citrus trees has suggested little to no effect on growth from varying rates of CRF (4,5). A review of the literature yielded little information on the effect of fertilizer rate on container grown 'Flying Dragon' rootstock. A need for lime recommendations was established through observations of Mn toxicity in some citrus nursery crops and large containers with low container pH (<4.0 in some cases). We believed the low container pH to be a result of acidic well water with low alkalinity, ammonia based fertilizer and the fact that most of these crops were grown in the same substrate for more than a year. The objective of this study was to provide information that would lead to fertilizer and lime recommendations for container grown 'Flying Dragon' rootstock.

This study was conducted from 10/19/17 to 10/11/18 at the Ornamental Horticulture Research Station in Mobile, AL. A 2x3 factorial was utilized to investigate fertilizer, dolomitic lime rates and potential interactions. Fertilizer rates consisted of 21, 27 and 33 g of Osmocote® 18-5-8 (12 to 14 months) (Everris®) top-dressed at planting, with a repeated application at 294 days after potting (DAP). The 21 and 27 g represented the medium and high label rate. The 33 g rate was 6 grams over the high rate and was included because growers considered citrus to be a heavy feeder. Dolomitic limestone

(pulverized) factor included 6, 10 and 14 lb·yd^{-3} (3.5, 5.9, 8.3 kg·m^{-3}) rates. All treatments utilized 100% aged pine bark. Supplemented with a micronutrient package (Micromax®, Everris®) at the label rate of 1.5 lb·yd^{-3} (0.9 kg·m^{-3}). On August 18, 2017 seedlings of *Poncirus trifoliata* var. *monstrosa* 'Flying Dragon' were potted from 60 ml cell tubes (Ray Leach Cone-tainer™, Tangent OR) into trade gallon containers (3.4 l). Seedlings averaged 30 cm in height but were blocked by size to control for variability. Plants were arranged in a randomized complete block design under overhead irrigation. Well water pH averaged 5.0 but ranged between 4.5 and 5.5. Container leachates were generally taken biweekly. Stem diameter was measured at 1 in. (2.54cm) above the soil line and plant heights were taken at 196, 245 and 372 DAP. Fresh and dry shoot biomass was taken at 387 DAP. Data were analyzed using ANOVA where date was included as a factor for leachate analysis, stem diameter and height.

Results and Discussion At termination only the dolomitic lime rate had a significant effect on both fresh and dry shoot biomass. There was a quadratic trend with effects of lime rate on biomass, where the 10 lb·yd^{-3} of lime produced the greatest shoot biomass. Dolomitic lime rates of 6 or 14 lb·yd^{-3} decreased fresh shoot biomass by 4 and 12%, respectively when compared to the 10 lbs·yd^{-3} (Table 1).

For plant height, quadratic trends were observed for the interaction of fertilizer and lime for 21 and 27 g (Table 2). Plants receiving 21 g of fertilizer and 10 lb·yd^{-3} of lime had the greatest plant height (54.2 cm) followed by 6 and 14 lb·yd^{-3} of lime (53.7 and 49.2 cm, respectively), representing 9.7% difference in plant height between the tallest and shortest plants. Plants grown using 27 grams of fertilizer performed best in plant height when 14 lb·yd-3 of lime was used (54.2 cm), followed by 6 and 10 lbs·yd^{-3} of lime (53.2 and 49.7 respectively). There was a 8.7% difference between plants grown in 14 and 10 lbs·yd^{-3} of lime when 27 g of fertilizer was used. No differences were found between lime rates when 33 g of fertilizer was used (Table 2).

Stem diameter was only affected by lime rate and date (Table 3). There was a quadratic trend for stem diameter between 196 DAP (4/3/18) and 245 DAP (5/22/18); however, the trend was linear between 286DAP (7/2/18) and 372 DAP (9/26/18). At 372 DAP stem diameter decreased as the lime rate increased. There was a 4 and 8% difference in stem diameter between 6 lb·yd^{-3} (10.6 mm) 10 and 14 lbs·yd^{-3} (10.2 and 9.8 mm, respectively) at 372 DAP.

Container pH and EC were also subject to ANOVA with 3 (fertilizer rates) x 3 (lime rates) x 23 (leachate analysis). No interactions were found between fertilizer x lime, fertilizer x lime x date, but interactions were observed for fertilizer x date and lime x date (Figures 1 and 2). When sliced by date, fertilizer X date was significant for 30% of the sample dates were lime x date was significant 70% of the sample dates. Lime rates had the same effect on pH until 15 weeks after potting. It has been demonstrated that the effect of dolomitic lime on pH plateaus above 8 lbs·yd^{-3} (4.8 kg·m^{-3}) due to the solubility (1. 2). This may suggest no benefit for dolomitic lime rates above 8 lb·yd^{-3}; however, higher rates may provide a longer residual buffering capacity as suggest by

Shreckhise et al. (9). This may be important in situations where low well water pH is an issue and/or plants are grown in the same container for over one year. In Figure 2, the pooled EC level drops and subsequently pH rises for all lime treatments. The rise in pH could be attributed to reduced ammonia and subsequently less nitrification (an acid producing process). When acidic conditions are reduced, pH may climb to levels that are out of range for some crops if high rates of dolomitic lime are used.

As previously mentioned, similar results have been found with container grown citrus and controlled release products (4, 5). Lack of response in growth has also been reported for fertigated containerized citrus under continuously fertigated N rates ranging from 25 to 200 ppm for a 12-month period (6) and 12.5 to 200 ppm for 26 weeks (7). Maust and Williamson (7) established a critical concentration of nitrogen in the medium solution to be 16 ppm, above which no increase in yield was realized for 'Hamlin' orange budded on Cleopatra mandarin and Carrizo citrange. The lack of response to increasing rates of controlled release products may be related to what has been described as episodic growth rhythms between shoot and roots of citrus (8). Nitrogen uptake has been correlated to various growth stages of some citrus species (3, 8). Coordinating fertilizer rate with shoot flushes may increase nutrient use efficiency when fertigated products are used.

Medium or moderate fertilizer rates may be best for 'Flying Dragon'. Increasing fertilizer rates beyond the medium rate significantly affected plant height but only for 21 and 27 g of fertilizer when interacted with varying rates of lime. While significant, this only translates into a difference of 9.7% and 8.7% between the smallest and largest plants. Fertilizer also had no significant effect on shoot biomass. Effects on stem diameter would be of the greatest interest to growers producing this crop; however, in this study stem diameter was unaffected by fertilizer rate. Increasing above the medium rate of the fertilizer used in this study would translate into an additional $4800 per acre (assuming containers were jammed and a space utilization efficiency of 80%). Future studies should evaluate lower fertilizer rates. Results from this study also suggest using 6 $lb \cdot yd^{-3}$ (3.5 $kg \cdot m^{-3}$) of pulverized dolomitic limestone may provide the best pH range for this crop. Future studies will focus on a wider range of fertilizer rates on budded trifoliate citrus to further improve fertilizer and lime recommendations for Satsuma nursery stock.

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Table 1. Effects of fertilizer and lime rate on fresh and dry shoot biomass.

Fresh weight		Dry weight	
ANOVA	Pr > F	ANOVA	Pr > F
Block	<.0001	Block	<.0001
Fert	0.1409	Fert	0.1612
Lime	0.0428	Lime	0.0159
F x L	0.5501	F x L	0.337

Shoot Biomass		
Lime rate (lbs/yd)	Fresh (g)	Dry (g)
6	60.9	30.6
10	63.5	31.4
14	55.6	27
Sign[Y]	Q*	Q*

[Z]The lime main affect was significant at P < 0.05.
[Y]Significance (Sign.) quadratic (Q) trend using simple model regressions at P < 0.05 (*).

Table 2. Effects of fertilizer and lime on plant height of 'Flying Dragon' root stock.

ANOVA	Pr > F	DAP	Date	
Block	<.0001	0	9/19/2017	29.9
Fert	0.9951	196	4/3/2018	37.8
Lime	0.6207	245	5/22/2018	40.6
F x L	0.0015	294	7/2/2018	61.1
Days	<.0001	387	9/26/2018	92.2
F x D	0.5956		Sign.[Z]	Q***
L x D	0.7333			
F x L x D	0.5119			

	Lime (lb/yd)[Y]			
Fert (g)	6	10	14	Sign.[y]
21	53.7[W]	54.2	49.2	Q*
27	53.2	49.7	54.2	Q*
33	49.3	55.2	52.3	NS
Sign.	NS	NS	NS	

[Z]Significant (Sign.) quadratic (Q) trend using simple regression

[Y]The fertilizer by lime interaction and the date main effect were significant at $P < 0.05$.

[X]Not significant (NS) or significant (Sign.) quadratic (Q) trends using qualitative/quantitative regression models at $P < 0.05$ (*).

[W]Plant height measured in cm.

Table 3. Effects of fertilizer and lime on stem diameter.[z]

ANOVA	Pr > F
Block	<.0001
Fert	0.1200
Lime	<.0001
F x L	0.1808
Days	<.0001
F x D	0.0681
L x D	0.0002
F x L x D	0.4994

	Lime (lbs/yd)			
Date	6	10	14	Sign.[Y]
9/19/2017	4.54[X]	4.61	4.53	NS
4/3/2018	4.99	4.68	4.81	Q*
5/22/2018	6.85	6.11	6.03	Q*
7/2/2018	8.35	7.97	7.50	L***
9/26/2018	10.60	10.18	9.77	L**
Sign.	Q***	Q***	Q***	

[z]The lime by date interaction was significant at P < 0.05.
[Y]Not significant (NS) or significant (Sign.) linear (L) quadratic (Q) trends using qualitative/quantitative regression models at P < 0.05 (*), 0.01 (**) or 0.001
[X]Stem diameter measured in mm.

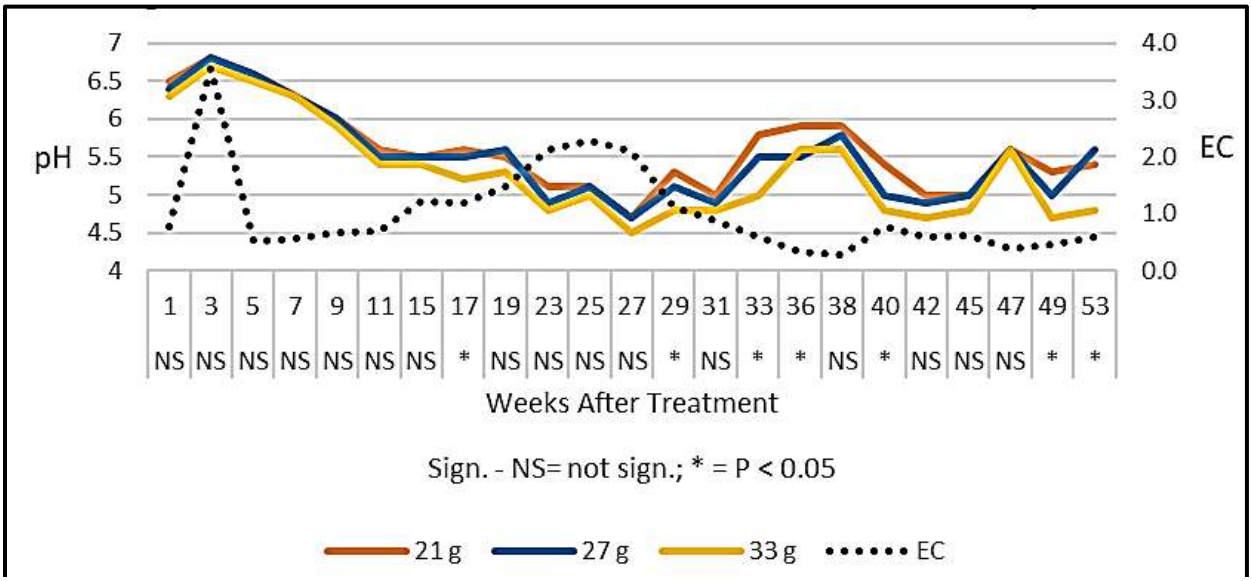

Figure 1. Effect of Fertilizer Rate*Date on container pH

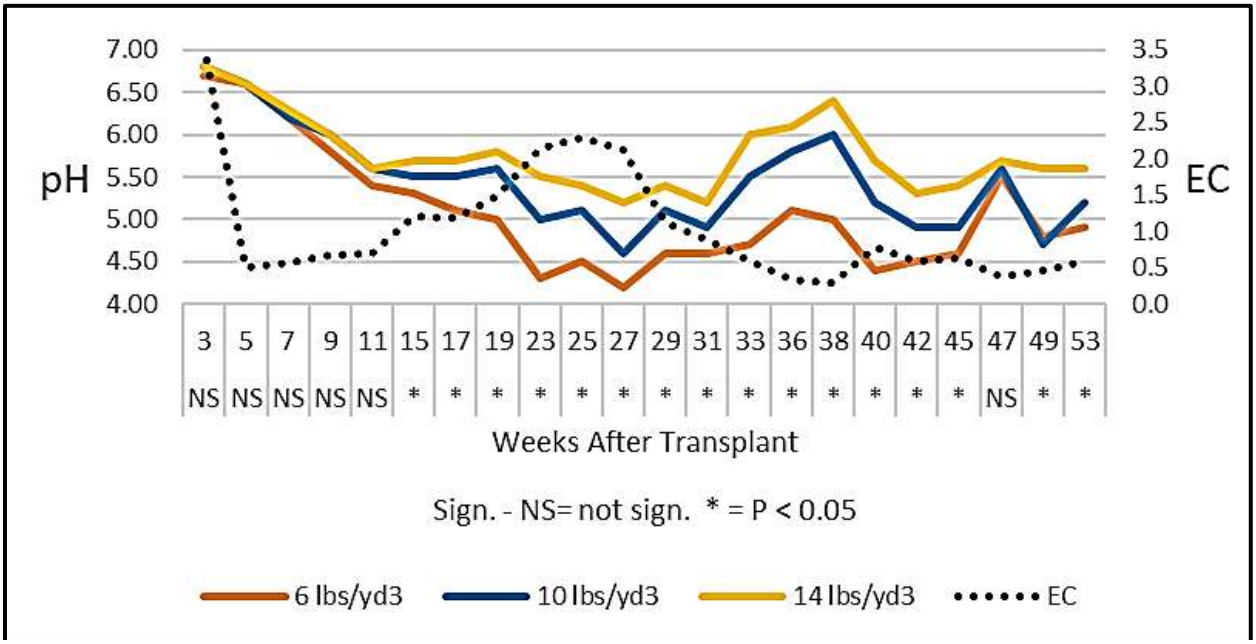

Figure 2. Effect of Lime Rate*Date on container pH

Effects of Compost Substrates on Root Zone Temperature and Growth of 'Green Giant' Arborvitae

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Index Words Thuja, container production, pine bark

Significance to the Industry Container grown nursery crops encounter extended periods of supraoptimal root zone temperatures (RZT) throughout the summer which have detrimental effects on plants. Implementing practices to moderate RZT will reduce plant stress leading to increased growth and healthier plants. Compost can be added to pine bark substrates for increased nutrient and water retention, but may provide other benefits such as buffering RZT. This study evaluated arborvitae growth and substrate temperature in two types of containers and compost amended substrates. White containers resulted in 14 to 33% larger plants when compared to plants grown in black containers. Root zone temperature remained above 38°C (100°F) for much longer in black containers (17.5%) compared to white containers (3.5%). Compost did not affect RZT, but a 10% compost amendment resulted in larger plants overall.

Nature of Work Composts have become readily accessible due to increased production and availability of various feedstocks such as municipal green wastes, vermicompost, and spent mushroom compost. Although the processing method and source material may differ, various types of compost can be utilized as a substrate amendment for container grown crops. The benefits of compost include increased water retention, enhanced nutrient availability, and potential disease suppressive properties due to increased microbial activity (1, 9). Compost can be a less expensive alternative to peatmoss while providing similar benefits as an amendment for pine park substrates (3, 6).

Root zone temperature in container grown crops can frequently exceed 54°C (129°F) during the summer months, but root growth of many nursery crops will cease at temperatures above 38°C (100°F) and roots can be permanently damaged at short-term exposure to temperatures above 46°C (115°F) (2, 4). Substrates store heat that has been converted from solar radiation captured from the substrate surface and container exterior, resulting in extended periods of supraoptimal RZT. A number of variables can affect RZT including substrate properties (components, porosity, and moisture content), container properties (color and type of material), and irrigation management (5).

Methods for reducing RZT include reduced spacing between containers, use of white and/or porous containers, and using substrates with greater thermal diffusion and moisture retention (2, 7). The objective of this study was to evaluate the effects of compost substrates and container color for buffering RZT and growth of 'Green Giant' arborvitae (*Thuja standishii x plicata* 'Green Giant').

The experiment was conducted at the Otis L. Floyd Nursery Research Center in McMinnville, TN. Two container types were evaluated in combination with three substrates (six total treatments; 12 replicates per treatment). Containers included black and white 3 gal (11.3 L) solid wall containers (Nursery Supplies Inc., Kissimmee, FL). Substrates included pine bark alone (PB) or combined (v:v) with compost (C; vermicompost, Silver Bait LLC, Coalmont, TN), PB:C (9:1) and PB:C (7:3). On May 8, 2018, liners (3 in. containers) of 'Green Giant' arborvitae were transplanted and containers were placed on a gravel pad arranged in a randomized complete block design.

Separate irrigation zones were used for each treatment to monitor and adjust irrigation application rates. Irrigation application volume for each treatment was adjusted throughout the study based on replacement of daily water use. Water was delivered to each plant with a dribble ring (15 cm diameter; Dramm Corp., Manitowoc, WI) fitted with a pressure compensated emitter (8 lph; Netafim USA, Fresno, CA). Decagon 5TM sensors and EM50 data loggers (Decagon Devices Inc., Pullman, WA) were used to measure and collect substrate temperature and volumetric water content. Sensors were positioned vertically approximately 1.7 in. (4.5 cm) from the container sidewall and placed below the substrate surface extending 4.3 in. (11 cm). The study was terminated 5 months after transplant (MAT; October 10, 2018) and plants were destructively harvested. Plant height and diameter were measured (1, 2, 3, 4, and 5 MAT) and growth index (GI) was calculated [(height + max width + perpendicular width)/3]. Height difference and GI difference were calculated by subtracting the initial and final measurements. Shoot dry weight (n=12) and root dry weight (n=12) were measured after being oven dried at 60°C for 5 days. Substrate pH and electrical conductivity (EC) were analyzed from leachate samples (n=4) collected (1, 2, 3, 4, and 5 MAT) using the Virginia Tech Pour-through Method. The percent of time roots were exposed to temperatures above critical thresholds (38 and 46°C; 100.4 and 114.8°F) reported by Ingram et al. (2) was calculated using the total number of data recordings for each day between 12 pm and 12 am.

All data were analyzed with linear models using the GLIMMIX procedure of SAS (Version 9.3; SAS Institute, Inc., Cary, NC). Differences between treatment means (simple and main effects) were determined using the Tukey method ($P < 0.05$).

Results and Discussion Plant height was similar for plants grown in black containers at 5 MAT, regardless of substrate (Table 1). In white containers, plant height was lowest in PB:C (7:3) but similar for in PB and PB:C (9:1). Within each substrate, plant height was 14% to 33% greater in white containers compared with black containers. At the end

of the study, the difference in height was over 1.7 times greater for plants in white containers compared with black containers. Plants in white containers also had greater final GI and over 1.5 times greater difference in GI compared with black containers. At the end of the study, plants in PB:C (9:1) had the greatest GI, difference in GI, and shoot dry weight (SDW). Root dry weight (RDW) and SDW were overall lower in black containers while RDW was similar for PB and PB:C (9:1) in white containers.

Throughout the study, substrate pH ranged from 6.3 to 7.6 and tended to decrease with increasing amount of compost (Table 2). Substrate EC was significantly lowest in PB except at the end of the study and EC tended to increase with the addition of compost. Root zone temperature remained above 38°C for 17.5% of the time in black containers, 14% longer than in white containers Table 3). In black containers, RZT was above 46°C for 0.7% of the time while RZT did not reach 46°C in white containers. Substrate did not affect RZT at either threshold.

Lower substrate temperature and increased plant growth in white containers has been demonstrated in previous studies (2, 4, 8). The enhanced plant performance in white containers in the current study is likely due to reduced heat stress in the root zone. The addition of compost at 10% had an overall positive effect on plant growth compared to pine back alone. Conversely, substrates with 30% compost resulted in less plant growth overall compared with pine bark alone and compost at 10%. Moore (6) reported plant response to compost substrates can vary greatly depending on several factors including amount of compost, type of compost, and plant species. The 30% compost substrate in our study may have remained too moist and resulted in reduced growth due to low aeration. Although substrate did not affect RZT, substrate porosity has been reported to affect RZT with lower porosity leading to reduced temperatures (5). Substrate physical properties and volumetric water content data for this study will be analyzed and used to further interpret results.

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Table 1. Effects of container color[z] and substrate[y] on plant growth[x] of *Thuja standishii x plicata* 'Green Giant' after five months.

		Final Height (cm)	Δ Height (cm)	Final GI	Δ GI	Root Dry Weight (g)	Shoot Dry Weight (g)
				Significance of Treatment Factors[w]			
Container		<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Substrate		0.0003	0.8208	0.0098	0.0629	0.0337	<.0001
Container*Substrate		0.0073	0.1675	0.1603	0.6297	0.0381	0.2373
				Least Squares Means for Main Effects[v]			
Container	Substrate						
Black		-	20.8 b	47.6 b	20.2 b	-	85.3 b
White		-	36.7 a	58.3 a	31.3 a	-	133.3 a
	PB	-	29.0 A	52.5 B	24.5 B	-	100.8 B
	PB:C (9:1)	-	29.1 A	55.0 A	26.9 A	-	124.3 A
	PB:C (7:3)	-	28.1 A	51.5 B	25.9 AB	-	102.7 B
				Treatment Least Squares Means Grouped by Container Color[u]			
Container	Substrate						
Black	PB	63.3 a	19.9	45.9	18.4	8.6 a	72.3
	PB:C (9:1)	64.2 a	20.4	49.9	21.8	10.0 a	100.1
	PB:C (7:3)	61.7 a	22.1	47.1	20.5	9.4 a	83.6
White	PB	84.4 A	38.2	59.0	30.6	16.9 A	129.4
	PB:C (9:1)	80.8 A	37.7	60.1	32.1	17.5 A	148.6
	PB:C (7:3)	70.6 B	34.1	55.9	31.2	13.6 B	121.9

[z]3 gal (11.3 L) solid wall containers (Nursery Supplies Inc., Kissimmee, FL)

[y]Pine bark alone (PB) or combined (v:v) with compost (C), PB:C (9:1) and PB:C (7:3).

[x]Δ Height (difference in height) = Final height - initial height; Growth index (GI) = (height + max width + perpendicular width)/3; Δ GI = Final GI - initial GI.

[w]*P* values.

[v]When the interaction term in the model is not significant ($p > 0.10$), main effects means for treatments within each treatment factor (container or substrate) followed by the same letter are not significantly different using the Tukey method ($\alpha = 0.05$).

[u]When the interaction term in the model is significant ($p \leq 0.10$), simple effects means for each substrate within a container color followed by the same letter are not significantly different using the Tukey method ($\alpha = 0.05$); Otherwise, treatment means presented without letter groupings for informational purposes.

Table 2. Effects of container[z] color and substrate[y] on leachate pH and electrical conductivity (EC) collected from *Thuja standishii x plicata* 'Green Giant'.

		pH					EC (µS/cm^3)				
		1 MAT[x]	2 MAT	3 MAT	4 MAT	5 MAT	1 MAT	2 MAT	3 MAT	4 MAT	5 MAT
		Significance of Treatment Factors[w]									
Container		0.0002	0.0018	0.0003	0.0001	<.0001	<.0001	0.0248	0.0014	0.162	0.0004
Substrate		<.0001	0.0003	0.0011	<.0001	<.0001	<.0001	<.0001	0.0003	0.0132	0.1817
Container*Substrate		0.4336	0.4761	0.3343	0.1959	0.1572	0.052	0.3645	0.3417	0.7829	0.8039
		Least Squares Means for Main Effects[v]									
Container	Substrate										
Black		7.3 b	6.9 b	6.5 b	6.6 b	6.8 b	-	2495 a	3366 a	1684 a	965 a
White		7.5 a	7.1 a	7.0 a	6.9 a	7.3 a	-	1884 b	2001 b	1274 a	479 b
	PB	7.6 A	7.3 A	7.1 A	7.1 A	7.3 A	-	1045 C	1410 B	808 B	611 A
	PB:C (9:1)	7.3 B	6.9 B	6.7 B	6.6 B	7.0 B	-	2398 B	2986 A	1876 A	694 A
	PB:C (7:3)	7.2 B	6.9 B	6.5 B	6.6 B	6.8 C	-	3127 A	3654 A	1753 A	860 A
		Treatment Least Squares Means Grouped by Container[u]									
Container	Substrate										
	PB	7.5	7.2	6.9	7.0	7.1	705 c	1096	1721	875	804
Black	PB:C (9:1)	7.2	6.8	6.3	6.3	6.7	1700 b	2845	3893	2165	967
	PB:C (7:3)	7.1	6.7	6.3	6.4	6.6	2220 a	3546	4483	2012	1123
	PB	7.6	7.4	7.2	7.2	7.5	518 B	993	1099	741	417
White	PB:C (9:1)	7.5	7.1	7.0	6.9	7.3	1070 A	1951	2079	1587	422
	PB:C (7:3)	7.4	7.0	6.7	6.8	7.0	1411 A	2708	2825	1494	597

[z]3 gal (11.3 L) solid wall containers (Nursery Supplies Inc., Kissimmee, FL).
[y]Pine bark alone (PB) or combined (v:v) with compost (C), PB:C (9:1) and PB:C (7:3).
[x]Months after transplant (MAT).
[w]*P* values.
[v]When the interaction term in the model is not significant ($p > 0.10$), main effects means for treatments within each treatment factor (container or substrate) followed by the same letter are not significantly different using the Tukey method ($\alpha = 0.05$).
[u]When the interaction term in the model is significant ($p \leq 0.10$), simple effects means for each substrate within a container color followed by the same letter are not significantly different using the Tukey method ($\alpha = 0.05$); Otherwise, treatment means presented without letter groupings for informational purposes.

Table 3. Percent of time substrate temperature remained at or above critical thresholds (38 and 46°C) in different containers[z] and substrates[y].

		38°C (%)	46°C (%)
		Significance of Treatment Factors[x]	
Container		<.0001	0.0026
Substrate		0.5414	0.8015
Container*Substrate		0.1199	0.8015
		Least Squares Means for Main Effects[w]	
Container	Substrate		
Black		17.5 a	0.69 a
White		3.5 b	0.00 b
	PB	9.5 A	0.22 A
	PB:C (9:1)	9.4 A	0.30 A
	PB:C (7:3)	11.3 A	0.45 A
		Treatment Least Squares Means Grouped by Container[v]	
Container	Substrate		
	PB	16.8	0.54
Black	PB:C (9:1)	17.4	0.75
	PB:C (7:3)	18.1	0.76
	PB	4.6	0.00
White	PB:C (9:1)	4.0	0.00
	PB:C (7:3)	1.1	0.00

[z]3 gal (11.3 L) solid wall containers (Nursery Supplies Inc., Kissimmee, FL).
[y]Pine bark alone (PB) or combined (v:v) with compost (C), PB:C (9:1) and PB:C (7:3).
[x]*P* values.
[w]When the interaction term in the model is not significant ($p > 0.10$), main effects means for treatments within each treatment factor (container or substrate) followed by the same letter are not significantly different using the Tukey method ($\alpha = 0.05$).
[v]When the interaction term in the model is significant ($p \leq 0.10$), simple effects means for each substrate within a container color followed by the same letter are not significantly different using the Tukey method ($\alpha = 0.05$); Otherwise, treatment means presented without letter groupings for informational purposes.

Greenhouse Gas Emissions as Impacted by High Wood Fiber Substrate in the Production of Three Annual Crops

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Index Words alternative substrate, WholeTree, carbon sequestration, global warming, climate change

Significance to Industry Implementation of best management practices across the nursery and greenhouse industry differ based on varying availability of infrastructure, finances, natural resources (water, land, etc), and labor. Growers continually evaluate their available options with respect to both fertilizer and water application rates and methods, as well as weed, disease and insect control, and make decisions for their operations based on previously mentioned resources. While climate change may not be an influencer in the decision-making process at this time, the potential exists for incentives aimed at reducing greenhouse gas emissions in the production of ornamental plants. Current programs have already begun to emerge across the agronomic industry (2, 6, 9, 10). Offset incentive projects currently in place generally indicate four standards that must be met in order to qualify for payments: 1) Projects, or offset initiatives, must be additional, or occur from activities that would not have occurred in the absence of the incentive, 2) Initiatives must be quantifiable, 3) Initiatives must be permanent, and 4) Initiatives are subject to verification by a third-party inspection (9). The objective of this work aims to assist nursery and greenhouse producers in finding actionable practices to decrease greenhouse gas emissions with minimal changes to their best management practices, and to provide quantifiable evidence of those reductions.

Nature of Work This experiment was conducted on the campus of Auburn University at the Paterson Greenhouse Complex. Wholetree (WT) substrate amendment was obtained from Young's Plant Farm in Auburn, AL on 15 June 2018. Freshly cut pine (8-10 in caliper) had been previous obtained from a pine plantation in Macon County, AL, and processed through a Woodsman Model 334 Biomass Chipper (Woodsman, LLC Farwell, MI). Chips were further processed through a 0.375 in screen in a hammermill (Meteor Mill #40, Williams Patent Crusher and Pulverizer Co., Inc St. Louis, MO). Material was stored in polypropylene bulk bags (2.33 yd^3) in full sun. All substrate treatments were mixed on 18 June 2018. Treatments included an 80:20 fine

professional sphagnum peatmoss:coarse horticultural perlite (P:P) blend, an 80:20 peatmoss:Wholetree (P:WT) blend, and a 60:40 P:WT blend. All substrates were amended by incorporation, prior to planting, with 2.0 lb•yd^{-3} of a 8-5-12 starter nutrient charge (GreenCare Fertilizers, Kankakee, IL), 5.0 lb•yd^{-3} dolomitic limestone, and 1.2 lb•yd^{-3} Aqua-Gro G (The Scotts Co., Marysville, OH). On the same day, 1.41 qt pots (06.00 AZ TW; Dillen Products, Middlefield, OH), were filled with substrates, and potted with one of three annual species. Pots were planted with one rooted cutting of 'Redhead' coleus (*Solenostemon scutellarioides* Thonn. 'Redhead') or two rooted plugs (200-cell flats) of either 'Cooler Grape' vinca (*Catharanthus roseus* L. 'Cooler Grape') or 'Super Elfin XP White' impatiens (*Impatiens walleriana* Hook. f. 'Super Elfin XP White'). All containers were placed on one bench inside a twin-walled polycarbonate-covered greenhouse. Plants were hand irrigated and fertigated as needed with municipal water and a 150 ppm N 20-10-20 fertilizer (GreenCare Fertilizers, Kankakee, IL).

Data collected included trace greenhouse gases (GHG) (CO_2, N_2O, and CH_4) emitted from plant-pot systems, sampled twice weekly (*in situ*) for 52 days (18 June 2018 to 9 August 2018). Custom-made gas efflux chambers, based on standards established in GRACEnet protocols, were used to collect trace gases using the static closed chamber method (1, 3, 4, 7). Structural bases constructed from polyvinyl chloride (PVC) cylinders with an inside diameter of 25.4 cm (10.0 in) and a height of 38.4 cm (15.1 in) were sealed at the bottom and covered with reflective tape. Tops with matching inside diameters, a height of 11.4 cm (4.5 in), and a center sampling port, were also covered with reflective tape, and fitted with a wide [10.4 cm (4.1 in)] rubber band to seal the top and bottom together during sampling. During gas measurements, the entire plant-pot system was placed inside the base cylinder, and gas samples were taken at 0, 20, and 40 min intervals following chamber closure. Samples were analyzed using gas chromatography (Shimadzu GC-2014, Columbia, MD). Concentrations of each GHG were determined by comparison with standard curves developed using gas standards obtained from Air Liquide America Specialty Gases LLC (Plumsteadville, PA), and ambient air samples. Using the rate of change in concentrations over the forty minute period that the chambers were closed, gas effluxes were calculated (8). Calculations in this study were used to express data as mg gas emitted cumulatively per pot.

A final determination of plant size as a factor of species and media effect were estimated at study termination shoot and root dry weight. Shoot dry weights (SDW) (g) were determined by cutting and subsequently drying the above-substrate portion of the plant in a 170.0°F forced air oven for 72 hours. Root dry weights (RDW) (g) were determined by removing the substrate from root interface using water applied at high pressure, and drying the within-substrate portion of the plant in a 170.0°F forced air oven for 144 hours.

The experiment was conducted as a 3 × 3 factorial design (3 species × 3 medias) with four blocks. Plants were arranged in a completely randomized block design on one greenhouse bench. Data analyses were conducted using the Mixed Models Procedure (Proc Mixed) of the Statistical Analysis System (5). Error terms appropriate to the

factorial design were used to test the significance of main effects and their interactions. A significance level of ($P \leq 0.05$) was established *a priori*.

Results and Discussion Changes in cumulative CO_2 efflux was observed as an effect of both species and media (Table 1). With respect to plant species, coleus was observed to have the highest cumulative CO_2 loss (1641.1 mg/pot), although results were not significantly different than those observed for vinca (1537.5 mg/pot). Impatiens had the least amount of cumulative CO_2 efflux over the course of the study (1470.5 mg/pot), but was only significantly less than coleus (statistically similar to vinca). These differences can be linked to differences in plant size. At study termination, shoot, root and total dry weight was highest for coleus (total dry weight = 17.58 g), while dry weights for both vinca and impatiens were statistically similar, both were much smaller than coleus in general (vinca total dry weight = 9.00 g; impatiens total dry weight = 8.07 g). The primary differences in CO_2 efflux as an effect of differences in media are found between the 80:20 peat:perlite treatment (1483.1 mg/pot) and the 60:40 peat:Wholetree treatment (1615.6 mg/pot) (Table 1). Replacing the 20% portion of perlite in the first treatment with an equal portion of Wholetree had little to no effect on CO_2 efflux (80:20 peat:Wholetree = 1550.5 mg/pot). For container producers aiming to replace perlite with a locally available, high wood fiber substrate, these results are promising. CO_2 efflux as effected by the interaction of species and media were observed for impatiens only (Table 1). While significantly smaller, impatiens grown in a 60:40 peat:Wholetree blend [6.99 g total dry weight (Table 2); 1612.4 mg/pot CO_2 (Table 1)] had greater CO_2 efflux over the duration of the study than those grown in a 80:20 peat:perlite blend [9.11 g total dry weight (Table 2); 1327.4 mg/pot CO_2 (Table 1)]. These results indicate that further research may be required to confirm higher CO_2 efflux associated with higher percentages of wood fiber alternative or amendments to container substrates. Cumulative efflux for N_2O emissions was unaffected by changes in species, media, or the interaction of the two (Table 1). As with previous studies, cumulative Ch_4 efflux was also minimal and unaffected by differences in plant species or media (Table 1).

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Table 1. Total cumulative CO_2, N_2O, and CH_4 efflux[z] over 52 days from three annual species[y] grown in one of three substrate blends.

Main Effects		Cumulative Efflux		
Species Effect		CO_2-C (mg/pot)	N_2O-N (mg/pot)	CH_4 (mg/pot)
Coleus		1641.1 a[w]	0.1305[ns]	-0.1753[ns]
Vinca		1537.5 ab	0.1401	-0.0017
Impatiens		1470.5 b	0.1307	-0.3084
	p:	*0.019*	*0.840*	*0.188*
Media Effect				
80:20 Peat:perlite		1483.1 b	0.1284[ns]	-0.0365[ns]
80:20 Peat:Wholetree		1550.5 ab	0.1320	0.2364
60:40 Peat:Wholetree		1615.6 a	0.1409	-0.0686
	p:	*0.082*	*0.788*	*0.446*

Interaction Effects			Cumulative Efflux		
Species		Fertilizer Placement	CO_2-C (mg/pot)	N_2O-N (mg/pot)	CH_4 (mg/pot)
Coleus	-	80:20 Peat:perlite	1585.4[ns]	0.1151[ns]	-0.3404[ns]
Coleus	-	80:20 Peat:Wholetree	1634.7	0.1396	-0.0176
Coleus	-	60:40 Peat:Wholetree	1703.1	0.1367	-0.1680
Vinca	-	80:20 Peat:perlite	1536.4[ns]	0.1429[ns]	-0.0296[ns]
Vinca	-	80:20 Peat:Wholetree	1545.0	0.1223	0.2196
Vinca	-	60:40 Peat:Wholetree	1531.1	0.1552	-0.1951
Impatiens	-	80:20 Peat:perlite	1327.4 b	0.1271[ns]	0.2607[ns]
Impatiens	-	80:20 Peat:Wholetree	1471.8 ab	0.1342	0.5072
Impatiens	-	60:40 Peat:Wholetree	1612.4 a	0.1309	0.1572
		p:	*0.368*	*0.854*	*0.986*

[z] Cumulative efflux for 52 days (18 June 2018 to 9 August 2018) was calculated using the trapezoid rule (n=4).

[y] 'Redhead' coleus (*Solenostemon scutellarioides* 'Redhead'), 'Cooler Grape' vinca (*Catharanthus roseus* 'Cooler Grape') and 'Super Elfin White' impatiens (Impatiens walleriana 'Super Elfin XP White') were potted into 1.41 qt containers filled with one of three substrates (80:20 peat:perlite, 80:20 peat:Wholetree, or 60:40 peat:Wholetree), and amended with 2.0 lb/yd^3 8-5-12 starter nutrient charge, 1.2 lb/yd^3 Aqua-Gro G wetting agent, and 5.0 lb/yd^3 dolomotic limestone.

[w] Within a column, means followed by the same letter are not significantly different ($p \leq 0.05$) according to the LSMeans statement under the Proc Mixed Procedure of SAS. For interaction effects, letters designate differences within species only.

[ns] Not significantly different.

Table 2. Dry weights[z,y] following 52 days of growth for three annual species[x] grown in one of three substrate blends.

Main Effects Species Effect		Shoot Dry Weight (g)	Root Dry Weight (g)	Total Dry Weight (g)[w]
Coleus		14.83 a[v]	2.75 a	17.58 a
Vinca		8.02 b	0.98 b	9.00 b
Impatiens		7.08 b	1.00 b	8.07 b
	p:	*<0.001*	*<0.001*	*<0.001*
Media Effect				
80:20 Peat:perlite		11.53 a	1.74[ns]	13.27 a
80:20 Peat:Wholetree		10.04 b	1.53	11.56 b
60:40 Peat:Wholetree		8.36 c	1.46	9.82 c
	p:	*<0.001*	*0.070*	*<0.001*

Interaction Effects Species		Fertilizer Placement	Shoot Dry Weight (g)	Root Dry Weight (g)	Total Dry Weight (g)
Coleus	-	80:20 Peat:perlite	16.80 a	3.16 a	19.96 a
Coleus	-	80:20 Peat:Wholetree	14.41 b	2.60 b	17.01 b
Coleus	-	60:40 Peat:Wholetree	13.26 b	2.50 b	15.77 b
Vinca	-	80:20 Peat:perlite	9.68 a	1.06[ns]	10.74 a
Vinca	-	80:20 Peat:Wholetree	8.55 a	1.02	9.56 a
Vinca	-	60:40 Peat:Wholetree	5.82 b	0.88	6.70 b
Impatiens	-	80:20 Peat:perlite	8.09 a	1.02[ns]	9.11 a
Impatiens	-	80:20 Peat:Wholetree	7.15 ab	0.97	8.12 ab
Impatiens	-	60:40 Peat:Wholetree	5.99 b	1.00	6.99 b
		p:	*0.431*	*0.214*	*0.269*

[z] Shoot dry weights (g) determined by drying the above-substrate portion of the plant in a 170.0°F forced air oven for 72 hours.

[y] Root dry weights (g) were determined by removing the substrate from root interface, and drying the within-substrate portion of the plant in a 170.0°F forced air oven for 144 hours.

[x] 'Redhead' coleus (*Solenostemon scutellarioides* 'Redhead'), 'Cooler Grape' vinca (*Catharanthus roseus* Cooler Grape'), and 'Super Elfin White' impatiens (Impatiens walleriana 'Super Elfin XP White') were potted into 1.41 qt containers filled with one of three substrates (80:20 peat:perlite, 80:20 peat:Wholetree, or 60:40 peat:Wholetree), and amended with 2.0 lb/yd^3 8-5-12 starter nutrient charge, 1.2 lb/yd^3 Aqua-Gro G wetting agent, and 5.0 lb/yd^3 dolomitic limestone.

[w] Total dry weight = Shoot dry weight + root dry weight.

[v] Within a column, means followed by the same letter are not significantly different (p≤0.05) according to the LSMeans statement under the Proc Mixed Procedure of SAS. For interaction effects, letters designate differences within species only.

[ns] Not significantly different.

Response of *Spiraea* and *Buddleia* to Controlled-release Fertilizer With or Without Phosphorus

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Index Words Perennial plant production

Significance to Industry *Spiraea* and *Buddleia* were grown at Saunders Brothers Nursery in Piney River, Virginia with 100% pine bark substrate in trade 3-gallon containers. Plant growth data from the evaluation indicated that fertilizers surface-applied with longevities of 3–4 months and applied at lower application rates compared to the nursery's standard woody plant fertilization practice with fertilizer longevity of 8–9 months, resulted in similar or more growth after 13 weeks. Application of fertilizer without phosphorus and with 3–4 months longevity was detrimental for growth of *Spiraea* and *Buddleia*.

Nature of Work Perennial plants usually have a shorter production time than many woody plants so fertilizer application rates and longevities should be different for the two crops. In addition, previous research indicated that indigenous and applied phosphorus leached readily from pine bark substrates (2). Hence perennial plants with a relatively short production time may be able to obtain some or sufficient phosphorus from the pine bark. The purpose of this research was to evaluate *Spiraea* and *Buddleia* growth response to fertilizers with and without phosphorus and 3–4 months for nutrient release compared to the nursery's standard fertilizer practice of using an 8–9 months nutrient release fertilizer that contained phosphorus.

Spiraea japonica 'Neon Flash' (36-plant tray) and *Buddleia davidii* Lo & Behold® 'Pink Micro Chip' liners (2.25 inches container) were planted June 15, 2017 (Week 24) in 100% pine bark substrate in trade 3-gallon containers (≈ 700 cubic inches) at Saunders Brothers Nursery in Piney River, Virginia. The substrate was amended with 0.8 lb·yard^{-3} Micromax® (ICL Fertilizers, Dublin, OH 43017) and 8 lbs·yard^{-3} dolomitic limestone. Approximately 950 *Spiraea* plants and 350 *Buddleia* plants were planted and placed container-to-container in triangular arrangement on polypropylene ground cloth under sprinkler irrigation (≈ 0.3 inch·day^{-1}). Within each species group, four blocks each of 48 plants were selected. Each block was composed of a completely randomized arrangement of four fertilizer treatments with 12 replicate plants per treatment. The four fertilizer treatments that were surface-applied to *Spiraea* on June 19 and to *Buddleia* on June 21 (Week 25) are given in Table 1. All border plants were surface-fertilized with Osmocote® Plus at ≈ 80 g per container, which is the application rate for the Osmocote® Plus used by the nursery.

Plant size was initially determined for five plants per treatment for each block. Plant height was measured from the substrate surface to top of plant canopy and plant canopy width determined at the widest point. A second width measurement was made perpendicular to the first measurement. Size data for *Spiraea* were taken on June 27 (Week 26), July 18 (Week 29), August 1 (Week 31), and September 20 (Week 38), and data for *Buddleia* were taken on June 26 (Week 26), July 18 (Week 29), and September 21 (Week 38). A growth index was calculated as height plus average width and change in growth index was calculated by subtracting initial growth index for each plant from final growth index at Week 38. Growth index change differences were determined using Fisher's LSD.

Pour-through (PT) leachate extracts were collected from one container per treatment for each block. Leachates were collected in the morning after drainage from the previous irrigation. Approximately 350 ml of distilled water were poured on the surface of containers for *Spiraea* and 500 ml of well water were used for *Buddleia*. Well water electrical conductivity (EC), pH, and total phosphorus (TP) were 0.1 mmhos/cm, 6.0, and 0.05 mg/L, respectively. PT leachate extracts were collected on June 21 (Week 25), June 28 (Week 26), July 20 (Week 29), July 31 (Week 31), and September 18 (Week 38) for *Spiraea*, and on June 29 (Week 26), August 1 (Week 31), and September 19 (Week 38) for *Buddleia*. The EC and pH of leachates for *Spiraea* and EC for *Buddleia* were determined in the field. Leachate samples for *Spiraea* were filtered and sent to the Analytical Research Laboratory at University of Florida for nitrate nitrogen (NO_3-N), total phosphorus (TP), and potassium (K) analyses using standard procedures (https//arl.ifas.ufl.edu).

Spiraea plants were spaced during Week 32 and *Buddleia* plants were spaced during Week 35. The distances between containers after spacing were 5–6 inches within the row and 6–7.5 inches between the rows of containers. Spacing was necessary to achieve optimal growth and quality for market. Marketable plants have heights and widths of 10 and 12 inches and 8 and 12 inches, respectively, for the cultivars of *Spiraea* and *Buddleia* studied (personal communication, Tom Saunders).

Results and Discussion The change in growth index was highest for *Spiraea* when F1 and F2 were applied, and no difference was observed between these fertilizers; whereas, F3 and F4 resulted in less growth (Table 2). For *Buddleia*, F1, F2, and F4 were similar (Table 3). The change in growth index for F4 was suppressed compared to F1 and F2 for *Buddleia*. Lower growth index change for F3 of both species indicates that insufficient phosphorus was available, likely due to the lack of phosphorus in the fertilizer. However, for two of the five sample dates for *Spiraea*, the TP in PT leachate for F3 was higher than 5–10 mg/L (Figure 1), the optimal PT leachate phosphorus (1). The extractable TP likely came from the pine bark because the irrigation water TP concentration was 0.09 mg/L. Yeager and Wright (2) have previously documented water soluble phosphorus in pine bark. The PT leachate pH ranged from 4.3 to 6.6 for *Spiraea*.

The reduction in growth index change for F4 compared with F1 and F2 for *Spiraea* and the suppressed growth index change for *Buddleia* that received F4 are likely due to excessive salts in the substrate. PT data for EC (Figures 2 and 3) indicate that ECs were highest at Weeks 25, 26, and 38 for F4, although not excessive, when compared to other fertilizers. Nitrate nitrogen (Figure 4) and K (Figure 5) concentrations for F4 were also highest for the same three weeks and likely contributors to the EC.
During the 13-week evaluation, *Buddleia* that received fertilizer with 3–4 months longevity achieved marketable size with average height and width of 9 and 12 inches, respectively, while *Spiraea* was approximately 91% of marketable size with average height and width of 9 and 11 inches, respectively. The growth needed to achieve marketable size probably could have been obtained by planting a few weeks earlier. Despite the fact that *Spiraea* was slightly smaller than marketable size, these data indicate that fertilizers with 3-4 months longevity are a viable option for the nursery when growing *Spiraea japonica* 'Neon Flash' and *Buddleia davidii* Lo & Behold® 'Pink Micro Chip'.

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Acknowledgement

The authors thank Harrell's Inc., Lakeland, FL for supplying fertilizers. The authors appreciate the assistance of Saunders Brothers Nursery personnel.

Disclaimer

Trade names, companies, and products are mentioned for informational purposes only.

Table 1. Fertilizers surface-applied at Week 25 of 2017 to *Spiraea japonica* 'Neon Flash' and *Buddleia davidii* Lo & Behold® 'Pink Micro Chip' grown in100% pine bark substrate.

Treatment[z]	Grade (N-P-K)	Brand	Longevity (mo)	Amount/trade 3-gal container (g)
F1	13-5.7-10.8	Harrell's	3–4	46
F2	17-2.6-10	Harrell's	3–4	36
F3	43-0-0 +	Harrell's	3–4	14
	0-0-16.6	Harrell's	3–4	30
F4	15-3.9-10	Osmocote® Plus	8–9	80

[z]F1=13-13-13, F2=17-6-12, F3=43-0-0+0-0-20, F4=15-9-12
Harrell's is a product of Harrell's Inc., Lakeland, FL 33802
Osmocote® Plus is a product of ICL Fertilizers, Dublin, OH 43017

Table 2. Plant height (H) and average width (W) for *Spiraea japonica* 'Neon Flash' fertilized week 25 and grown for 13 weeks with 100% pine bark substrate in trade 3-gallon containers.

Treatment	Week 26		Week 29		Week 31		Week 38		Growth[z] index change
	H (in)	W (in)	H (in)	W (in)	H (in)	W (in)	H (in)	W (in)	
F1	4.5	3.8	6.4	6.4	7.5	8.3	8.9	11.3	12.1 a
F2	4.7	4.3	6.9	6.9	8.1	8.6	8.8	11.6	11.3 a
F3	5.1	4.5	6.6	6.4	7.5	7.6	7.5	10.2	8.2 b
F4	4.7	4.2	5.9	6.3	6.8	7.8	7.8	10.1	8.9 b

[z]Growth index was calculated as height plus average width. Means separated within column by Fisher's LSD at 5% level. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12

Table 3. Plant height (H) and average width (W) for *Buddleia davidii* Lo & Behold® 'Pink Micro Chip' fertilized week 25 and grown for 13 weeks with100% pine bark substrate in trade 3-gallon containers.

Treatment	Week 26		Week 29		Week 38		Growth[z] index change
	H (in)	W (in)	H (in)	W (in)	H (in)	W (in)	
F1	3.7	3.6	4.9	5.5	8.8	12.8	14.5 a
F2	3.8	3.7	5.3	6.2	8.9	12.5	14.0 a
F3	3.7	3.6	4.2	4.4	7.6	10.8	11.3 b
F4	3.8	3.6	5.3	6.6	8.1	12.6	13.3 a

[z]Growth index was calculated as height plus average width. Means separated within column by Fisher's LSD at 5% level. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12

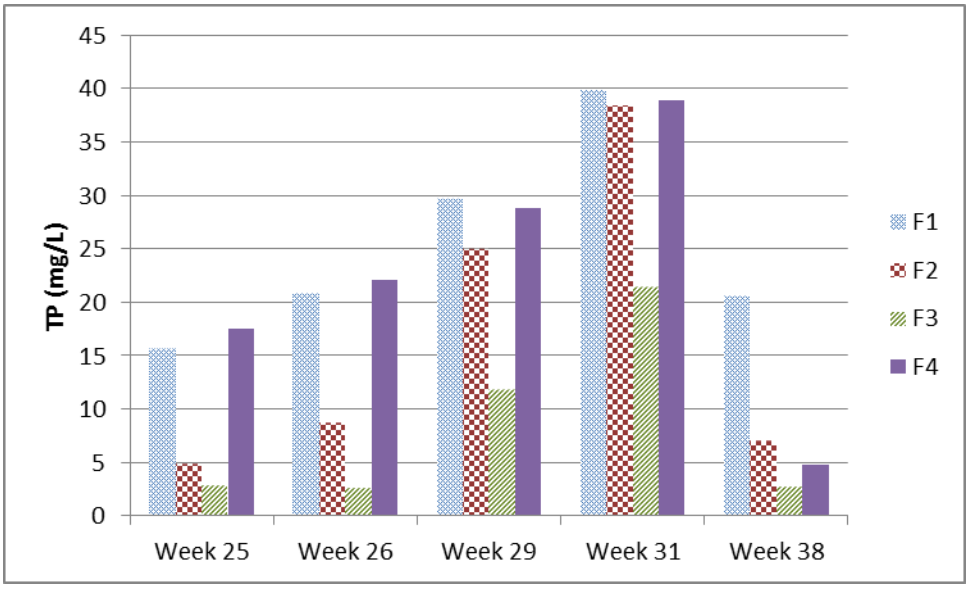

Figure 1. Pour-through extracts total phosphorus (TP) concentrations for *Spiraea japonica* 'Neon Flash' grown for 13 weeks with 100% pine bark substrate in trade 3-gallon containers. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12.

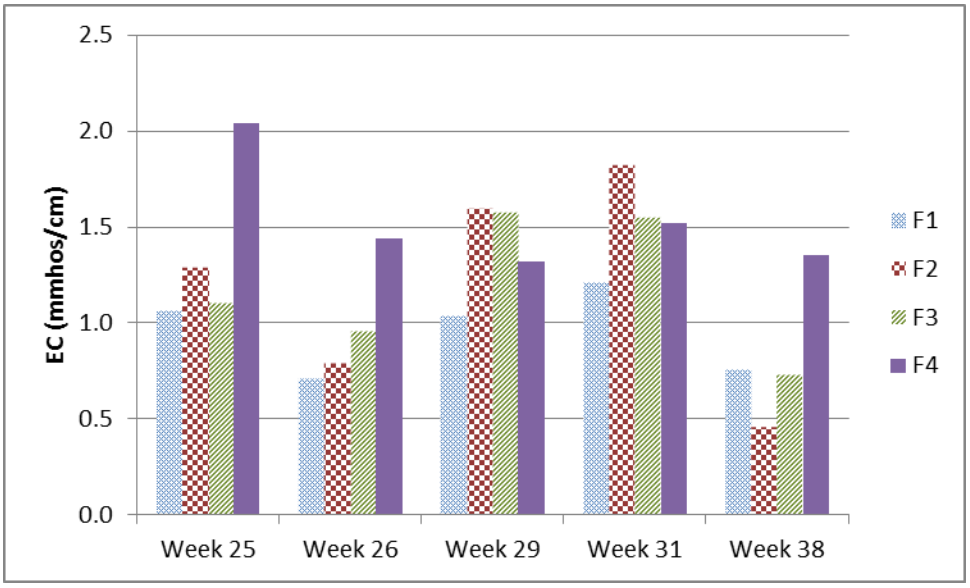

Figure 2. Pour-through extracts electrical conductivity (EC) for *Spiraea japonica* 'Neon Flash' grown for 13 weeks with 100% pine bark substrate in trade 3-gallon containers. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12.

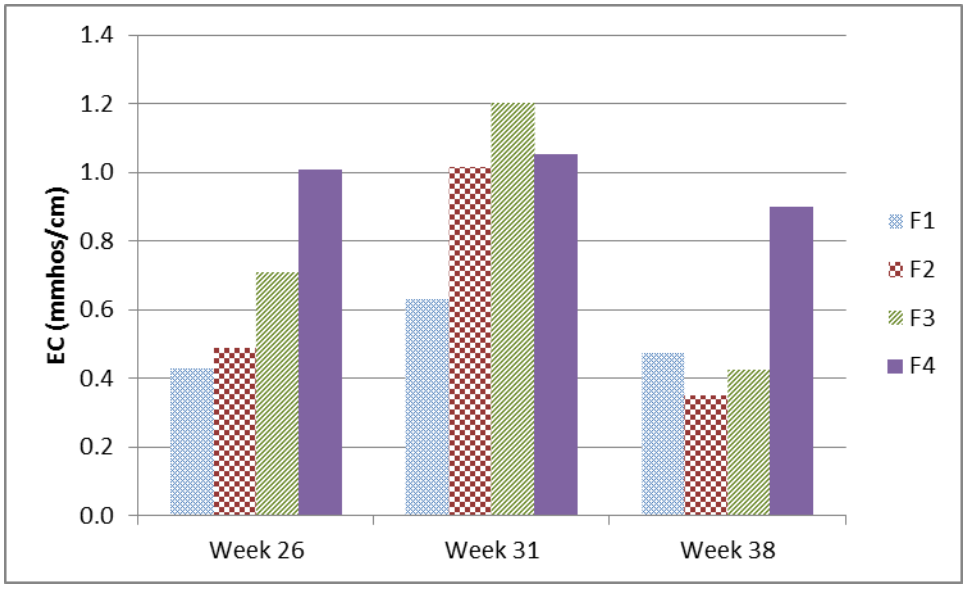

Figure 3. Pour-through extracts electrical conductivity (EC) for *Buddleia* davidii Lo & Behold® 'Pink Micro Chip' grown for 13 weeks with 100% pine bark substrate in trade 3-gallon containers. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12.

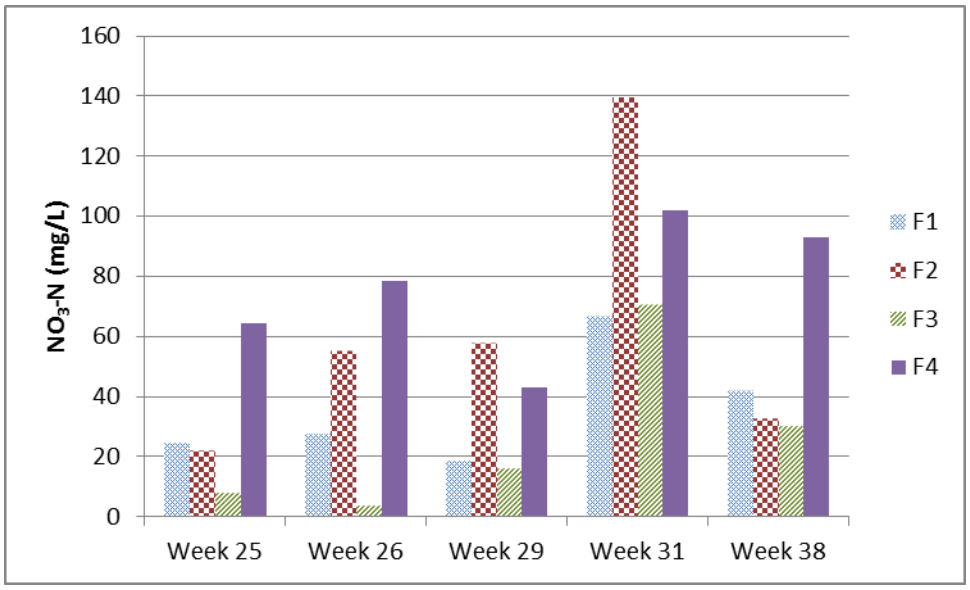

Figure 4. Pour-through extracts nitrate nitrogen (NO_3-N) concentrations for *Spiraea japonica* 'Neon Flash' grown for 13 weeks with 100% pine bark substrate in trade 3-gallon containers. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12.

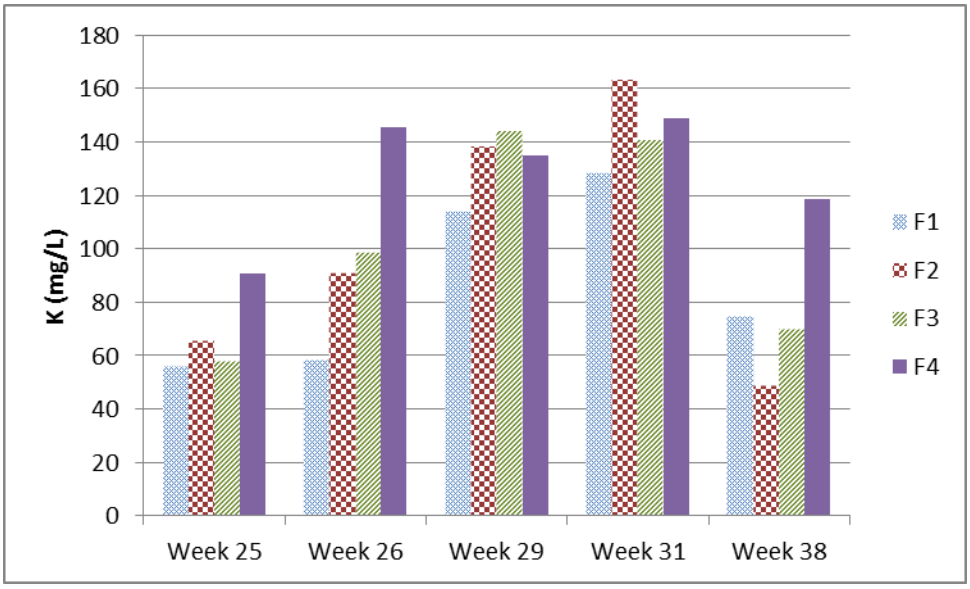

Figure 5. Pour-through extracts potassium (K) concentrations for *Spiraea japonica* 'Neon Flash' grown for 13 weeks with 100% pine bark substrate in trade 3-gallon containers. F1=Harrell's 13-13-13, F2=Harrell's 17-6-12, F3=Harrell's 43-0-0+0-0-20, F4=Osmocote® Plus 15-9-12.

Root Colonization with Arbuscular Mycorrhizal Fungi and Supplementary P Improves Nutrient Status, Growth and Physiological Performance of the Flamingo Flower (*Anthurium pedato-radiatum* Schott. ssp. *pedato-radiatum*: Araceae)

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Index Words: *Anthurium*, mycorrhizae, vesicular arbuscular mycorrhizas, plant nutrition.

Significance to Industry The nursery industry stands to gain advantage from both selected and naturally occurring soil microorganisms such as beneficial bacteria and fungi. Mycorrhizal fungi symbionts enhance plant health, growth and production when properly interacting with roots. Scientists, propagators, and growers have special interest in studying mycorrhizas because they can be commercially used in sustainable agricultural systems including greenhouse, nursery and field production conditions. In this research, we studied the impact of P fertilization and mycorrhiza functioning on several aspects of plant performance after a micropropagation step. We demonstrated that inoculated *Anthurium pedato-radiatum* Schott. ssp. *pedato-radiatum* plantlets were colonized with a fungi consortium. In general, overall plant growth and physiology performance and nutrient status was significantly increased by mycorrhizas and the level of P received by the plant during fertilization when compared to the control. These results suggest that there is great potential in using selected mycorrhizal isolates for improving growth of shade tolerant and slow-growing plant species after micropropagation and during field establishment. This information has application to other ornamental plant species cultivated under commercial nursery production systems.

Nature of Work In the American ornamental horticulture industry, the Areceae is the most important economic family, with several genus under commercial expanded cultivation such as *Aglaonema, Alocasia, Anthurium, Caladium, Calla, Colocasia, Dieffenbachia, Epipremnum, Philodendron, Spathyphyllum, Syngonium, Monstera*,

among others (1, 2, 3). The genus *Anthurium* includes the most outstanding plants in the industry with *A. andreanum* the most cultivated species and consequently with the greatest economic importance worldwide (2, 3). Other species such as *A. scherzerianum*, *A. andicola, A. podophyllum, A. nizandese* and *A. pedato-radiatum* Schott ssp*. pedato-radiatum* are good candidates as foliage plants for indoors and outdoors. The last one is an endemic Mexican wild species, which is a perennial and herbaceous plant with beautiful and striking leaf morphology (4) that represents a great potential to be commercially exploited as potted plant.

Ubiquitous mycorrhizal fungi establish mutualistic and beneficial associations with many plant species including angiosperms and gymnosperms (5). According to several reports, *Anthurium andraeanum* roots form mycorrhizas with *Acaulospora* (*A. longula*), several species of *Glomus* (*G. intraradices, G. etunicatum*), and *Gigaspora* (*G. albida*) (6, 7, 8, 9). As a result, the mycorrhizal colonization promotes better growth and enhances nutrient uptake and is potentially significant in the ecology of wild and selected ornamental anthuriums. Although some studies have been published to evaluate the effects of mycorrhizas in *A. andraeanum* (6, 7, 8, 9), there is only limited information on the majority of more than 700 species that comprises this genus.

We ran a factorial experiment to study the effects of the colonization with vesicular arbuscular mycorrhizal fungi (VAM: +VAM, -VAM) and four P fertilization regimes (0, 22, 44 and 66 ppm) on physiological performance, growth, and nutrient concentration and uptake of *Anthurium pedato-radiatum* Schott. ssp. *pedato-radiatum* young micropropagated plantlets. The experimental VAM inoculum was a Mexican consortium named Selva composed by 3 *Glomus* species: *G. constrictum*, *G. fasciculatum*, *G. tortuosum*, and *Acaulospora scrobiculata*. During transplantation, the fungi inoculum, which corresponded to approximately 1,000 fungal spores, was applied by banding just below the root system. Fertilization was provided with the Long Ashton nutrient solution modified according the experimental treatments. After sixteen months of culture under greenhouse conditions in which about 100 µmol/m^2/s^{-1} of light intensity were imposed, several growth measurements including leaf number, plant height (cm), dry mass (DM) (g), root number, and root length (cm), were determined in all treatments. Root:shoot and shoot:root ratio were calculated with the root and shoot DM data. Gas exchange (λ, gs, E, WUE) and plant photosynthetic performance (Fv/Fm ratio and PI) were also evaluated. Additionally, we tested the aerial part of the plants for nutrient status of all macronutrients plus Fe, Mn, Cu, Na, Zn. Root colonization by VAM was also determined.

Results and Discussion Our data showed that after sixteen months of greenhouse culture the roots of control plants remained free of VAM colonization while inoculated plants showed typical structures of fungi development. Under microscope evaluation, we observed internal hyphae, spores, vesicles, and arbuscules in cortical cells. Data on root colonization varied fron 25 to 65% according the experimental treatments tested. *Anthurium pedato-radiatum* Schott. ssp. *pedato-radiatum* plants seem to be highly dependent of mycorrhizas because the colonization by the fungi under limited

supplementation of P significantly increased overall plant growth, physiological performance and nutrient status when compared to the control treatment (Tables 1, 2, 3). Significant effects of P level were recorded as the rate of fertilization was increased from 22, 44 and 66 ppm in –VAM plants. Similar effects were observed in inoculated plants in medium P-levels (22 and 44 ppm P). In contrast to this, 66 ppm P seemed to be excessive and negative for the fungi-plant interaction functioning (Tables 1, 2, 3). Most variables evaluated to characterize growth resulted significant to the presence of VAM including plant height, leaf number, leaf, root and plant dry weight, however, those ones that did not (leaf area, root number and length and the ratios of root to shoot and shoot to root) showed a similar tendency since considerable differences were observed when compared the +VAM plants and the control under P stress. In addition to this, supplementary P had more impact in all variables tested.

Similar to what we observed in plant growth, the interaction with VAM and the different P levels positively affected the physiological performance of the plants (Table 3). The P stressed plants were photosynthetically more active and had better functioning than the control but again the supplementary P also had greater impact in all results (Table 3). Foliar tissue elemental content varied considerably according the experimental treatments. Mycorrhizal associations had increased concentrations of P, Ca, and S but had lower contents of Fe, Zn and Mn than -VAM plants under P conditions. However, the nutrient status of the plants was significantly improved with increases of P supply.

Acknowledgements: Authors want to thank CINVESTAV-IPN for the support provided through the use of greenhouse facilities.

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Table 1. Effect of VAM and P fertilization regime on plant growth (phenotype) of *A. pedato-radiatum* Schott ssp*. pedato-radiatum* after 16 months of inoculation.

Fungi	P Level (ppm)	Plant Height (cm)	Leaf Number	Leaf Area (cm^2)	Root Number	Root Length (cm)
-VAM °	0	11.18	4.00	48.283	6.33	9.16
-VAM	22	30.77	17.14	657.994	17.50	17.51
-VAM	44	25.09	14.38	775.900	16.50	16.15
-VAM	66	29.10	11.63	593.397	17.33	14.30
+VAM •	0	13.77	13.00	145.422	10.00	11.84
+VAM	22	23.95	19.75	460.979	15.17	17.63
+VAM	44	26.25	18.00	620.958	14.83	15.83
+VAM	66	20.46	15.25	405.160	9.67	14.58
Significance:						
VAM		*	**	NS	NS	NS
P level		***	**	***	***	**
VAM X P Level		**	NS$^{\oplus}$	NS	NS	NS

°-VAM: (Control Non Inoculated), •+VAM: Vesicular Arbuscular Mycorrhizal Fungi, $^{\oplus}$NS= Non significant, *= Significant (0.05), **= Significant (0.01), ***= Significant (0.001). n=8.

Table 2. Effect of VAM and P fertilization regime on plant growth (dry mass accumulation) of *A. pedato-radiatum* Schott ssp*. pedato-radiatum* after 16 months of inoculation.

Fungi	P Level (ppm)	Leaf Dry Weight (g)	Root Dry Weight (g)	Plant Dry Weight (g)	Root to Shoot Ratio	Shoot to Root Ratio
-VAM °	0	0.3	0.4	0.7	1.4	1.0
-VAM	22	6.7	2.7	9.4	0.4	2.5
-VAM	44	6.4	3.1	9.5	0.5	2.1
-VAM	66	4.8	2.5	7.3	0.5	2.1
+VAM •	0	1.0	0.6	1.6	0.7	1.6
+VAM	22	4.2	2.2	6.4	0.5	2.0
+VAM	44	5.4	2.5	7.8	0.5	2.2
+VAM	66	2.3	1.3	3.6	0.7	1.7
Significance:						
VAM		**	*	**	NS	NS
P level		***	***	***	***	***
VAM X P Level		*	NS$^{\oplus}$	NS	**	NS

°-VAM: (Control Non Inoculated), •+VAM: Vesicular Arbuscular Mycorrhizal Fungi, $^{\oplus}$NS= Non significant, *= Significant (0.05), **= Significant (0.01), ***= Significant (0.001). n=6.

Table 3. Effect of VAM and P fertilization regime on photosynthesis and gas exchange capacity of *A. pedato-radiatum* Schott ssp*. pedato-radiatum* plants after 16 months of inoculation.

Fungi	**P Level (ppm)**	**Fv/Fm**	**PI**	**λ (μmol/ m^{-2}/s^{-1})**	**g_s (μmol/ m^{-2}/s^{-1})**	**E (mmol/ m^{-2}/s^{-1})**	**WUE (mmol/ m^{-2}/s^{-1})**
-VAM °	0	0.80	4.27	0.31	22.67	0.82	0.47
-VAM	22	0.84	7.36	4.47	103.53	2.16	2.09
-VAM	44	0.83	7.46	5.21	121.80	2.40	2.19
-VAM	66	0.83	6.94	4.99	110.20	2.28	2.17
+VAM •	0	0.82	5.48	1.09	33.53	0.97	0.98
+VAM	22	0.83	6.94	2.90	55.07	1.43	2.10
+VAM	44	0.83	6.27	5.83	154.53	2.47	2.39
+VAM	66	0.83	4.97	2.88	73.33	1.63	1.78
Significance:							
VAM		NS$^{\oplus}$	NS	NS	NS	NS	NS
P level		***	***	***	***	***	***
VAM X P Level		*	*	**	NS	NS	NS

°-VAM: (Control Non Inoculated), •+VAM: Vesicular Arbuscular Mycorrhizal Fungi, $^{\oplus}$NS= Non significant, *= Significant (0.05), **= Significant (0.01), ***= Significant (0.001). n=5.

Table 4. Effects of VAM and P fertilization regime on plant nutrient status of *A. pedato-radiatum* Schott ssp*. pedato-radiatum* plants after 16 months of inoculation.

Fungi	P Level (ppm)	P (%)	Ca (%)	S (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)
-VAM °	0	0.03	1.6	0.207	208.0	26.7	116.0
-VAM	22	0.42	1.1	0.122	83.3	15.2	83.2
-VAM	44	0.39	1.1	0.142	95.7	21.8	129.3
-VAM	66	0.42	1.0	0.137	91.5	19.9	125.3
+VAM •	0	0.05	1.9	0.214	101.2	24.7	93.7
+VAM	22	0.34	1.3	0.165	92.0	18.3	100.3
+VAM	44	0.33	1.3	0.155	97.8	15.3	116.5
+VAM	66	0.41	1.1	0.205	95.5	17.7	152.2
Significance:							
VAM		NS ⊕	NS	*	**	NS	NS
P level		***	**	**	***	***	*
VAM X P Level		NS	NS	NS	***	NS	NS

°-VAM: (Control Non Inoculated), •+VAM: Vesicular Arbuscular Mycorrhizal Fungi, ⊕NS= Non significant, *= Significant (0.05), **= Significant (0.01), ***= Significant (0.001). n=3.