Container Grown Plant Production

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Section Editor

Overwintering Method Affects Growth of *Sarracenia leucophylla* (white topped pitcher plant)

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Significance to Industry: Potential exists for increased use of *Sarracenia leucophylla* due to unique ornamental attributes for use in containers, cut flower arrangements, and bog gardens. Identifying methods for overwintering may decrease production times from seed and speed breeding and hybridization efforts. Results indicate that the first winter dormancy period may be skipped and seedlings can remain in the greenhouse during the first winter following sowing from seed. Results of this study could be used to improve nursery production, provide greater access to the plants for public gardens and other educational institutions, and increase public awareness of the conservation status of these plants.

Nature of Work: Little work has been done on *Sarracenia* cultivation outside of that by hobbyists and commercial growers. Successful growth strategies are largely anecdotal and are shared within the carnivorous plant community via, websites, online forums, and personal communications. Winter dormancy is a central feature of perennial plant phenology (4). Likewise, winter dormancy is essential for survival of all North American carnivorous plants (5).The dormancy period of *Sarracenia* should last at least three months for mature plants (1, 2). Production of *Sarracenia* from seed to sexual maturity has been reported to take three or more years (6), although anecdotal evidence shows that dormancy can be skipped in seedling *Sarracenia* plants to accelerate growth during the first season (3). The objective of this research is to compare the effect of overwintering method on growth of *Sarracenia leucophylla* seedlings through the winter, as well as resumption of growth during the subsequent growing season.
In the Fall of 2013, 9-mo old seedlings of *S. leucophylla* (white topped pitcher plant) were introduced into one of three overwintering treatments: outdoors in shaded cold frames, in a walk-in cooler in the dark (40 F), or in a heated greenhouse (70 F). Plants outdoors were watered by automated overhead sprinklers for 10 minutes each day and received no additional cold protection. These remained outside until March 2014. Plants in the cooler remained there until March 2014. While in the cooler, plants were not watered regularly but monitored to ensure they never dried out entirely. Plants in the greenhouse were watered by hand daily. In March 2014, prior to any visible emergence from dormancy, all seedlings were repotted into 10 cm plastic pots in a 2:1 peat:perlite (v:v) and moved into the greenhouse. Plants were watered by hand daily in the greenhouse.

Plant size was quantified by measuring height of the tallest pitcher, width of the tallest open pitcher, number of pitchers taller than 10 cm, and number of pitchers between 5.75 cm and 10 cm tall. Height was measured from the base of the crown to the highest point of the pitcher. Width was measured at the widest point at the top of the pitcher opening. These data were collected in April and June 2014 on 33 single container replications per treatment. Data were analyzed for significance of overwintering treatment and measurement date main effects and interactions using PROC GLIMMIX, and means were separated using TUKEY (SAS, Inc., Cary, NC).

Results and Discussion: The interaction between overwintering treatment and measurement date was not significant for any variable measured. Main effects of overwintering treatment and measurement date were significant for all variables measured ($P<0.0001$ for both factors). Plants overwintered in the greenhouse were largest and had the most pitchers; plants overwintered outdoors were smallest and had the fewest pitchers (Table 1). All plant size variables increased over time (Table 1). Although not quantified, visual quality of plants overwintered in the greenhouse also seemed highest. Additionally, those plants in the greenhouse were large enough and vigorous enough (multiple pitchers, visible crown) to appear marketable or ready for transplanting into the landscape indicating that plants could be outplanted or sold one year after sowing from seed. Plants in the cooler emerged from dormancy larger and with more pitchers than those overwintered outdoors. Although not quantified, plants in the cooler experienced some fungal problems, and plants outdoors experienced some crown rot. Additionally, mortality was more frequent among plants receiving chilling than those remaining in the greenhouse (date not presented). Although there appeared to be no negative effects on growth resulting from lack of chilling (greenhouse), differences may arise later in the growing season. Also, it is possible that plants should not skip more than one overwintering period, thus this practice may not be able to be extended indefinitely. Of the plants that did receive chilling, simply placing in a cooler seemed sufficient, although space may be a limitation if the crop is large. In summary, *S. leucophylla* is easy to produce from seed and thus has good commercial and educational potential. Data suggest that chilling may be skipped the first year to shorten production time.

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Table 1. Effect of overwintering treatment and measurement date on size of *Sarracenia leucophylla* (n=33).

Overwintering Treatment	Height (cm) [z]	Width (cm)	No. >10 cm	No. 5.75–10 cm
Greenhouse	17.7a[z]	1.7a	4.6a	6.2a
Cooler	10.5b	0.7b	1.5b	2.9b
Outside	8.3c	0.6b	0.6c	1.6c
Measurement Date				
April	9.8b	0.7b	1.0b	2.4b
June	14.5a	1.3a	3.4a	4.7a

[z]Data collected include height and width of tallest pitcher, number of pitchers taller than 10 cm, and number of pitchers between 5.75 cm and 10 cm tall.
[y]Letters indicate significant differences among overwintering treatment or between measurement date.

Irrigation Timing and Volume Affects Growth of Container Grown Maples

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Index Words: nursery production, container production, irrigation leachate, irrigation management, cyclic irrigation, *Acer rubrum* 'Sun Valley'

Significance to Industry: These results can assist producers in developing irrigation management strategies that minimize nutrient effluent as well as produce a quality container grown tree. Overall, plants had more height and trunk growth when irrigated mostly in the afternoon compared to early morning irrigation. Reducing the volume of irrigation with a tri-cyclic irrigation regime did not affect height growth, but reduced the amount trunk diameter. Irrigation emitters had an effect on plant growth and levels of electrical conductivity, nitrate-N and ortho-P leachate effluent. As a result, modifying cultural practices could be a viable tool for irrigation and nutrient management.

Nature of Work: Container nursery production requires large inputs of water and nutrients but frequently irrigation inputs exceed plant demand and lack application precision or are not applied at optimal times for plant production. Often irrigation is scheduled by the capacity of the water supply at the nursery or at the convenience of the nursery workers. Cyclic irrigation is used to apply irrigation more effectively to keep plants hydrated as well as reduce irrigation and leachate effluent from containers (1,2,4 and 5). There are many irrigation controllers used in the nursery industry that can be programmed for cyclic irrigation, however, only a few are complex enough to allow different time duration for each independent cyclic of irrigation. Lea-Cox (3) is leading a team of scientists and nursery producers to use smart irrigation using sensor technology for precision irrigation and nutrient use; however, until smart irrigation is embraced by the industry, modifying cultural practices could be a viable tool to irrigation and nutrient management. The objective of this research was to evaluate irrigation timing and volume with a tri-cyclic irrigation regime and the resulting plant growth.

On 28 March 2012, uniform liners of *Acer rubrum* 'Sun Valley' grown in #3 nursery containers were potted into solid wall #15 nursery containers at the TSU Nursery Research Center in McMinnville, TN. Container substrate was a 100% pine bark amended with 6.5 kg (11.0 lb) Osmocote Pro 19-5-9 (19N-2.2P-7.5K) (O.M. Scotts Co., Maryville, OH) controlled-release fertilizer, 0.9 kg (1.5 lb) Micromax (O.M. Scotts Co.), and 0.6 kg (1.0 lb) Aqua-Gro (Aquatrols, Paulsboro, NJ) per m^3 (per $yard^3$).

Three irrigation emitters were evaluated: 1) Maxijet 360 (Maxijet, Dundee, FL), Maxijet fan pot stake (Maxijet) and an in-line emitter ring with six micro emitters per ring (The

Toro Co., Bloomington, MN). Four daily cyclic irrigation times were evaluated: 1) a 6-8-10 am, 10-12-2 pm, 12-2-4 pm and a 2-4-6 pm. With each irrigation time, three irrigation durations were used: 1) 1x-1x-1x, 2) 1x-1x-1/2x, or 3) 1x, 1/2x, 1/2x, so that the irrigation volume applied was reduced by half with either the second or third cycle. Each emitter was calibrated to deliver the same amount of irrigation volume during each cycle. As plant water use increased throughout the growing season, irrigation volume was increase to maintain a 20% leaching fraction using the Maxijet 360 as the indicator emitter. Leachate was collected twelve times (about every two weeks) during the growing season shortly after each irrigation cycle, measured (data not presented) and analyzed for levels of electrical conductivity (EC), nitrate-nitrogen (nitrate-N) and ortho-phosphate (ortho-P).

Plant height and trunk diameter (measured at 15 cm (6 in) above the substrate surface) growth were determined by subtracting the initial growth measurements made at the onset of the test (29 March 2012) from the growth measurements made at the end of the growing season (11 October 2012). On 15 October 2012, all plants from each experimental unit were harvested for shoot and root dry weights by severing shoots from the roots at the substrate surface then dried in a forced-air oven at 56C (133F) (data not shown). Weed control and pest management were maintained with traditional nursery practices during the growing season.

Each irrigation regime/emitter was replicated six times in a completely randomized design. Data were analyzed using analysis of variance procedures of the SAS program (Version 9.1, SAS Institute, Cary, NC).

Results and Discussion: The type of emitter had an effect on the height and trunk diameter growth (Figure 1). Plants irrigated with the Toro Ag ring had the most height growth and were 12% and 20% larger than plants grown with the Maxijet 360 emitter or Maxijet pot stake (fan), respectively, and plants with the Maxijet 360 emitter were 9% larger than with the Maxijet fan. The trunk diameter growth was largest with the Toro Ag ring; however, the trunk diameter growth was similar between the Maxijet 360 emitter and the Maxijet fan.

The time of day irrigation was applied affected the height and trunk diameter growth (Figure 2). Plants that were irrigated in early afternoon (12-2-4 pm) had the most height growth and were similar to those that were irrigated in the 10-12-2 pm cycle. Plants that were irrigated in the early morning (6-8-10 am) had the least amount of height growth but were similar to plants that received late afternoon irrigation. Trunk growth was similar with the 10-12-2, 12-2-4, and 2-4-6 cycles; however, the plants irrigated in the early morning had the least amount of trunk growth.

Plant height growth was not affected by the volume of irrigation applied (Figure 3). Reducing the amount of irrigation applied in the second and third cycle (1x-1x-1/2x and 1x-1/2x-1/2x) did affect trunk growth. Plants receiving a 1x-1x-1x had 8% and 10% more trunk growth than plants receiving either 1x-1x-1/2x or 1x-1/2x-1/2x volume of irrigation, respectively. The shoot and root dry weights followed a similar trend with a reduction in biomass with a reduced irrigation volume (data not shown).

The type of the emitter had an influence on effluent levels in the container leachate when averaged among leachate dates (Figure 4). The highest levels of electrical conductivity (EC), nitrate-N and ortho-P in the container leachate were from plants irrigated with in-line emitter ring. The in-line emitter ring had the least amount of container leachate volume (data not presented) which contributes to the high effluent levels compared to the other emitters. Plants grown with the Maxijet 360 had 49% lower levels in the EC, 72% less nitrate-N and 61% less ortho-P compared to the in-line emitter ring. The Maxijet 360 emitter distributes the irrigation in a complete circle from the emitter and depending on the placement of the emitter, the irrigation can hit the inside wall of the container then channel down the interface of the container substrate and inside container wall. As a result, this emitter had the most volume of leachate collected. The EC, nitrate-N, and ortho-P levels with the Maxijet fan was intermediate between the in-line emitter ring with 40% lower EC, 53% less nitrate-N and 46% less ortho-P and the in-line emitter ring. The placement of this emitter in the container also influenced the container leachate volume. Often the fan had to be readjusted to prevent the irrigation fan from spraying over the top of the container or spraying to the inside wall of the container instead of the substrate surface.

Time of day of irrigation did not affect levels of EC, nitrate-N or ortho-P in the container leachate (data not shown). Leachate levels ranged from 0.5 to 0.55 for EC, 19.0 to 20.4 for nitrate-N, and 0.83 to 1.03 for ortho-P. In contrast, reducing the volume of irrigation during the second and third cycle did have influence on the levels of EC and ortho-P, both of which had significantly higher levels in the 1x-1/2x-1/2x than 1x-1x-1/2x or the 1x-1x-1x regimes.

Overall plants had more height and trunk growth when irrigated mostly in the afternoon compared to early morning irrigation. Reducing the volume of irrigation with a tri-cyclic irrigation regime did not affect height growth, but reduced the amount trunk girth. The type of irrigation emitter had an effect on plant growth and chemical levels of leachate effluent such as nitrate-N and ortho-P.

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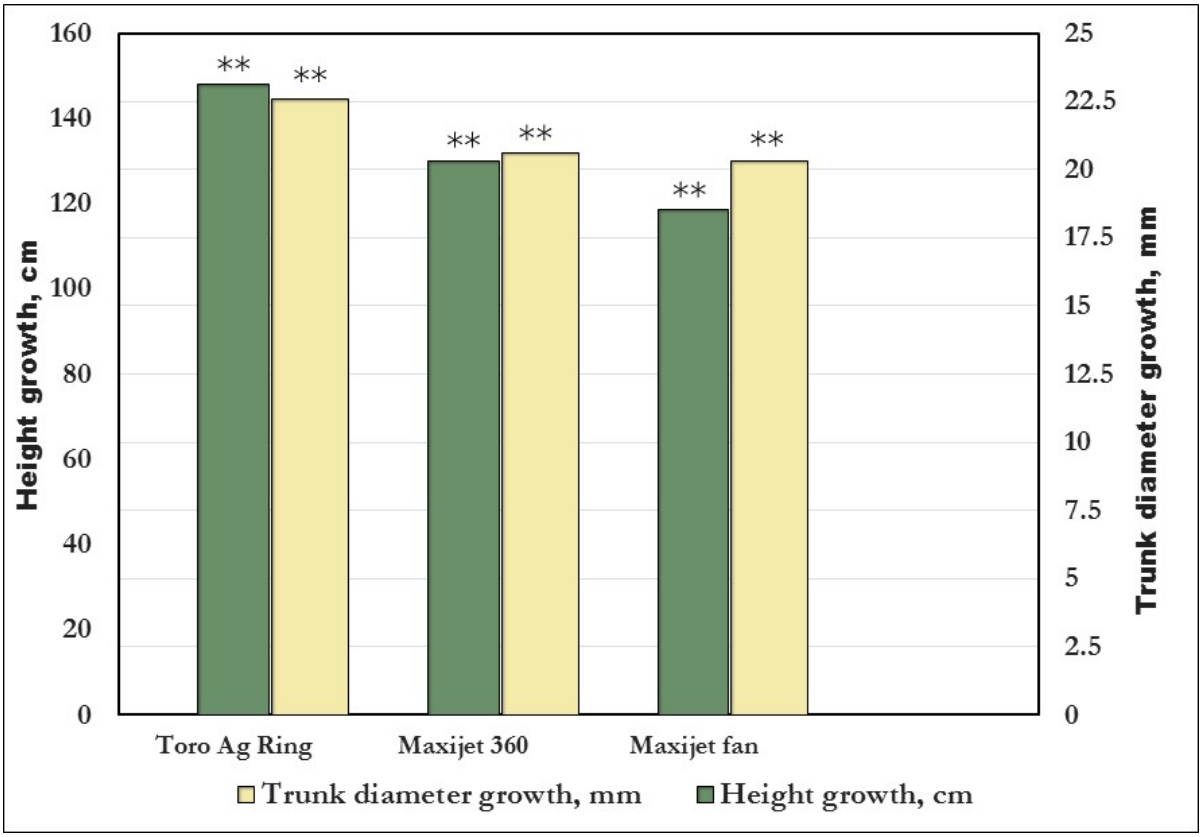

Figure 1. Influence of irrigation emitter style on growth of *Acer rubrum* 'Sun Valley' maple grown in #15 nursery containers. Plant height and trunk diameter (measured at 15 cm (6 in) above the substrate surface) growth were determined by subtracting the initial growth measurements made at the onset of the test (29 March 2012) from the growth measurements made at the end of the growing season (11 October 2012). Significance at 0.01 and 0.0001 is indicated by * and **.

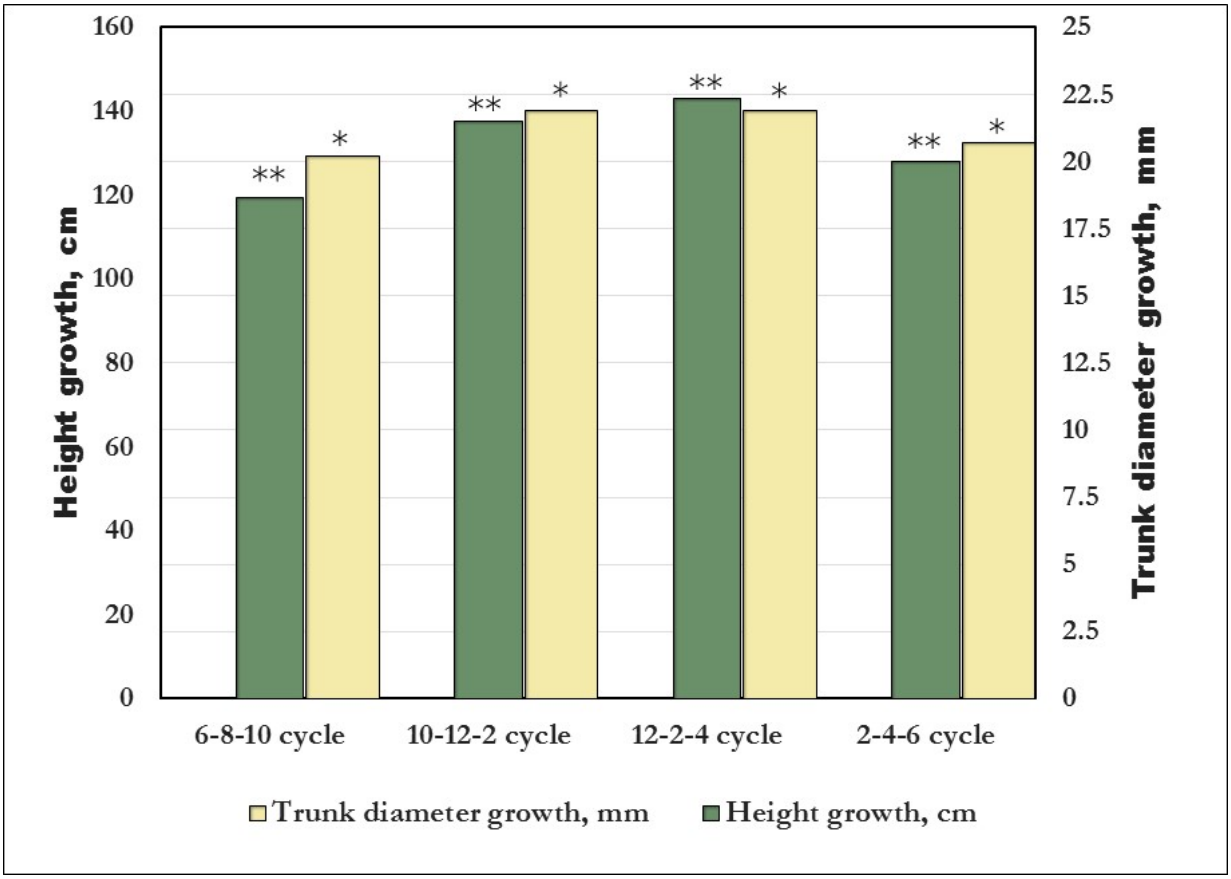

Figure 2. Influence of time of irrigation on growth of *Acer rubrum* 'Sun Valley' maple grown in #15 nursery containers. Plant height and trunk diameter (measured at 15 cm (6 in) above the substrate surface) growth were determined by subtracting the initial growth measurements made at the onset of the test (29 March 2012) from the growth measurements made at the end of the growing season (11 October 2012). Significance at 0.01 and 0.0001 is indicated by * and **.

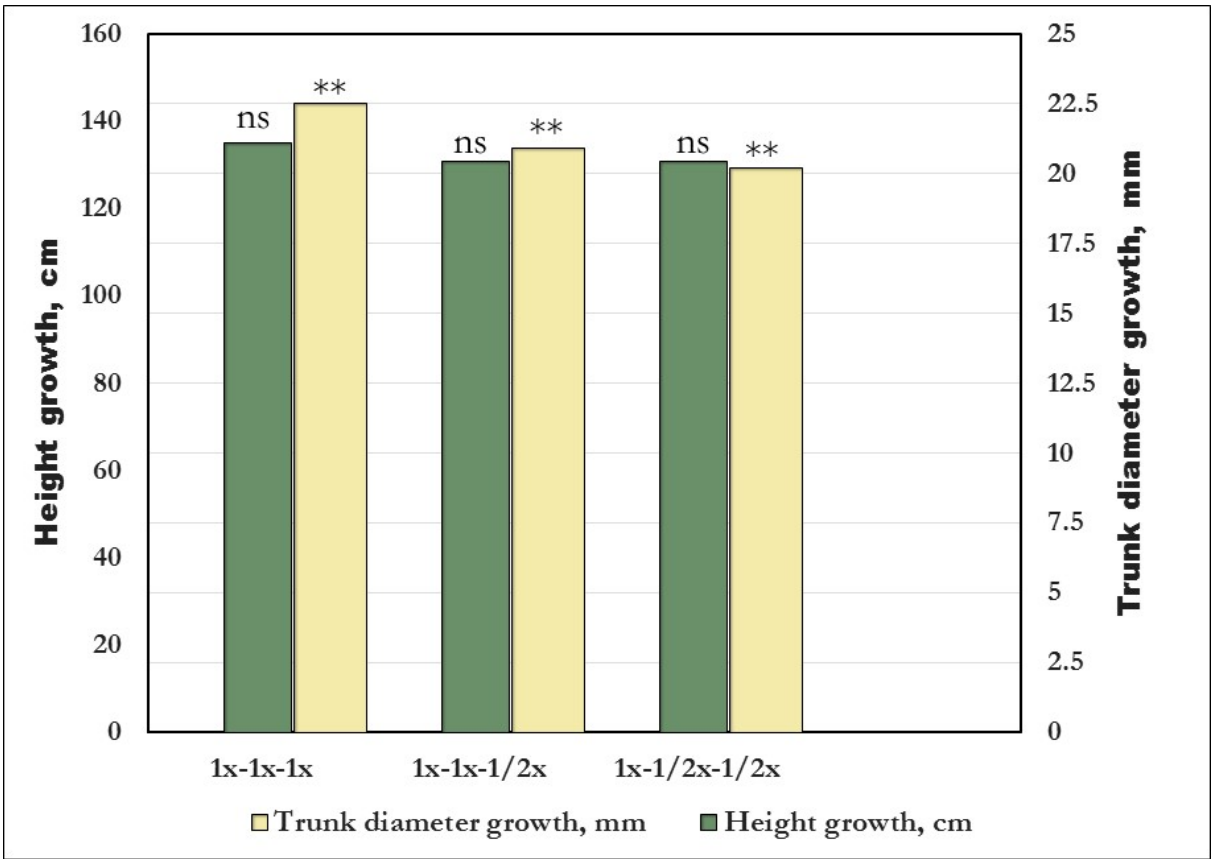

Figure 3. Influence of irrigation volume on growth of *Acer rubrum* 'Sun Valley' maple grown in #15 nursery containers. Plant height and trunk diameter (measured at 15 cm (6 in) above the substrate surface) growth were determined by subtracting the initial growth measurements made at the onset of the test (29 March 2012) from the growth measurements made at the end of the growing season (11 October 2012). Significance at non-significance, 0.01 and 0.0001 is indicated by ns, * and **.

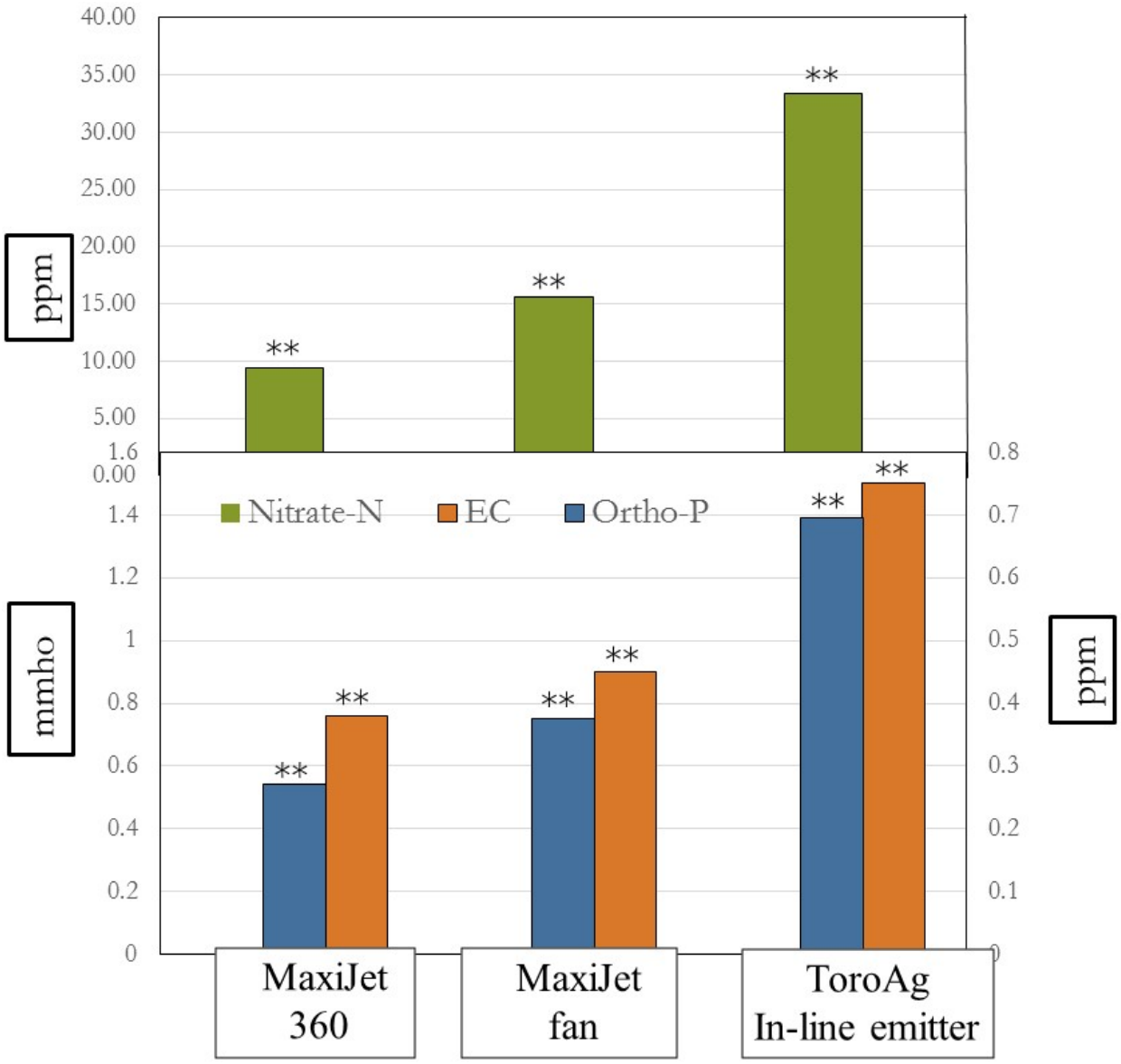

Figure 4. Influence of irrigation emitter type on levels of nitrate-N, ortho-P and electrical conductivity (EC) in container leachate averaged from twelve irrigation dates during the 2012 growing season. Significance at 0.01 and 0.0001 is indicated by * and **.

Comparison of Charred and Uncharred Wood Aggregates in Horticultural Substrates

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Index Words: biochar, greenhouse media, root growth

Significance to Industry: This work provides additional evidence of the potential use of biochar in greenhouse substrates for crop production. However, biochar can be produced using different methods, temperatures, and feedstock, which will affect the chemical and physical properties of the final biochar product. Therefore, it is important to know and measure the conditions of producing biochar in order to understand how and why it affects substrates and crop production. Biochar can then also be produced consistently, and potentially producing more consistent results with crop production. This study indicates that biochar can be mixed with peat similar to perlite and produce substrates with similar physical properties. Chemical analysis reported a wide pH increase after the substrates were limed, indicating that there are properties of biochar that will aid in pH increase of peat substrates and could affect pH buffering. Plant root growth was not negatively affected by the presence of biochar in the substrate, further aiding in the potential use of biochar in substrates for container production.

Nature of Work: Interest in using biochar for horticultural purposes has increased substantially in recent years due to its potential benefits, such as high carbon content and nutrient holding/exchanging capacity. Biochar also has the potential to be a local and renewable product, produced from waste products and/or regionally available material (8). There are many parameters that affect the end-product when making biochar, including feedstock, particle size of feedstock, burn temperature, and time of pyrolysis/charring. These factors alter the physical and chemical properties of biochar as well as how the biochar performs in soil or soilless substrates. There is potential for horticultural use of biochar in soilless substrates used for container production of greenhouse crops (6); however reports of the influence of biochar on substrates do not show consistent benefits. This could be due to the wide range of feedstock used to produce biochar, from organic wastes to peanut hulls, which could alter nutrient composition in the final biochar product. There is a need to explore the impact of the vast range of biochar properties on their potential use in greenhouse and nursery container production (1).

Biochar has potential as a substrate replacement for perlite, as both are lightweight and porous, as well as a potential economic benefit (cost savings) since perlite is the most

expensive (by volume) individual component in greenhouse/perennial substrates. Research has shown improved plant growth when biochar (produced from citrus wood in a charcoal pit) was amended with coir and tuff (4). Improved plant growth was also reported when biochar (produced from hardwood at commercial charcoal-production company) was added to sphagnum peat (6). Increased root growth was reported when biochar was amended with a peat-based substrate (7), however quantification of increased root growth in biochar amended substrates has not been published. Most reports using biochar do not provide sufficient data on the processing and repeatability of biochar production.

To investigate the potential of using biochar in greenhouse substrates, biochar needed to be produced with known/measurable parameters so that the end product is consistent. To investigate the effect of biochar on root growth, mini-Horhizotrons were used to quantify and observe root growth and development (5). The objectives of this study were 1) to test the effects of biochar on substrate physical and chemical properties, and 2) test the effects of biochar amended substrate on plant root growth using mini-Horhizotrons.

Loblolly pine trees (*Pinus taeda* L.) were harvested and hammer-milled to yield 6.35 mm (0.25 in.) pine-wood-chips (PWC). A portion of this material was reserved to test chemical and physical properties, and the rest of the material was used to produce biochar at North Carolina State University. The biochar production system used in this study was a top-lit updraft gasifier (2). On 17 April 2014, 1.5 m^3 (2 yd^3) of the PWC material was loaded into a large gasifier reactor using a conveyor to insure level placement of the material. The PWC material was lit at the top inside the gasifier reactor, and then the reactor was quickly closed to control the gasification of the material. Combustion was sustained by regulating the amount of air entering from the bottom (96.2 $ft^3 \cdot min^{-1}$ or 2.7 $m^3 \cdot min^{-1}$) and passing up through the material. A vent at the top of the reactor allowed combustible gas from the process to leave the system, and this gas was lit to reduce the amount of smoke produced. A temperature probe inside the reactor measured the internal temperature of the flame front and resulting biochar as the front passes. The temperature of the flame front during this production was 720° C (1328° F). The external temperature of the reactor was measured with an infrared thermometer (Westward #2ZB46, UK) to determine speed of the flame front and to ensure the flame front was, in essence, level. Once the flame front reached the bottom of the gasifier, the air flow was shut off and compressed nitrogen gas was then fed through from the bottom for 24 h, prevent any flare up as the biochar cooled. Once cooled, the char was removed from the reactor and stored in 1.5m^3 (2 yd^3) industrial bags under shelter.

The study was executed on 14 May 2014 in greenhouses at North Carolina State University, Raleigh, NC. Six substrates were used: peat moss at 90% (v/v) amended with 10% perlite (PL), pine-wood-chips (PWC), or biochar (BC), and peat moss at 80% (v/v) amended with 20% PL, PWC or BC. Substrates were mixed on 12 May 2014, and all substrates were tested for initial pH and then amended with dolomitic limestone at

3.85 kg·m^{-3} (6.5 lb·yd^{-3}) to achieve an expected pH of 5.8. The substrates containing biochar had a beginning pH of 3.7, and sufficient lime was added to those substrates to raise the pH to an optimal level (5.8). On 14 May 2014, eight mini-Horhizotrons were divided in the center to separate each chamber and allowed for a different substrate to fill the chamber. Four mini-Horhizotrons were divided and each chamber was randomly chosen to be filled with one of the 90:10 peat:aggregate (PL, PWC or BC) substrates. The other four mini-Horhizotrons were divided and each chamber filled with one of the 80:20 peat:aggregate substrates. The mini-Horhizotron chambers were filled with an individual substrate and the whole mini-Horhizotron was tapped three times, by lifting the mini-Horhizotron 10 cm (4 in.) from a hard surface and gently dropping, to settle the substrate. Mini-Horhizotrons were then filled to the top with substrate again, to accommodate for substrate settling which occurs after initial irrigation events in the greenhouse. Once filled, the divider was gently removed, allowing for each substrate to be united in the center, where one plug of tomato (*Solanum lycopersicum* 'Roma') was planted. Twenty-four 10 cm (4 in. dia.) greenhouse containers were also filled, four per each substrate, to be used for substrate chemical analysis (pH and EC measurements). Tomato plugs were planted in the center of the containers as well. Mini-Horhizotrons and containers were placed in the greenhouse and plants in each substrate were over-head watered as needed depending on weather conditions, and never showed symptoms of water stress. Plants were fertilized at each watering with 200 ppm nitrogen with Peters Professional 20-10-20 Peat-Lite Special (The Scotts Co., Marysville, OH).

Root length measurements (cm) were taken on the three longest roots appearing on the clear side of each chamber every 3 days after planting (DAP) until 21 DAP. Each chamber has two measureable sides giving a sum of two chamber sides for each substrate in one mini-Horhizotron. Measurements were taken by placing a transparent sheet (3M Visual Systems Division, Austin, TX) with a 0.39 x 0.39 in. grid on each face, and roots were measured from the center of the mini-Horhizotron to the end of the gridlines, which reached the end of the chamber. Once a week, a pour-through was conducted on the container-grown plants to measure the pH and electrical conductivity (EC) of every substrate according to the pour-through extraction procedure (9) using a Hanna pH/EC meter (HI 9811, Hanna Instruments, Ann Arbor, MI). On 4 June 2014, the study was terminated and shoots were removed at the substrate surface in the mini-Horhizotrons. The root balls in the mini-Horhizotrons were removed and the varying substrate sections were carefully cut 5 cm (2 in.) from the center, in order to determine root mass within the specific substrate in which it was growing. Roots were then carefully washed to remove substrate in preparation for dry weight determination. Both the shoots and washed root systems were dried at 70° C for 48 h. Data were subjected to the general linear model procedures, and root length measurements, pH and EC was subjected to regression analysis (SAS Institute version 9.3, Cary, NC). Means were separated by least significant differences at $P \leq 0.05$.

Physical properties including air space (AS), container capacity (CC) and total porosity (TP) were determined for each substrate blend at experiment initiation using the North

Carolina State University Porometer method (3). Properties were determined using three representative samples of each substrate. To determine particle size distribution of the three aggregates (PL, PWC and BC), four samples of each aggregate were dried at 105° C for 48 h and placed in a Ro-tap Shaker (Model B, W.S. Tyler, Mentor, OH) fitted with seven sieves; 6.3 mm (0.25 in.), 2mm (0.08 in.), 0.71 mm (0.03 in.), 0.5 mm (0.02 in.), 0.25 mm (0.009 in.), and 0.106 mm (0.004 in.) for five min. The sample from each sieve was weighed, and particle size was expressed as a percentage of the total weight of the sample. Data from physical property analyses were subjected to the general linear model procedures and means were separated by least significant differences at $P \leq 0.05$.

Results and Discussion: Chemical analysis of the substrates revealed that at 5 DAP, the pH for all substrates were above 6.5 (Table 1). The initial pH of the PWC and BC aggregates were 4.2 and 7.0, respectively. When making the substrates, initial pH of the biochar substrates was similar to other research reports (6). Substrate pH was measured after lime was added and these pH values were approximately 5.8 for all substrates. Biochar aggregates may contain bicarbonates that will raise substrate pH (6), however there was a large increase in pH of all the substrates and therefore this increase could be due to other factors, such as the reaction between the peat and lime addition. At 5 DAP, the pH of 10% BC and PWC substrates were higher than the 10% PL (Table 1). At 12 DAP, the 10% PWC substrate was higher than the other substrates, and at 19 DAP there were no differences among the substrates. The pH for the 20% substrates was only different at 12 DAP, when 20% PWC substrate was greater than the other substrates. Electrical conductivity for both the 10% and 20% substrates increased from 5 to 12 DAP, and dropped lower at 19 DAP (Table 1). Comparing the PL and BC substrates, EC was not different at all measuring dates, indicating that the biochar aggregate used appears to have no significant nitrogen drawdown/tie-up.

Substrate physical properties indicate that there are no differences among the 10% PL, PWC or BC substrates for all properties (Table 2). For 20% BC substrate, there was greater TP and CC, with lower AS. This could be due to the greater amount of fines and medium-sized particles found in the biochar aggregate that fill in pores in the peat and lower AS and raise CC (Table 2). This indicates that charring process caused a significant difference in particle size distribution; the process reduced the size of the larger PWC particles and created more medium and fine BC particles. 20% PWC substrate had greater AS with lower CC, and this could be due to the PWC aggregate having lower amounts of medium-sized and fine particles. 20% PL had a lower TP compared to 20% BC, however for CC and AS for the two substrates were not different. Both PL and BC aggregates had similar extra-large, large and fine particles, but BC had greater amounts of medium-sized particles than PL. Replacing PL with BC in peat substrates created comparable physical environments for the tomato plants.

In the substrates with 90% peat amended with 10% PL, PWC or BC, tomato root lengths measured from 3 to 6 DAP were not different (Fig. 1A). At 9 DAP, roots in the 10% PL substrate were significantly longer than roots in the other substrates. At 12

DAP, roots growing in 10% PL and PWC were significantly longer than roots growing in the 10% BC substrate. After 15 DAP, there was no difference in tomato root growth among the three substrates. Although differences were observed in root growth among the substrates from 9 to 12 DAP, roots growing in 10% BC caught up in length to the other substrates by the next measurement date. Data from the dry weight analysis indicates that root growth was not different among the substrates (Fig. 2A). By the end of the study (21 DAP), there was no differences in root growth among the substrates, with root growth and mass comparable between 10% PL and BC.

In the substrates containing 80% peat with 20% PL, PWC or BC, tomato root lengths show differences from 6 DAP until 21 DAP. At 6 and 12 DAP, roots growing in 20% BC were significantly greater than roots growing in the other substrates (Fig. 1B). At 9 and 21 DAP, tomato roots growing in 20% PL and BC were longer than roots growing in 20% PWC. Data from the dry weight analysis indicates that root growth was not different among the substrates (Fig. 2B). There were observable differences in visible root growth along the sides of the mini-Horhizotron, with greater root growth in 20% BC substrate compared to roots in the 20% PWC substrate. This could be due to the charring process; the 20% BC substrate seemed to stimulate root growth. However, by the end of the study root mass in the substrate (not all visible) was similar among the substrates.

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Table 1. pH and electrical conductivity (EC) of all substrates used in mini-Horhizotron study.

		Days after planting (DAP)					
		5		12		19	
Ratio[z]	Substrate	pH	EC	pH	EC	pH	EC
90:10:00	PL[y]	6.6 b[x]	1.04 a	6.6 b	1.07 a	6.6 a	0.66 a
	PWC[w]	6.7 a	0.80 b	6.7 a	1.04 a	6.6 a	0.66 a
	BC[v]	6.7 a	1.04 a	6.6 b	1.11 a	6.6 a	0.66 a
80:20:00	PL	6.8 a	1.05 a	6.6 b	1.03 ab	6.8 a	0.74 a
	PWC	6.8 a	0.80 a	7.0 a	0.92 b	6.9 a	0.68 a
	BC	6.8 a	0.88 ab	6.8 b	1.06 a	6.9 a	0.74 a

[z]Ratio = peat substrate amended with PL, PWC or BC as specified percent ratios (v/v).

[y]PL = peat amended with perlite.

[x]Means separated within columns by DAP and ratio for chemical properties distribution by Least Significant Difference (LSD), $P \leq 0.05$. Means followed by the same letter are not significantly different.

[w]PWC = peat amended with pine-wood-chips, PWC is produced by chipping and hammer-milling (6.35mm or 0.25 in. screen) loblolly (*Pinus taeda* L.) pine logs.

[v]BC = biochar aggregate used in making substrates for this study; BC is produced by PWC gasification.

Table 2. Physical properties of all substrates used in a mini-Horhizotron experiment and particle size distribution of the aggregates amended in the substrates.

		Physical properties[z]		
Ratio[y]	Substrate	Container capacity[x] (% vol)	Air space[w] (% vol)	Total porosity[v] (% vol)
90:10	PL[u]	69.7 a[t]	21.1 a	90.8 a
	PWC[s]	70.2 a	21.1 a	91.3 a
	BC[r]	72.0 a	20.2 a	92.0 a
80:20	PL	68.2 ab	21.9 ab	90.1 b
	PWC	62.9 b	28.0 a	91.0 ab
	BC	71.2 a	20.5 b	91.7 a

	Particle size distribution[q] (% weight)			
	X-Large (>6.3 mm)	Large (6.3>2.0 mm)	Medium (2.0>0.5 mm)	Fine (≤0.5 mm)
PL[p]	0.12 b[o]	60.36 b	28.78 b	10.74 a
PWC[n]	1.56 a	78.95 a	19.03 c	0.46 b
BC[m]	0.37 b	48.88 b	46.44 a	4.39 ab

[z]Physical properties data were collected from three samples per substrate and represented as means. Analysis performed using the North Carolina State University Porometer method (Fonteno et al., 1995).

[y]Ratio = peat substrate amended with PL, PWC or BC as specified percent ratios (v/v).

[x]Container capacity = (wet weight – oven dry weight) ÷ volume of the sample.

[w]Air space = volume of water drained from the sample ÷ volume of the sample.

[v]Total porosity = container capacity + air space.

[u]PL = peat amended with perlite.

[t]Means separated within columns by ratio for physical properties by Least Significant Difference (LSD), $P \leq 0.05$. Means followed by the same letter are not significantly different.

[s]PWC = peat amended with pine-wood-chips, PWC is produced by chipping and hammer-milling (6.35mm or 0.25 in. screen) loblolly (*Pinus taeda* L.) pine logs.

[r]BC = peat amended with biochar, BC is produced by PWC gasification.

[q]Particle size distribution data were collected from four samples per aggregate and represented as mean percent by weight of the samples. Analysis performed using Ro-tap Shaker (Model B, W.S. Tyler, Mentor, Ohio) fitted with seven sieves; 6.3 mm (0.25 in.), 2mm (0.08 in.), 0.71 mm (0.03 in.), 0.5 mm (0.02 in.), 0.25 mm (0.009 in.), and 0.106 mm (0.004 in.).

[p]PL = perlite aggregate used in making substrates for this study.

[o]Means separated within columns for particle size distribution by Least Significant Difference (LSD), $P \leq 0.05$. Means followed by the same letter are not significantly different.

[n]PWC = pine-wood-chip aggregate used in making substrates for this study; PWC is produced by chipping and hammer-milling (6.35mm or 0.25 in. screen) loblolly pine logs.

[m]BC = biochar aggregate used in making substrates for this study; BC is produced by PWC gasification.

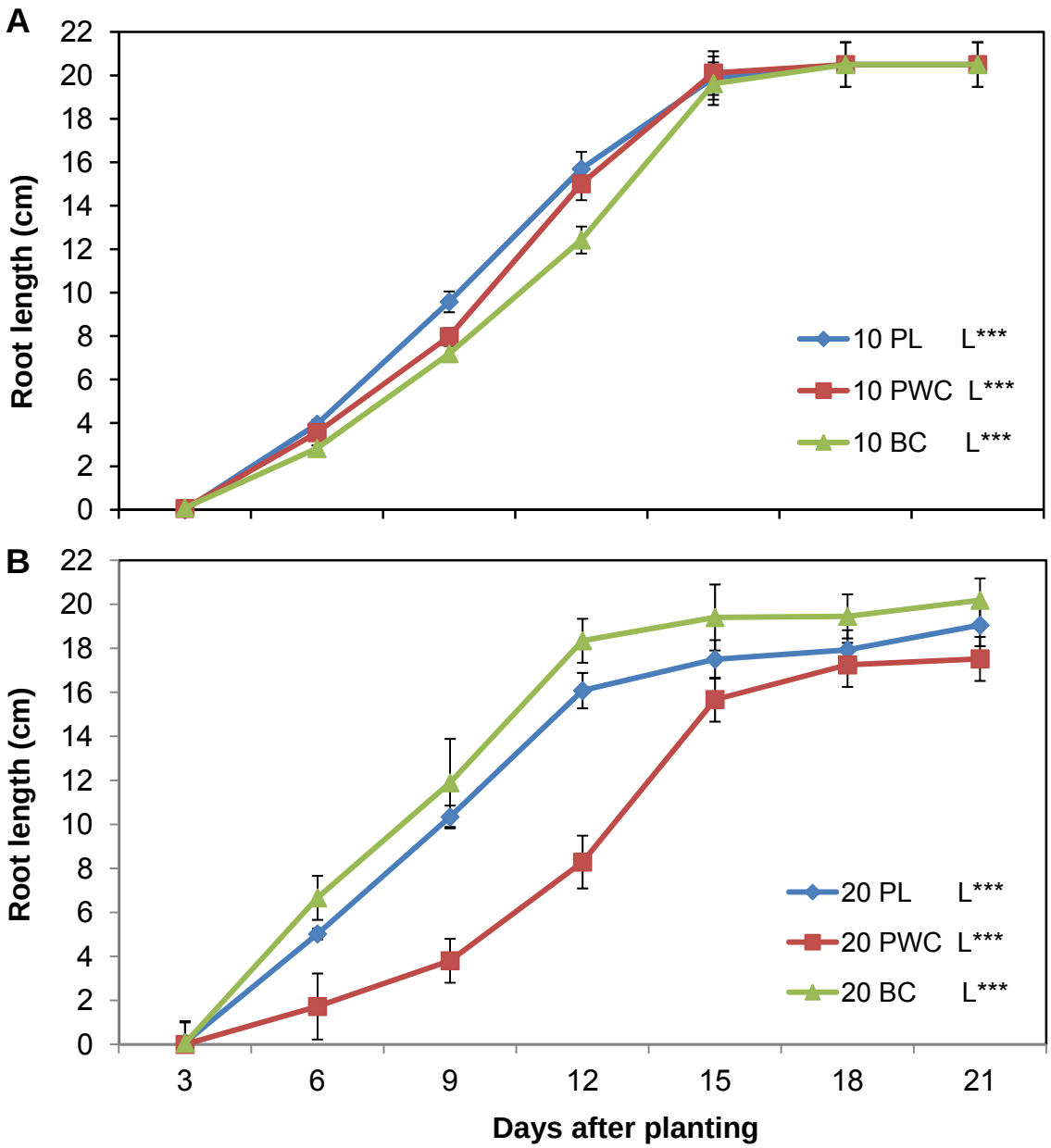

Figure 1. Root length measurements (1 cm = 0.394 in.) of tomato (*Solanum lycopersicum* 'Roma') plants in mini-Horhizotrons when grown in (A) 90% (v/v) peat amended with 10% of perlite (PL), pine-wood-chips (PWC) or biochar (BC) with error bars representing means separation ($P \leq 0.05$). (B) Root length measurements of plants in the mini-Horhizotrons when grown in 80% (v/v) peat amended with 20% PL, PWC or BC, with error bars representing means separation ($P \leq 0.05$). Letters next to substrate represent linear regression significance; L*** represents significant linear effects when $P \leq 0.001$.

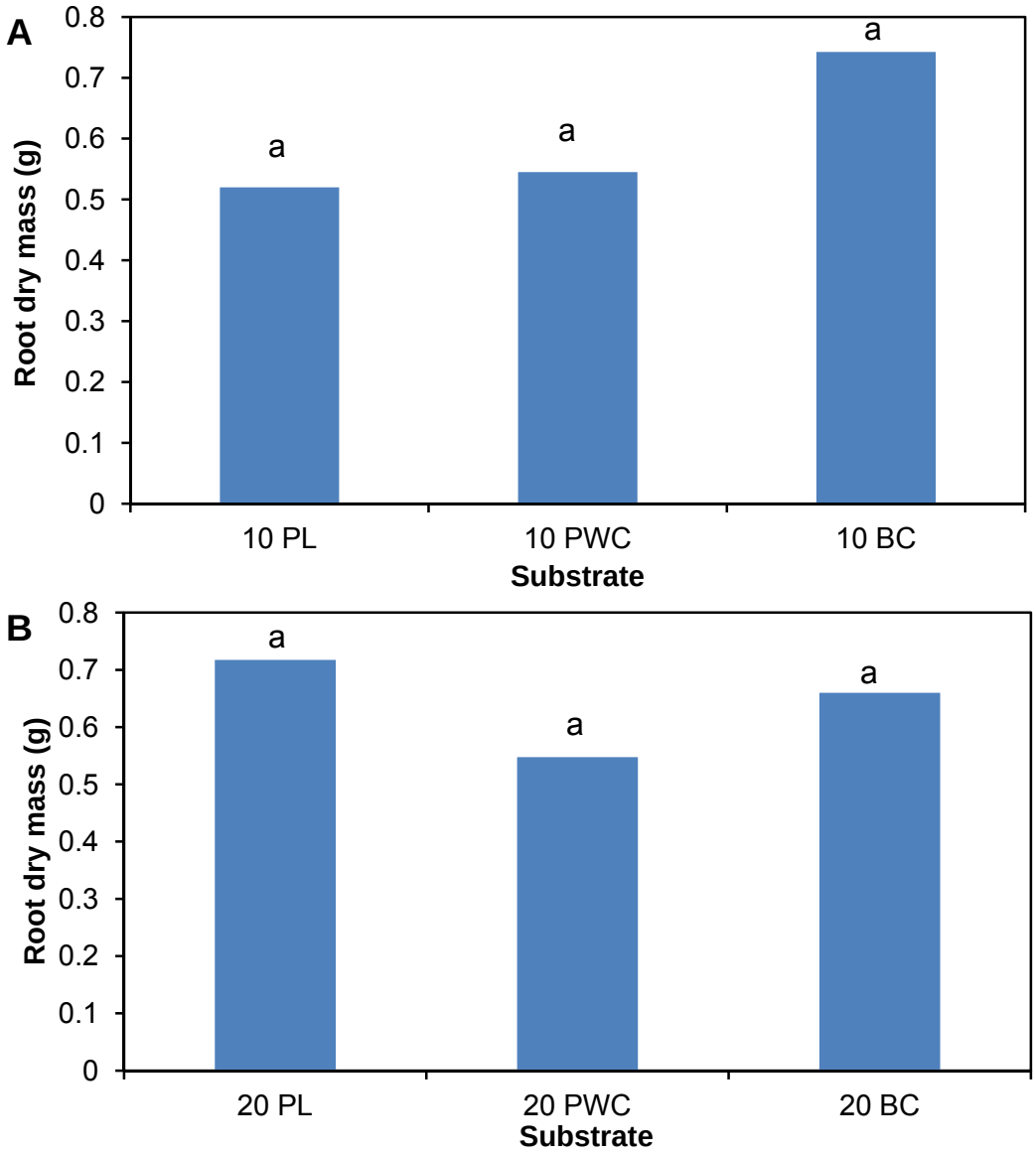

Figure 2**.** Root dry mass of tomato (*Solanum lycopersicum* 'Roma') plants grown in mini-Horhizotrons. (A) Root dry mass of plants grown in 90% (v/v) peat amended with 10% perlite (PL), pine-wood-chips (PWC) or biochar (BC). (B) Root dry mass of plants grown in 80% (v/v) peat amended with 20% PL, PWC or BC. Means separated across substrates by ratio by Least Significant Difference (LSD; $P \leq 0.05$), and same letter indicates means are not significantly different.

Effects of Biochar and Fertigation Regimes on Easter Lily Production

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Index words: biochar, fertigation regimes, Easter lily production, industrial substitutes, soilless plant media.

Significance to Industry: Currently, Easter lily, or other potted flower producers, depend greatly on the sphagnum peat-based substrate (1). Impact to the wetland ecosystem caused by peat harvest cannot be neglected; therefore, the need to replace peat-based substrate is increasing. This study demonstrated the possibility of reducing peat in container substrates with biochar. The effects of peat-based substrate amended with five percentages of biochar (0%, 20%, 40%, 60% and 80% by volume) and four fertigation regimes (200 ppm constant feeding, 300 ppm constant feeding, 200 ppm at every three watering, and 300 ppm at every three watering) were evaluated for Easter lily production. There was no interaction between biochar percentages and fertigation regimes on plant growth and development. Fertigation regimes did not have significant effects on plant height, plant dry weight or the number of days before full bloom, although plants treated with 200 and 300 ppm constant feeding had higher SPAD readings compared to those fertigated (200 and 300 ppm) at every three waterings. The results from the experiment showed that the growth and development of Easter lily plants grown in substrates amended with biochar were equal or slightly better compared to those grown in peat-based substrate.

Nature of Work: Easter lily is an important potted flowering crop in North America (1). The peat-based substrate is the most commonly used container substrate, but peat bogs are generally considered as fragile environments and shortages of peat have been reported in recent years (2). Therefore, renewable resources were explored to replace peat as a container substrate component, including biochar.
Biochar is a by-product of a pyrolysis process that utilizes renewable biomass. This procedure is carbon-negative (3), therefore it could be a desirable container substrate for the nursery industry. Research suggested biochar increased water (4) and nutrient retention (5), and improved soil physical properties, which resulted in improving crop performance (6).

This experiment was conducted in a glass greenhouse located on Texas A&M University campus at College Station, TX, from December 17, 2013 (week 1 of experiment) to April 18, 2014 (week 18). The pre-chilled Easter lily bulbs were obtained from Gloeckner (Fred C. Gloeckner & Company Inc., Harrison, NY), and were potted on December 17, 2013 in six-inch plastic pots (1680 ml) with Sunshine Mix #1 (Sun Gro Horticulture, Agawam, MA) amended with 0%, 20%, 40%, 60% or 80% biochar (by volume). Four fertigation regimes were evaluated: 200 ppm or 300 ppm constant feeding and 200 ppm or 300 ppm at every first watering (in a three-watering circle). The fertilizer used in this experiment was a water soluble fertilizer 15N-2P-12K (Peters 15-5-15; ScottsMiracle-Gro Company, Marysville, OH). After potting all pots were fertigated at 400 ppm. At January 6 (week 4), four fertigation regimes were initiated. Banrot® 40 WP (ScottsMiracle-Gro Company, Marysville, OH) and a mixture of Truban® 30 WP (ScottsMiracle-Gro Company, Everris NA Inc, Marysville, OH) and Cleary's 3336® F (Cleary Chemicals LLC, Dayton, NJ) were applied monthly at the labeled rate to prevent root rot disease.

Easter lily stems emerged above the substrate surface after week 5. Plant height (from the substrate surface to the top of a plant) was measured biweekly from week 6 to week 16. The first day of full bloom was recorded. The SPAD readings of three fully expanded green leaves per plant were taken from three plants per treatment in weeks 15, 16 and 17. Plants were harvested on April 18, 2014. Lengths of stem with brown leaves, yellow leaves or green leaves were measured. Plants were dissected into flowers, stems and leaves, and dry weight was recorded after oven-dried at 80 ºC until constant weight. This experiment utilized a split-plot design with fertigation regimes as the main plot and biochar percentages as the subplot with eight replications per treatment. The responses of Easter lily to different biochar percentages and fertigation regimes were analyzed by a two-way analysis of variance (ANOVA version 9.4; SAS Institute, Cary, NC), and means were separated by Student Newman Keuls' test (SNK) at 5% significance level.

Results and Discussion: There was no interaction between the percentages of biochar and fertigation regimes on any measured parameters (Table 1 and Table 2). Fertigation regimes did not have a significant effect on plant height from week 6 to week 18. The effects of biochar on plant height was significant from week 6 to week 14, and not significant in week 16 and week 18. Plants grown in substrates amended with 20% and 40% biochar had greater height than those in 80% biochar from week 6 to week 14. Plants grown in substrates amended with up to 60% biochar had equal or greater heights compared to those in 0% biochar from week 6 to week 18 (Table 2).

Fertigation regimes had a significant effect on leaf dry weight (Table 1 and Table 3), and plants under constant feeding (200 or 300 ppm) had higher leaf dry weight than those under fertigation (200 or 300 ppm) at every three watering (Table 3). Fertigation also had significant effects on plants SPAD reading from week 15 to week 17. Plants under 200 or 300 ppm constant feeding were not significantly different, and plants fertigated with 200 ppm at every three watering had the lowest SPAD reading from week 15 to week 17 (Table 1 and Table 4). However, plants were not visually affected by lower SPAD readings.

Biochar percentages had significant effects on the total stem length and length of stems with brown and yellow leaves. Both length of stem with brown leaves and length of stem with yellow leaves were significantly affected by biochar percentages and fertigation regimes (Table 1 and Table 5). Plants under constant feeding (200 or 300 ppm) had shorter stems with brown leaves but longer stems with yellow leaves than fertigation (200 or 300 ppm) at every first watering (in a three-watering circle). Plants grown in substrates amended with 20% and 40% biochar had greater total stem length, length of stem with brown leaves, length of stem with yellow leaves, and length of stem with brown and yellow leaves than those in 80% biochar. Plants grown in substrates amended with 20%, 40%, and 60% biochar had equal or greater total stem length, length of stem with brown leaves, length of stem with yellow leaves, and length of stem with brown and yellow leaves compared to those in 0% biochar. However, 80% biochar had the similar or higher ratios of length of stem with green leaves on the total stem length (Table 5). The possible cause of yellow leaves might be the presence of perlite (1) in Sunshine Mix #1 (Sun Gro Horticulture, Agawam, MA).

Overall, biochar percentages and fertigation had no interacting effects on plant growth and development. Also, neither treatment affected the number of flowers, the number of days before full bloom, and flower dry weight, in this experiment.
Fertigation regimes affected SPAD reading and leaf dry weight of Easter lily plants. These results suggest that constant feeding was better than fertigation at every first watering (in a three-watering circle).

Before week 14, plant height in substrates amended with 20%, 40%, and 60% biochar were not significantly different from those in 0% biochar, and after week 14 (from week 16 to week 18), there were no significant differences among all biochar percentage (0-80%). Easter lily grown in 80% biochar had the highest ratios of green leaves on the total stem length; which might result from lower perlite ratio in the substrates. Results indicated that biochar could replace a significant portion of the substrate that is normally peat-based in Easter lily production.

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Table 1. Analysis of variance (ANOVA) showing total stem length (TSL), flower dry weight (FDW), leaf dry weight (LDW), stem dry weight (SDW), total dry weight (TDW = FDW+LDW+SDW), the number of flowers (NF), the number of days before full bloom (NFB), total number of leaves (NL), length of stem with brown leaves (LSB), length of stem with yellow leaves (LSY), length of stem with green leaves (LSG), the summation of LSB and LSY, the ratio of LSG/TSL, and SPAD reading (week 15, week 16, and week 17) of Easter lily grown in substrate amended with five different ratios of biochar and fertigated at four different regimes.

	Flowering and Growth Data															
														SPAD		
Treatment	TSL	FDW	LDW	SDW	TDW	NF	NFB	NL	LSB	LSY	LSG	LSB+LSY	LSG/TSL	Week 15	Week 16	Week 17
Fertigation	NS[z]	NS	***	NS	NS	NS	NS	NS	***	***	NS	NS	NS	***	***	***
Biochar	**	NS	NS	NS	NS	NS	NS	NS	**	**	NS	***	**	NS	NS	NS
Biochar x Fertigation	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] NS (nonsignificant) or significant at P ≤ 0.01 (**), or 0.001 (***).

Table 2. Plant height (from the substrate surface to the top of plants) of Easter lily grown in Sunshine Mix #1 amended with five different percentages of biochar and fertigated at four regimes from week 6 to week 16. Flower buds emerged after week 14.

	Height (cm)						
Treatment	Week 6	Week 8	Week 10	Week 12	Week 14	Week 16	Week18
Biochar							
0%	8.2 b[z]	14.4 b	18.0 a	22.6 a	27.8 ab	35.3 a	41.0 a
20%	8.9 a	15.8 a	19.5 a	23.7 a	29.5 a	36.2 a	42.6 a
40%	8.5 ab	15.0 ab	19.2 a	23.7 a	29.4 a	36.3 a	43.0 a
60%	7.9 bc	14.1 b	18.4 a	22.8 a	27.9 ab	35.4 a	41.5 a
80%	7.4 c	12.9 c	16.6 b	20.4 b	26.0 b	33.9 a	39.8 a
Significance							
Fertigation	NS[y]	NS	NS	NS	NS	NS	NS
Biochar	***	***	***	***	***	NS	NS
Biochar x Fertigation	NS	NS	NS	NS	NS	NS	NS

[z] Means within a column followed by the same letter are not significantly different according to Student Newman Keuls' multiple comparison (P ≤ 0.05).
[y] NS (nonsignificant) or significant at P ≤ 0.001 (***).

Table 3. The leaf dry weight (LDW) of Easter lily grown in Sunshine Mix #1 amended with five different percentages of biochar and fertigated at four regimes. All data were collected at 18 weeks after bulb were potted.

Treatment	LDW (g)
Fertigation	
200 ppm	4.2 a[z]
300 ppm	4.3 a
200 ppm /3 watering	3.7 b
300 ppm /3 watering	3.8 b

[z] Means within a column followed by the same letter are not significantly different according to Student Newman Keuls' multiple comparison (P ≤ 0.05).

Table 4. SPAD reading at Week 15, 16, and 17 of Easter lily grown in Sunshine Mix #1 amended with five different percentages of biochar and fertilized at four fertigation regimes.

	SPAD		
Treatment	Week 15	Week 16	Week 17
Fertigation			
200 ppm	52.5 a[z]	56.7 ab	58.7 a
300 ppm	52.4 a	58.1 a	59.7 a
200 ppm /3 watering	48.7 b	54.0 c	52.1 c
300 ppm /3 watering	50.7 ab	55.2 bc	55.8 b

[z] Means within a column followed by the same letter are not significantly different according to Student Newman Keuls' multiple comparison (P ≤ 0.05).

Table 5. Total stem length (TSL), length of stem with brown leaves (LSB), length of stem with yellow leaves (LSY), the summation of LSB and LSY, and the ratio of length of stem with green leaves (LSG) on TSL of Easter lily grown in Sunshine Mix #1 amended with five different percentages of biochar and fertilized at four fertigation regimes. All data were collected at 18 weeks after bulb were potted.

Treatment	TSL	LSB	LSY	LSB+LSY	LSG/TSL (%)
Fertigation					
200 ppm	27.4 a[z]	4.8 b	6.7 a	11.5 a	58.0 a
300 ppm	27.7 a	4.7 b	6.8 a	11.5 a	58.6 a
200 ppm /3 watering	26.1 a	6.0 a	4.7 b	10.7 a	58.9 a
300 ppm /3 watering	25.8 a	5.7 a	4.5 b	10.1 a	60.3 a
Biochar					
0%	26.7 ab	5.6 ab	5.3 ab	10.9 ab	58.6 abc
20%	27.7 a	5.9 a	6.4 a	12.3 a	54.8 c
40%	27.5 a	5.5 ab	6.6 a	12.1 a	59.1 bc
60%	26.5 ab	4.5 c	5.5 ab	10.0 bc	62.3 ab
80%	24.6 b	4.9 bc	3.8 b	8.7 c	64.4 a

[z] Means within a column followed by the same letter are not significantly different according to Student Newman Keuls' multiple comparison ($P \leq 0.05$).

Effect of Nitrogen Rate and Irrigation Frequency on Plant Growth and Nutrient Uptake of Container-grown *Hydrangea macrophylla* 'Merritt's Supreme'

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Index Words: fertilizer, nutrient, nursery

Significance to Industry: The production of high quality container-grown nursery plants requires adequate but not excessive nutrients and water during production. With water restrictions and increased energy and fertilizer cost, the need for more efficient use of water and fertilizers is intensified. An efficient water and nutrient management program is challenging due to varying plant requirements and differing water and nutrient holding capacity of substrates used in nursery container production. Results of this study indicated that 210 ppm nitrogen (N) is sufficient for the production of hydrangea plants considering no difference in plant growth (PGI, dry weights, N content, photosynthetic performance) was found between plants fertilized with 210 ppm and 280 ppm N.

Nature of Work: Given the knowledge that N is the most important nutrient element for plant growth and that it is often the limiting factor (2), nursery growers tend to apply high levels of N fertilizer to avoid potential N deficiency. However, over-fertilization can be detrimental to plant growth due to potential salt accumulation under water shortage, or cause considerable loss of nutrients and environmental issues due to excessive irrigation. With sufficient nutrient supply, water availability can be a limiting factor for nutrient uptake by changing the conductivity of rhizosphere solution (4). Nutrient availability to plant roots in response to different N rates and irrigation frequency conditions has not been well clarified for hydrangea (1, 3). The objective of this study was to investigate the effect of N rate and irrigation frequency on plant growth and nutrient uptake of container-grown *Hydrangea macrophylla* 'Merritt's Supreme'.

This study was conducted at Mississippi State University (Lat. 33° 27' 20" N; Long. 88° 47' 25" W). Rooted *Hydrangea macrophylla* 'Merritt's Supreme' cuttings were potted into Elite/Ultra Azalea pots (17.8 cm in diam., 12.7 cm in height, 2100 cm^3 in volume; ITML Horticultural Products, Inc., Brantford, Ontario, Canada) containing Sun Gro 4 (Sun Gro Horticulture, Bellevue, WA) in July 2013 and grown outdoors under shadecloth (40% shade). Starting in early August, plants were fertilized twice a week with 250 ml of modified Hoagland's solution containing one of five N concentrations (0, 70, 140, 210, 280 ppm N from NH_4NO_3). All plants were watered through a drip-irrigation system with

half plants receiving one irrigation at 8:00 A.M. and the other half receiving two irrigations at 8:00 A.M. and 2:00 P.M. with the same total volume of water received by each plant per day.

Plants were measured for height, widths (width 1 (widest point) and width 2 (width perpendicular to width 1)), and SPAD every two weeks during the growing season. Plant growth index (PGI) was calculated by averaging plant height and the two widths. Daily water use (DWU) was calculated as the difference in container weight 0.5 h after irrigation and 24 h after irrigation. Plants were destructively harvested in late November 2013, divided into roots, stems, and leaves, and oven-dried at 60°C. Dry weight of each plant's tissue was recorded. Samples were then ground for nutrient analysis using a Wiley mill. Plants were measured for photosynthetic rate (Pn) and stomatal conductance (g_s) between 10:00 A.M. and 1:00 P.M. using a LI-6400 portable photosynthetic system (LI-COR Inc., Lincoln, NE) from September to October.

This study was set up in a randomized complete block design with five replications in each treatment combination. All data were analyzed in a factorial design using ANOVA, with N rate and irrigation frequency as the main effects. When indicated by ANOVA, means were separated using Fisher's Least Significant Difference test at $P \leq 0.05$. All analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC).

Results and Discussion: N rate had a significant effect on plant growth of hydrangea. In general, plants receiving higher N rates had greater PGI, SPAD readings, and total dry weights than plants receiving lower N rates, with no difference between 210 and 280 ppm N treatments (Table 1). Irrigation did not have an influence on PGI, SPAD, or plant dry weights. There was no interaction between N rate and irrigation frequency. DWU was affected by N rate. Plants treated with 210 ppm or 280 ppm N had greater DWU than plants treated with 0 or 70 ppm N (Table 1).

Generally, higher N fertilization resulted in greater tissue N concentration (data not shown) and content regardless of tissue type. Plants fertilized with 210 or 280 ppm N had greater N content in root, stem, leaf and the whole plant than those fertilized with 0 or 70 ppm N (Table 2).

Irrigation frequency did not have an influence on Pn. On Sep 10, Pn increased as N rate increased from 0 to 140 ppm, and from 140 to 280 ppm. (Table 1). There was no difference in stomatal conductance (g_s) among treatment combinations (data not shown), suggesting irrigation frequency (one or two irrigations per day) did not result in a difference in water availability to hydrangea plants.

Without being exposed to significantly different water stress induced by the two irrigation frequencies, plant N uptake may not have been limited by substrate water availability, thus N was the primary factor having a significant effect on most growth parameters at harvest, sharing a similar increasing trend as N rate increased. However, 210 ppm N may be the economic choice since there wasn't a significant difference in most growth parameters between plants treated with 210 or 280 ppm N.

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Table 1. Effects of nitrogen (N) rate on plant growth index (PGI), SPAD, daily water use (DWU), plant total dry weight (TDW), and net photosynthesis rate (Pn) in *Hydrangea macrophylla* 'Merritt's Supreme'.

N rate (ppm)	PGI [z] (cm)	SPAD [y]	TDW (g)	DWU (ml)	Pn ($\mu molCO_2 m^{-2} s^{-1}$)
0	20.80 c [x]	29.0 b	15.31 c	60 c	22.3 c
70	21.73 c	30.5 b	15.98 c	74 bc	24.47 c
140	23.95 b	34.3 a	22.82 b	77 b	28 b
210	24.95 ab	34.4 a	24.93 ab	95 a	27.82 b
280	26.03 a	36.3 a	26.59 a	100 a	31.59 a

[z] PGI = (height + width 1 + width 2)/3

[y] PGI, SPAD, and DWU data presented in the table are all from Nov 4, 2013; Pn data is from Sep 10, 2013.

[x] Means separation within columns. Means with the same letters are not significantly different according to Fisher's protected LSD at $P \leq 0.05$.

Table 2 Effects of N rate on N content of stem, leaf, root and the whole plant of *Hydrangea macrophylla* 'Merritt's Supreme'.

N rate (ppm)	Stem N content (mg)	Leaf N content (mg)	Root N content (mg)	Total N content (mg)
0	20.3 c [z]	63.8 c	45 d	129.1 c
70	25.0 c	69.2 c	60 c	154.2 c
140	30.2 b	118.0 b	73 b	221.2 b
210	34.0 b	135.0 ab	88 a	257.0 a
280	41.8 a	151.0 a	92 a	284.8 a

[z] Means separation within columns. Means with the same letters are not significantly different according to Fisher's protected LSD at $P \leq 0.05$.

Effects of Hydrogels on Timing and Severity of Wilt in Container-grown Annuals

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Index Words: dewpoint potentiameter, permanent wilt

Significance to Industry: Hydrogels have shown potential to increase water retention of media and to reduce irrigation frequency (3), and can potentially increase available water when incorporated into a medium (5). Different sizes of these gels are available but the effects of particle size are not well documented. Extending the time between waterings would be particularly useful in post-production by improving quality and survival of herbaceous plants in the retail sales area for consumers. The purpose of this study was to assess the response of two annual crops with different irrigation requirements (coleus and vinca) to hydrogel in two different sizes. In addition, this study showed that water potential values for vinca reached well beyond the traditional permanent wilting point range, which may indicate a need for more study of water potentials at or near what is considered permanent wilt.

Nature of Work: Hydrophilic polymers (hydrogels) are added to horticultural substrates to increase water-holding capacity and aeration, and to reduce watering frequency (3).There are studies that demonstrate that hydrogels have the potential to delay wilting in container crops and extend crop life and quality during the postproduction periods for the plant, which would reduce labor costs, watering needs, and crop loss in retail outlets (4). However, there are other studies that show either no effect or a detrimental effect of hydrogels in plant performance (4). There is little data on whether or not the particle size of hydrogels has any influence on plant performance.

The term plant available water refers to water being held on to a substrate at a suction low enough so that plants are able to uptake it for use. In field soils, plant available water is water held at suctions less than -1.5 MPa, beyond which water would be unavailable and held as the permanent wilting percentage (PWP). However, this value can vary depending on the plant species between -1.0 and 2.0 MPa (2). PWP is a term used to describe the point at which substrate water potential is too large for plants to pull moisture from the soil to recover. Several studies have shown the ability of plants to recover past the accepted PWP (1, 6).

Recently the WP4C dewpoint potentiameter (Decagon, Pullman, WA) has been shown to produce water potential readings for highly porous soilless container substrates at high potentials more accurately than previous methods, such as the 15 bar pressure plate (2,6). The WP4C dewpoint potentiameter measures the dewpoint of the substrate and calculates the water potential of the sample.

The experiment was implemented on 19, February 2014 at the Teaching Greenhouse at North Carolina State University. Forty-eight plugs each of Coleus (*Solenostemon scutellarioides* 'Kong Salmon Pink'), and Vinca (*Catharanthus roseus* 'Cora Apricot') were potted into substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of a potassium polyacrylate cross-linked powder hydrogel (Stockosorb 660, Evonik Corporation, Garyville, LA). Plants were placed on a greenhouse bench and arranged in a complete randomized block design with nine replications per treatment. Plants were hand watered as needed with 200 ppm N derived from 20-10-20 Peat-Lite Special fertilizer (The Scotts Co. Marysville, OH). To assess wilt, plants were placed in a large plastic tub to saturate the substrate before allowing the plants to dry down (6, May 2014 for coleus; and 8, May 2014 for vinca). Tap water was incrementally added to the tub to saturate the substrate until the water level reached just below the rim of the containers. The containers were allowed to saturate for ten minutes, then they were removed from the tub, allowed to drain for 10 minutes, weighed, and placed on a greenhouse bench. Plants were not irrigated and were allowed to dry under normal greenhouse conditions so that the degree of wilt could be observed. Wilting stages were visibly determined as follows: stage one – initial flagging, stage 2– leaves/petioles drooping (approximately 45°) towards the stem, and stage 3 – complete reduction of leaf surface and loss of turgidity. As plants reached each of the three wilting stages the substrate was sampled by removing the plants from their containers and extracting a 1-2 cm deep, 2 cm wide column of substrate from the entire profile of the root ball. Three replications of each plant species at each wilting stage were collected. Roots were removed from the substrate samples and the samples were placed in 3.7 x 1.1 cm stainless steel sample cups (Decagon, Pullman, WA) which were then placed in the dewpoint potentiameter to determine the water potential of the individual samples. Samples were weighed immediately after measurement in the dewpoint potentiameter, then dried in a forced air oven at 105°C and weighed again to determine moisture content. After the substrate sample was removed from each plant, the plant was irrigated and observed for visual signs of recovery. After all three stages of wilt were finished and plants recovered, shoots were harvested, dried, and weighed. Data were analyzed using Tukeys Studentized Range Test ($p \leq 0.05$) (SAS Institute version 9.1, Cary, NC).

Results and Discussion:

Coleus wilted quickly, taking only 48 hours to go from complete saturation to stage 3 wilt. However, plants with either hydrogel took twice as long to exhibit stage 1 wilt than controls. Plants grown in the control substrate reached stage one wilt after 11.7 hours, whereas the plants grown in the substrates with small and large hydrogels took 22.2 and 22.5 hours, respectively (Figure 1). Although the mean for the controls to reach stage 1 was 11.3, the individual plant values were 6.63, 6.1 and 22.35 hours. Therefore, there was no means separation at stage 1 due to the variation, but clearly there was a horticultural difference in 2 of the 3 plants. Stage 2 occurred between 26 and 27 hours with stage 3 happening 48 to 51 hours after saturation. There were no treatment differences at stages 2 or 3. Moisture content decreased between stages 1, 2 and 3, but there were no treatment differences (Figure 3). Water potentials for stages 1

and 2 were similar, between -0.4 and -0.5 MPa (Figure 5), and -0.9 MPa for Stage 3. However, there were no effects of the gels over controls for water potential. Plant dry weights were similar between 40 to 43 grams for all treatments (Figure 7). All plants recovered within 3 hours after being irrigated at all stages and all treatments.

Vinca took substantially longer before reaching stage 1 wilt compared to coleus (Figure 2). Vinca plants reached stage 1 between 93 and 103 hours after saturation which illustrates its heat and drought tolerance compared to coleus. Although the controls reached stage 1 over 10 hours before the gel treatments, there was no statistical differences. However, the controls did reach stage 2 sooner than the large and small gel treatments (119, 134, and 144 hours, respectively). Stage 3 was reached at 165, 178 and 187 hours for the control, large and small gel treatments, respectively. However, these were not statistically separate. Moisture content at wilt was much lower than Coleus at all stages of wilt (Figure 4). Vinca reached stage 1 at 20 – 25% moisture, stage 2 at 15 – 18% and stage 3 at 15 – 20% moisture. There were no differences among treatments for moisture content or water potential within wilting stages. Although there were no treatment differences, water potentials during wilting were much higher for vinca than for coleus (Figure 6). Stage 1 was reached at -10 MPa while coleus was only -0.4 MPa. Stage 2 occurred at water potentials between -15 and -21 MPa, while stage 3 went as high as -30 MPa. These values are much higher than the -1.5 MPa value usually regarded as where permanent wilt occurs. However, all plants at all stages recovered within 3 hours of rehydration. Shoot dry weight was highest for the plants grown in the control mix, and lowest for plants grown in the largest size hydrogel (Figure 7).

There was a marked difference in the time to wilt, moisture content and water potentials between coleus and vinca. Gel size did not seem to make a difference in the way plants dried. There was a 10 hour extension between saturation and stage 1 wilt for both species with the gel treatments. Vinca reached water potentials not previously reported and much greater than traditional values for permanent wilt with total plant recovery.

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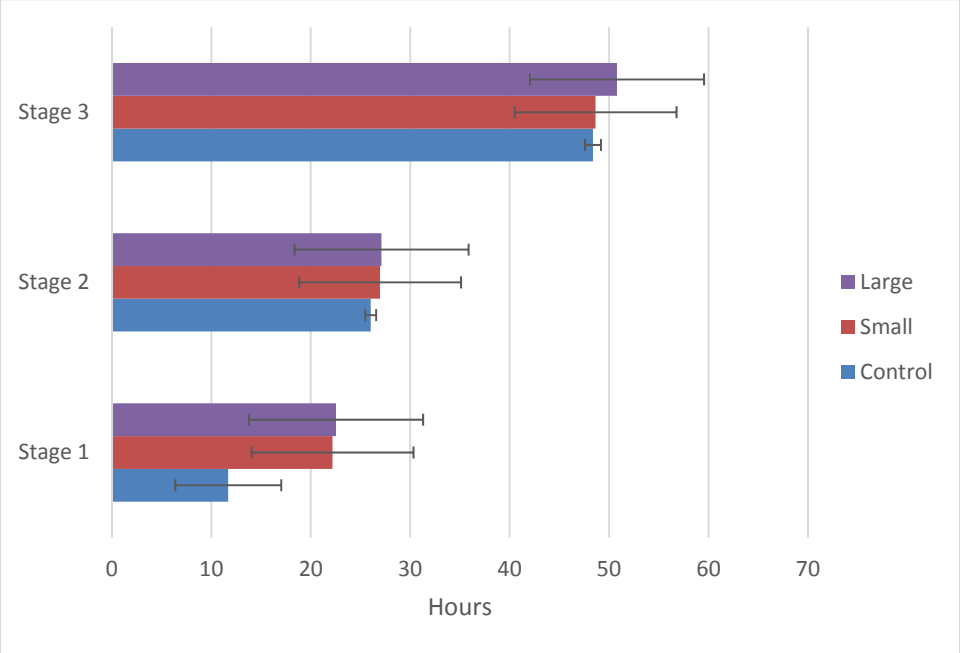

Figure 1. Hours taken to reach the three stages of wilt for coleus (*Solenostemon scutellarioides* 'Kong Salmon Pink') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

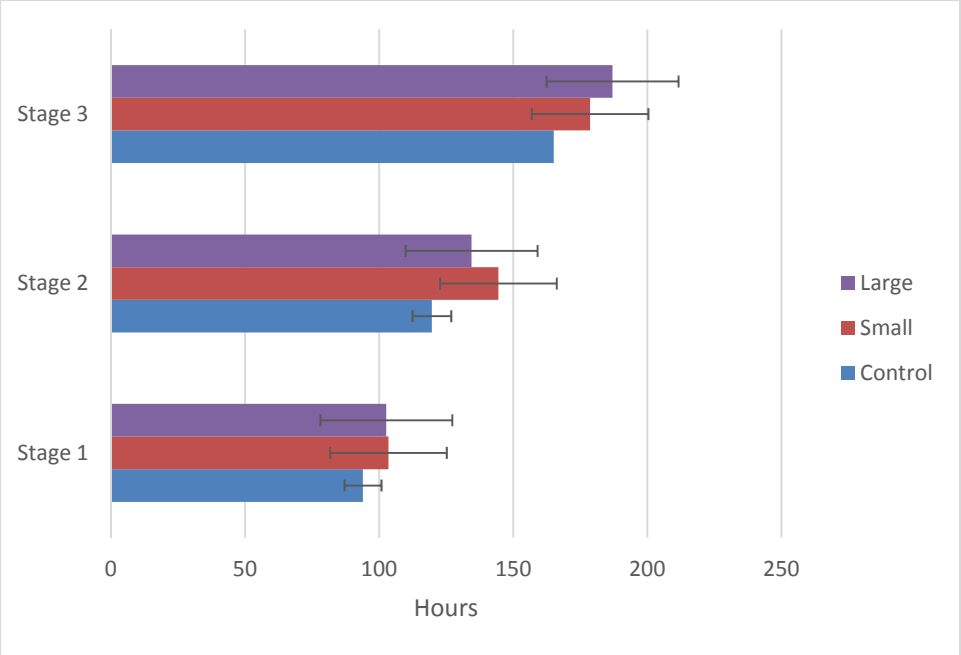

Figure 2. Hours taken to reach the three stages of wilt for vinca (*Catharanthus roseus* 'Cora Apricot') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

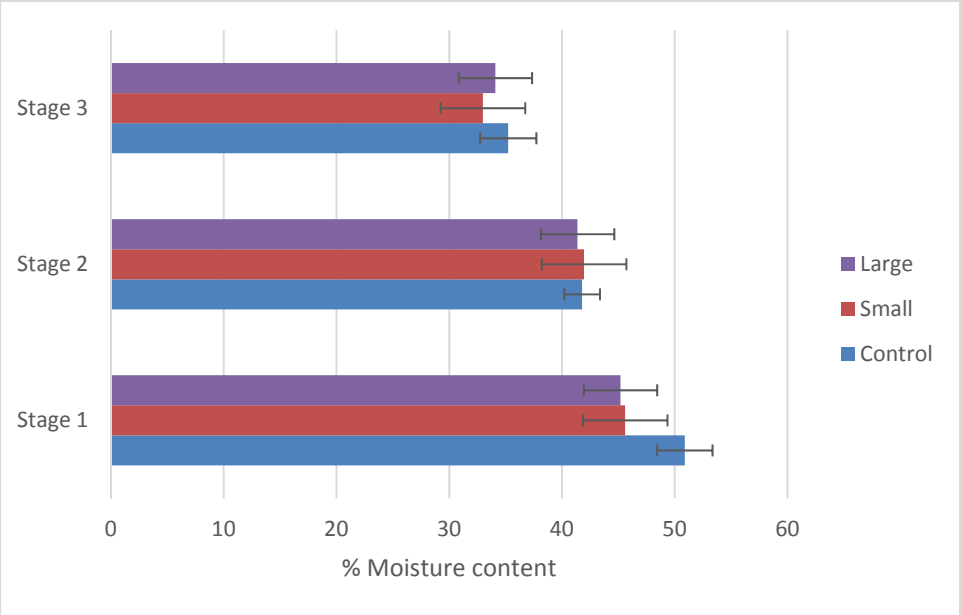

Figure 3. Moisture content of substrate samples of coleus (*Solenostemon scutellarioides* 'Kong Salmon Pink') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

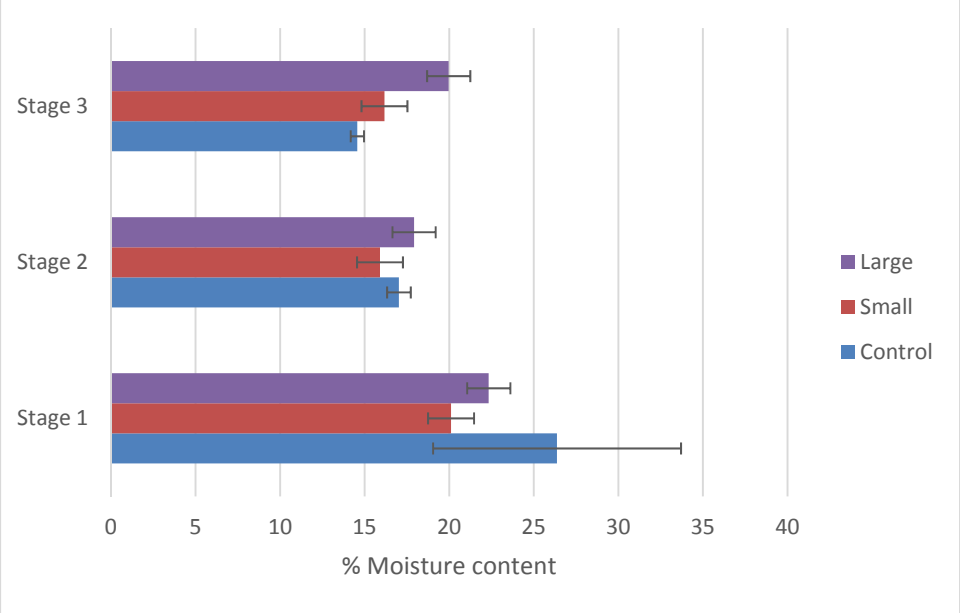

Figure 4. Moisture content of substrate samples of vinca (*Catharanthus roseus* 'Cora Apricot') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

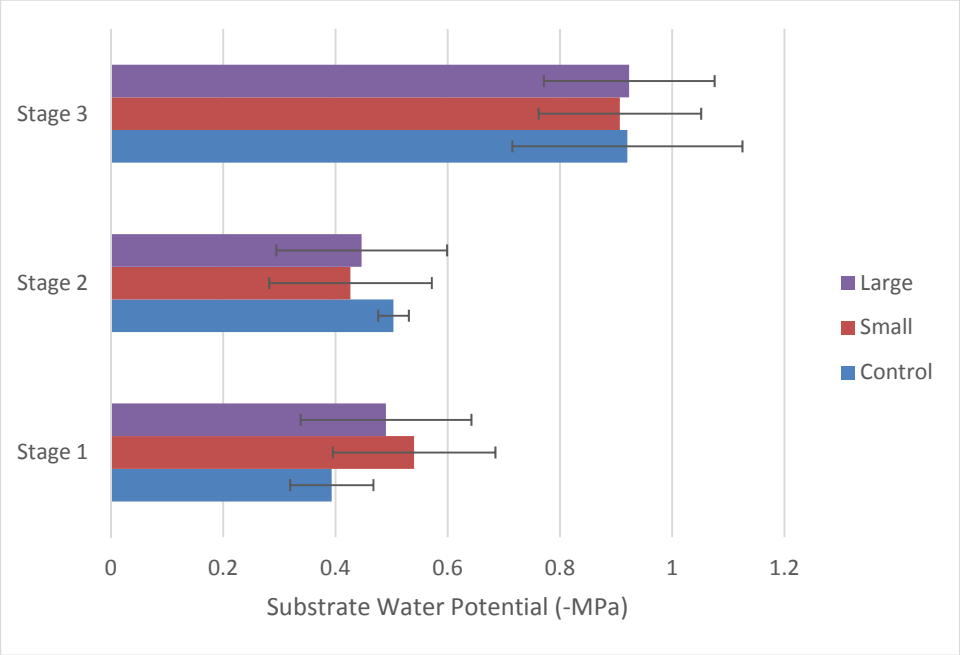

Figure 5. Substrate water potential for coleus (*Solenostemon scutellarioides* 'Kong Salmon Pink') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

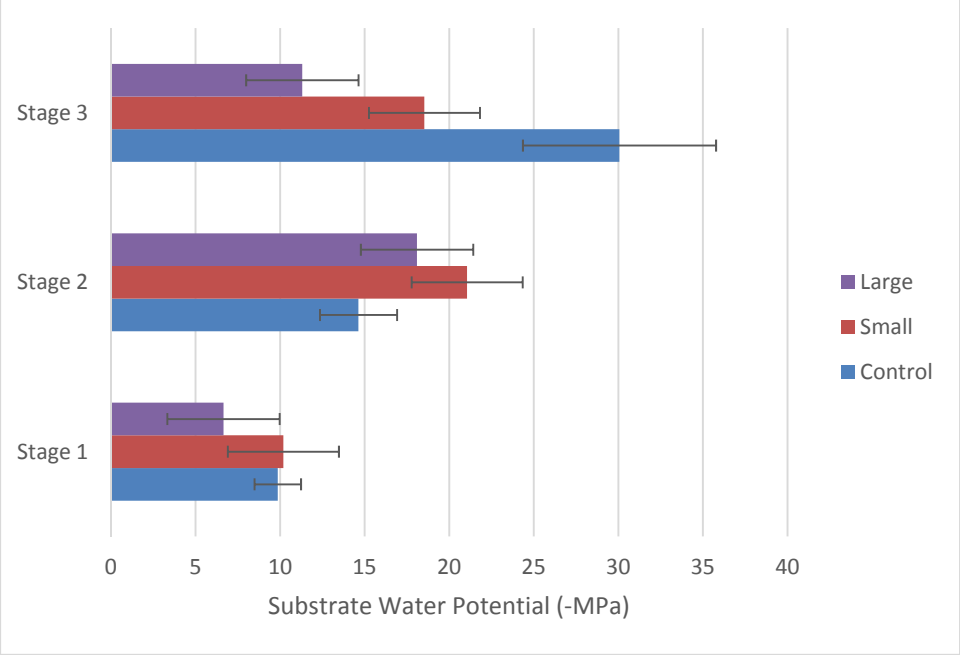

Figure 6. Substrate water potential for vinca (*Catharanthus roseus* 'Cora Apricot') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

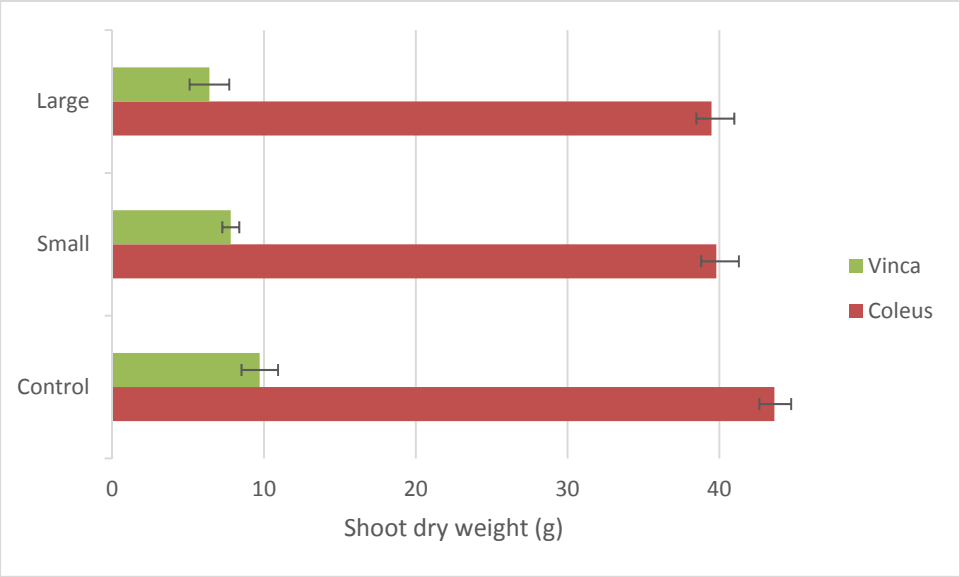

Figure 7. Shoot dry weight of coleus (*Solenostemon scutellarioides* 'Kong Salmon Pink') and vinca (*Catharanthus roseus* 'Cora Apricot') grown in substrates containing 3 parts peat moss: 1 part vermiculite: 1 part perlite, with no hydrogels incorporated (control) or with 34 g/ft^3 of two different particle sizes (small: 0.2mm – 0.8mm, and large: 0.8mm – 2.0mm) of hydrogel.

Repairing the Break in the "Cycle" of "Re-cycle": Bio-plastic Container Cropping System

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Index Words: Plastic containers, nursery/landscape industry, bio-plastic containers, plant fiber containers, plantable pots, SPI codes

Significance to the Industry: Agricultural businesses use 540 million tons of plastics with plastic containers (pots, flats, & trays) representing 59%. These plastics contribute to carbon emissions, represent 8% of the world's annual petroleum use (4% production, 4% transportation), create disposal issues (20% of solid landfill wastes by volume), are expensive, and remain in the environment indefinitely. Because recycling options for horticultural plastic containers are limited and reuse of plastic containers is not always economically feasible, the industry must take advantage of opportunities to reduce the volume of plastics used during crop production especially in honor of the name – 'the green industry.' The PolyAmide + PLA (70/40) container provided by Iowa State University (ISU) had some issues of remaining rigid in hot summer conditions. When picked up it could bend and spill substrate. The one and no coat paper fiber pots did not retain their structural integrity in the trial. Some had completely failed after the winter with their bottoms completely detaching from the remainder of the pot when picked up. The industry standard HDPE black pot used in this trial, performed extremely well, as expected. The two-coat polyurethane (partially derived from plants) paper-fiber pots; however, was statistically comparable for all measured variables to the control HDPE pot, for both species investigated. The paper fiber pots are also readily available, easily made, biodegradable and inexpensive.

Nature of Work: Alternatives to plastics include containers made of plant based fibers, plant or animal proteins (bioplastics), and recycled by-products of various industries. Little information about the performance of modern biodegradable pots (pots that degrade in compost piles) or plantable pots (pots that degrade when planted directly in the ground or buried beside the plant) exists in the scientific literature. Many horticultural companies are successfully using such 'green' pots even though most alternative pots currently on the market are yet to be examined in an applied setting. This lack of information is a competitive disadvantage to nursery container producers and nursery growers and is *critical* if the industry wants to properly utilize sustainable plant containers on a long-term basis. The Society of the Plastics Industry (SPI) established a classification system based on the numbers 1-7, in 1988. The **SPI** code, or number, is placed on each plastic product and is usually molded into the bottom. The SPI

number indicates what type of polymer was used to produce the item. Many nursery containers are made from high density polyethylene (HDPE) with an SPI code #2 or from polypropylene (PP) with an SPI code #5. The nursery HDPE containers are blow-molded and usually have a hole in the bottom of the container. HDPE resists breakage in full sunlight which results in its utility in container nurseries. Many recyclers will not take #5 plastics or #6 (which is polystyrene). Therefore, many #5 plastic containers will be discarded into landfill sites. Reusing HDPE containers can only be done with proper cleaning and sterilization. Most nurseries lack space required to store: 1) three types of containers, (i.e., new unused, washed for reuse, and unwashed to be reused) and 2) to hold containers, often in a converted truck trailer fed by a steam generator for several days during the sterilization process. Only small, specialty nurseries with high profit margins can consider the investment in the storage area required and the expense of cleaning and sterilization required for reuse. Another limitation to container reuse is return of the containers from end users. Nursery growers are not the end users of many of these containers; landscape, retail operations and the public are the end users thus there is a break in the 'cycle' part of 're-cycle.'

This research is in collaboration with ISU, and funded by USDA, Specialty Crop Research Initiative. ISU has lead for years in the development of corn and soy based plastics. The role of Ohio State University (OSU) in this project was to help understand the usefulness of biodegradable and plantable pots in production, landscape, and composting environments and to extend this information to the respective 'green industry' sectors. The overall goal is to reduce commercial greenhouse and nursery reliance on environmentally unfriendly and increasingly expensive plastic plant containers through four assessments: 1) Biodegradation and pot impacts on plants growth and quality produced in nursery sites; 2) Biodegradation, compostable and plantable ('green') pots in nursery production settings; 3) Windrow and backyard composting on the degradation of biodegradable pots; and, 4) Plantable pot impacts on crop growth and pot degradation in landscapes. This paper deals with the first assessment.

Materials and Methods: Two species were evaluated in the bio-plastic study at OSU in 2013, *Sedum pachyclados* (dwarf stonecrop) and *Forsythia ovata 'Northern Gold'.* The sedum was obtained from Millcreek Gardens LLC**,** Ostrander, OH as one, 80 cell seedling plug tray, where each cell plug volume was 16cc, on April 24, 2013. The forsythia was obtained as bare root liners from North Branch Nursery Inc., Pemberville, OH, on April 24, 2013. The sedum and forsythia were potted into one gallon pots May 14, 2013. Eight one gallon containers of each of eight types of pots were shipped from Iowa State University (ISU), Ames, IA on June 4, 2014 and were received at Ohio State University (OSU), Columbus, OH, June 10, 2014. The bio-plastic trial was initiated on June 14, 2013 with 8 pot types at OSU in a retractable roof greenhouse (Cravo, Brantford, Ontario, Canada). The pots were placed on black geotextile ground fabric, laid on top of a gravel bed, to prevent rooting into the gravel. Each pot type was replicated 4 times in a completely randomized design. The pot types consisted of two Mirel™ (Metabolix®, Cambridge, MA) composites, Mirel™ & lignin (80/ 20) (#11) and, Mirel™ P1008 (10% Starch) (#14-G); one polyamide composite and blend, PolyAmide +

PLA (70/40) (#17); one Aspen Research Corporation (Maple Grove, MN) pots, Recycled PLA # 2 (#24); one control, high density polyethylene pot (HDPE) (#26-G); and, three coated fiber containers, Paper-fiber (Polyurethane - one coat) (#27-G), Paper-fiber (Polyurethane - two coats) (#28-G) and Paper-fiber (Polyurethane – no coat) (29-G).

Mirel™, obtained from Metabolix®, is a bio-based Polyhydroxyalkanoaste (PHA). The Mirel products used in this study are PHA/ lignin – cellulose fiber composites. The cellulose and fibers are supplied from corn stover and dried distillers grains with solubles (DDGS). DDGS is a co-product of the ethanol production process and is a high nutrient feed valued by the livestock industry. When ethanol factories make ethanol, they use only starch from corn and grain sorghum. The remaining nutrients - protein, fiber and oil - are the by-products used to create livestock feed called DDGS. A third of the grain that goes into ethanol production comes out as DDGS. Each bushel of grain used in the ethanol-making process produces 2.7 gallons of ethanol; 18 pounds of DDGS and 18 pounds of carbon dioxide. The poly lactic acid or polylactide (PLA) used in this study is a thermoplastic aliphatic polyester produced from renewable resources, such as corn starch through a fermentation process. PLA is the most widely used bio-based and biodegradable polyesters. Polyamides are biodegradable poly-ester-amides (PEAs) which are biomaterials derived from α-amino acids, diols, and diacids. PEAs are promising materials for biomedical applications such as tissue engineering and drug delivery because of their optimized properties and susceptibility for either hydrolytic or enzymatic degradation. Because of their use in medicine these were also the most expensive material used in the trial. The paper fiber pots used consist of no, one or two coatings of polyurethane. The polyurethane used was manufactured in part with bio-materials.

Three evaluations were conducted at one month after potting (1 MAP), 2 MAP and 4 MAP. Evaluations consisted of rating the quality of the pots (including a measure of integrity and rigidity), and plant quality (including a measure of growth and appearance), on a scale of 0 to 10, where 10 is perfect and $\geq$7 is commercially acceptable. Dry weights of plant roots and shoots were not taken at 4 MAP as an evaluation of plant and pot was to be conducted post-overwintering in May, 2014.

Results and Discussion: For *Forsythia,* one coat polyurethane was statistically the lowest quality pot compared over all evaluation dates (Table 1); however, for *Sedum* the paper-fiber no polyurethane coating container was the lowest quality container (Table 1). The low pot quality of the one and no-coat polyurethane fiber containers included assessing integrity (by lifting) and rigidity (by lifting). We hypothesized the no-coat container would be have the shortest longevity regardless of species. We also hypothesized that species would be non-significant for pot appearance. With the *Sedum*, the plants were small and using less water early in the trial. The quality ratings were much lower for *Sedum* (Table 2) in date 1 and 2 evaluations versus *Forsythia* (Table 3). The *Forsythia* were larger and used more water and thus, the container media was kept less saturated versus the *Sedum.* We speculate this is why species was significant for pot appearance and why *Sedum* performed poorly with the no-coat (Table 1). The *Forsythia's* poor quality in the one-coat polyurethane containers (Table1)

we speculate was the result of a low rating in the date 4 evaluation (Table 3). The quality of *Forsythia* on the last date was statistically poorer in the no- and one- coat pots, but not statistically different from one another. Because of the decline in tquality of he *Forsythia* in the no- and one-coat pots the no-coat performed worse than expected probably due to higher saturated conditions for the pot (Table 1). PolyAmide + PLA (70/40) container had some issues with rigidity in hot summer conditions. Although note-worthy, it did not severely impact the pot appearance rating combined over dates (Table 1). When picked up, the PolyAmide + PLA (70/40) container would bend and spill substrate. This was more of an issue for the *Sedum* (dwarf stonecrop) than for the *Forsythia*. *Sedum pachyclados* is a ground cover sedum and true to this group is very shallowly rooted. The *S. pachyclados* has long horizontal trailing stems that grow along the surface of the soil and produces roots and shoots at the nodes or tips (2). This shallow creeping root habit was prone to damage when the PolyAmide + PLA (70/40) container would bend and spill when temperatures were highest (Table 2). The disruption in growth was quite damaging to the *Sedum* (Table 2) versus the *Forsythia* (Table 3). However, by the trial end, once the structural integrity of the pot was stronger in the cooler temperatures of fall, the stonecrop (Table 2) was growing comparatively well compared to the *Forsythia* (Table 3). The one and no coat paper fiber pots did not retain their structural integrity in the trial. Some had completely failed after the winter with their bottoms completely detaching from the remainder of the pot when picked up. All plants in the trial died in the unusually severe winter conditions of 2013-2014. Dwarf Stonecrop which was hardy to only -10°F experienced temperatures of -11°F overwintering in January 2014. The 'Northern Gold' was developed by Agriculture Canada and is known to have the hardiest of flower buds (3). However, roots are far less hardy than shoots. Steponkus (1) found shoots of very hardy plants can be as much as 15 degrees Fahrenheit hardier. The lack of hardiness of the roots systems and subsequent death of all trial plants rendered plant growth evaluations impossible for spring 2014 (as originally planned). The containers with acceptable structural integrity, however, were retained and repotted with new species for 2014 evaluations. Pots that had failed with their bottom collapsing when lifted were recorded and discarded.

Although, the Polyamides (PEAs) + PLA pots did well in this study for both species the PEAs are becoming very expensive. The standard HDPE black pot used as the industry standard also performed extremely well as expected. The two-coat polyurethane was comparable to the control HDPE pot for both species. Trials in 2014 will focus more on the paper-fiber pots with two coatings. The paper fiber pots are also readily available, easily made, biodegradable and inexpensive. We are continuing these trials in 2014 at OSU and will be doing pot degradation and composting studies as well.

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Table 1. Container appearance mean ratings for seven bio-plastic container types developed at Iowa State University, Ames, IA evaluated for appearance and averaged over evaluation dates for two species of plants grown in 2014 at Ohio State University, Columbus, OH compared to an HDPE (industry standard) trade gallon container.

Treatment	Date 1		Date 2		Date 4	
Mirel & Lignin	7.4≠	a∗	9.8	a	4.0	b
Mirel 1008	4.4	ab	4.4	abc	7.7	ab
PolyAmide + PLA	2.8	ab	2.5	c	7.4	ab
Recycled PLA#2	5.8	ab	6.5	abc	4.0	b
HDPE trade-gallon (check)	2.4	b	4.0	b	8.8	a
Paper-fiber (polyurethane) (1 coat)	5.0	ab	7.8	abc	4.5	b
Paper-fiber (polyurethane) (2 coat)	6.6	ab	9.6	ab	6.0	ab
Paper-fiber (polyurethane) (no coat)	4.5	ab	5.0	abc	6.5	ab

∗Means with the same letters are not statistical different from one another using at p> 0.05, lsmeans.

≠ Rating of container appearance is 0-10, where 10 is no visible appearance problems, ≥ 7 is commercially acceptable and 0 is a disintegrated container.

Table 2. Plant quality means for *Sedum pachyclados* grown in seven bio-plastic container types developed at Iowa State University, Ames, IA evaluated at three dates in the 2014 growing season at Ohio State University, Columbus, OH compared to an HDPE (industry standard) trade gallon container.

Treatment	*Forsythia ovata* 'Northern Gold'		*Sedum pachyclados*	
Mirel & Lignin	10.0≠	a∗	9.0	a
Mirel 1008	10.0	a	10.0	a
PolyAmide + PLA	10.0	a	9.4	a
Recycled PLA#2	8.0	b	9.8	a
HDPE trade-gallon (check)	10.0	a	10.0	a
Paper-fiber (polyurethane) (1coat)	4.8	c	6.0	b
Paper-fiber (polyurethane) (2coat)	8.4	b	7.2	b
Paper-fiber (polyurethane) (no coat)	7.0	b	4.4	c

∗Means with the same letters are not statistical different from one another using at p> 0.05, lsmeans.
≠Plant injury rating is 0-10, where 10 is no phytotoxicity, ≥ 7 is commercially acceptable and 0 is a dead plant.

Table 3. Plant quality means for *Forsythia ovata* 'Northern Gold' grown in seven bio-plastic container types developed at Iowa State University, Ames, IA evaluated at three dates in the 2014 growing season at Ohio State University, Columbus, OH compared to an HDPE (industry standard) trade gallon container.

Treatment	Date 1		Date 2		Date 4	
Mirel & Lignin	10.0	ns∗	10.0	ns	5.8	ns
Mirel 1008	10.0	ns	10.0	ns	5.4	ns
PolyAmide + PLA	10.0	ns	10.0	ns	6.5	ns
Recycled PLA#2	10.0	ns	10.0	ns	7.0	ns
HDPE trade-gallon (check)	10.0	ns	10.0	ns	6.8	ns
Paper-fiber (polyurethane) (one coat)	9.8	ns	10.0	ns	4.4	a
Paper-fiber (polyurethane) (two coat)	10.0	ns	10.0	ns	6.8	ns
Paper-fiber (polyurethane) (no coat)	10.0	ns	10.0	ns	4.7	a

∗Means with the same letters are not statistical different from one another using at p> 0.05, lsmeans; ns signifies non-statistically different
≠Plant injury rating is 0-10, where 10 is no phytotoxicity, ≥ 7 is commercially acceptable and 0 is a dead plant.

Physical and Hydrologic Properties of Processed Pine Bark and Wood

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Significance to Industry: It is well known that substrate particle size distribution and physical properties affect irrigation frequency, nutrient availability, air space and container capacity. This research shows two common horticultural substrate components, pine bark and pine wood have varying physical properties and water release patterns at similar particle sizes. Physical properties of these materials can be manipulated by adjusting variables in processing. Attention to processing is important for attaining consistent properties. Bark particles hold more water than wood, most likely due to their internal structure. Particle size distribution of pine bark or pine wood does not guarantee that physical properties of those substrate materials will be similar, even with identical processing. An understanding of bark and wood processing and particle size is needed to produce substrates with desired physical and hydrologic properties.

Nature of Work: Pine bark has been researched for decades, but little work has been conducted on the processing of pine bark and the effects it may have on particle size and physical properties when it is used as a substrate component. The size and shape of milled pine bark has been shown to vary considerably (1). Measuring substrate particle size distribution helps determine the physical nature and anticipated physical properties of a substrate component (3,8). Altering particle size distribution of pine bark has been shown to significantly affect water-holding characteristics (12).

Generally, in soils, plant available water is held on or between particles. However, with organic materials, such as pine bark, it has been shown that individual particles can hold water within internal pore spaces. Water within these internal pore spaces has been shown to be available for plant use provided adequate root development has occurred (9,11).

Processing fresh pine wood for use in plant production substrates has become more common in recent years. However there is little research on the processing of pine wood materials and how they relate to substrate physical properties and crop production. Since pine wood particle size is created during the milling process, producers have the ability to develop particle sizes specific to their needs (7). Manipulating particle sizes and the resultant pore sizes within a substrate could allow the engineering of a substrate with desired plant growing conditions (4). However, due

to the lack of research in this area useful particle size distributions of wood-based materials are currently unknown. The purpose of this study was to explore how manipulating particle size affects substrate air and water relations in milled pine wood compared to milled pine bark.

Unprocessed pine bark nuggets and coarse loblolly pine wood chips (*Pinus taeda)* were acquired. Both materials were processed in a hammer mill (Meadows Mills, North Wilkesboro, NC) at the Substrate Processing and Research Center located at the Horticultural Field Laboratory on the campus of North Carolina State University located in Raleigh, NC. The materials were processed through the mill with no screen inserted to assure a wide variation of particle sizes (known to occur as experienced in personal observations). To prevent moisture loss after milling, processed materials were sealed in plastic 55-gallon drums for further testing.

For particle size distribution, three 100g samples of each material were dried at 105°C for 48 hours and placed in a Ro-tap Shaker (Model B, W.S. Tyler, Mentor, OH) for 5 minutes with six sieve sizes of 6.3, 2, 0.71, 0.5, 0.25, and 0.106 mm and a pan at the bottom to collect all materials that passed through the smallest sieve. Due to the hydrophobicity of dried pine bark (2), and the need to keep the materials moist for physical property testing, particle size distribution of representative moist samples for both materials was obtained using the same method, on non-dried samples. Both pine wood and pine bark were then sieved and grouped into four individual size fractions: extra-large, > 6.3mm, large, < 6.3mm > 2mm, medium, < 2 > 0.5mm and fine, ≤ 0.5mm. Physical properties of all sieve fractions of both the processed pine wood and pine bark were determined using the North Carolina State University Porometer Method (5).

After sieving, the particle size fractions observed in the milled pine wood were re-engineered in pine bark. This same process was then conducted on pine wood, blending the fractioned material to have the same particle size distribution observed in pine bark. All samples were hydrated to 60% moisture (w/w) except for the largest two pine wood fractions, which were wetted to 50% (w/w) to represent appropriate wetness for use in horticulture production and allowed to equilibrate for 24 hours. The above physical properties were determined on the reengineered particle size materials.

Drying characteristics for the large (< 6.3mm > 2mm) and medium (< 2 > 0.5mm) sized fractions of both materials were determined. Nine samples were taken from the large and medium fractions of both pine wood and pine bark, for a total of 36 samples. Samples were oven dried at 30°C. Three samples of each material were weighed at 2, 4 and 26 hours to determine moisture content. Data were analyzed using general linear model procedures and regression analysis (SAS Institute version 9.3, Cary, NC). Means were separated by least significant differences at $P \leq 0.05$.

Results and Discussion: Particle size distribution of oven-dried material compared to their moist counterparts was found to have no difference in the pine wood. Similarly, no difference was found in the pine bark distributions except for the fine bark fractions of

≤ 0.5mm in which a 5% loss was observed (Table 1). This can be accounted for by the moisture present in the materials allowing a small percentage of the fines to stick to the larger particles. Wood had inherently more large particles and less than half as many fines than the bark.

Fewer fines resulted in almost twice the air space for wood (42%) compared to pine bark (25%) with only slightly different bulk densities between the two (Table 2). When pine bark was re-engineered with the same particle size distribution as pine wood, reducing the number of fines by 13%, there was no observable difference in the water holding characteristics. The physical properties of the pine wood changed considerably when modified into the bark distribution, here increasing the amount of fines increased the container capacity, which is expected (6).

Fines held more water than any other particles. Extra-large particles also behaved as expected and were similar for both materials. Large and medium sized particles collectively seem to hold approximately 20% more water in bark than in the wood materials. A large amount of the water holding capacity seems to be held in these middle two fractions. This may be accounted for by the internal cellular connections and the amount of variation in size and structure that have been observed in milled bark particles (1).

To address this difference in internal structure, the large and medium bark and wood fractions were dried. The large bark particles hold more water than wood and dry at approximately the same rate (Figure 1). However, the medium size bark and wood materials have the same moisture content but dry differently (Figure 2). The bark held more water at 2 and 4 hours of drying. This slower drying pattern is indicative of water being held within the particles and having to dry from within. The large size material did not exhibit this same pattern. Although the bark and wood used in this study were taken from the same species it is evident that there are fundamental differences in their ability to hold and release water. Wood may have less internal structure for holding water. Further research needs to be conducted on the manufacture of wood materials for use in horticultural substrates.

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Table 1. Particle size distribution of pine bark and pine wood.

Substrate	Extra–large (>6.3mm)	Large (6.3 to 2.0mm)	Medium (2.0 to 0.5mm)	Fines (≤0.5mm)
Bark dry	4.3 a[z]	30.5 b	29.2 c	40.5 a
Bark moist	5.0 a	27.3 b	32.3 bc	35.4 b
Wood dry	4.1 a	46.4 a	35.9 a	13.6 c
Wood moist	5.6 a	47.2 a	35.0 ab	12.2 c

[z]Means separation between all materials by LSD, P<0.05. Means followed by the same letter the same column are not significantly different.

Table 2. Physical properties of milled pine bark, wood and the materials when recreated with each other's particle size distribution (PSD).

Substrate	Total porosity (% vol)	Container capacity (% vol)	Air space (% vol)	Bulk density g/cc
Bark	81.3 b[z]	56.0 b	25.3 b	0.18 a
Engineered[1] bark	79.5 b	54.2 b	25.3 b	0.18 a
Wood	87.9 a	45.6 c	42.3 a	0.16 b
Engineered[2] wood	87.2 a	68.7 a	18.5 c	0.15 b

Means separation between all materials by LSD, P<0.05. Means followed by the same letter the same column are not significantly different.

[1] Bark engineered to have particle size distribution originally found in wood of 5.6% extra-large, 47.2% large, 35% medium and 12.2% fine particles.

[2] Wood engineered to have the particle size distribution originally found in bark of 5% extra-large, 27.3% large, 32.3% medium and 35.4% fine particles.

Table 3. Physical properties of four individual size fractions for milled pine bark and wood.

Substrate	Total porosity (% vol)	Container capacity (% vol)	Air space (% vol)	Bulk density g/cc
Bark x-large[y]	83.6 abc[z]	29.1 f	54.5 a	0.13 dc
Wood x-large	82.7 bc	26.1 f	56.6 a	0.18 a
Bark large[x]	82.7 bc	44.3 d	38.4 c	0.16 abc
Wood large	80.0 c	34.3 e	45.7 b	0.15 bcd
Bark medium[w]	84.8 abc	65.4 b	19.4 e	0.17 ab
Wood medium	87.9 a	55.8 c	32.0 d	0.13 dc
Bark fines[u]	83.2 abc	74.2 a	9.0 f	0.19 a
Wood fines	87.2 ab	76.3 a	10.8 f	0.12 d

[z]Means separation between all materials by LSD, P<0.05. Means followed by the same letter the same column are not significantly different.

[y]X-large particles > 6.3mm in diameter.

[x]Large particles < 6.3mm > 2mm in diameter.

[w]Medium particles < 2 > 0.5mm in diameter.

[u]Fine particles ≤ 0.5mm in diameter.

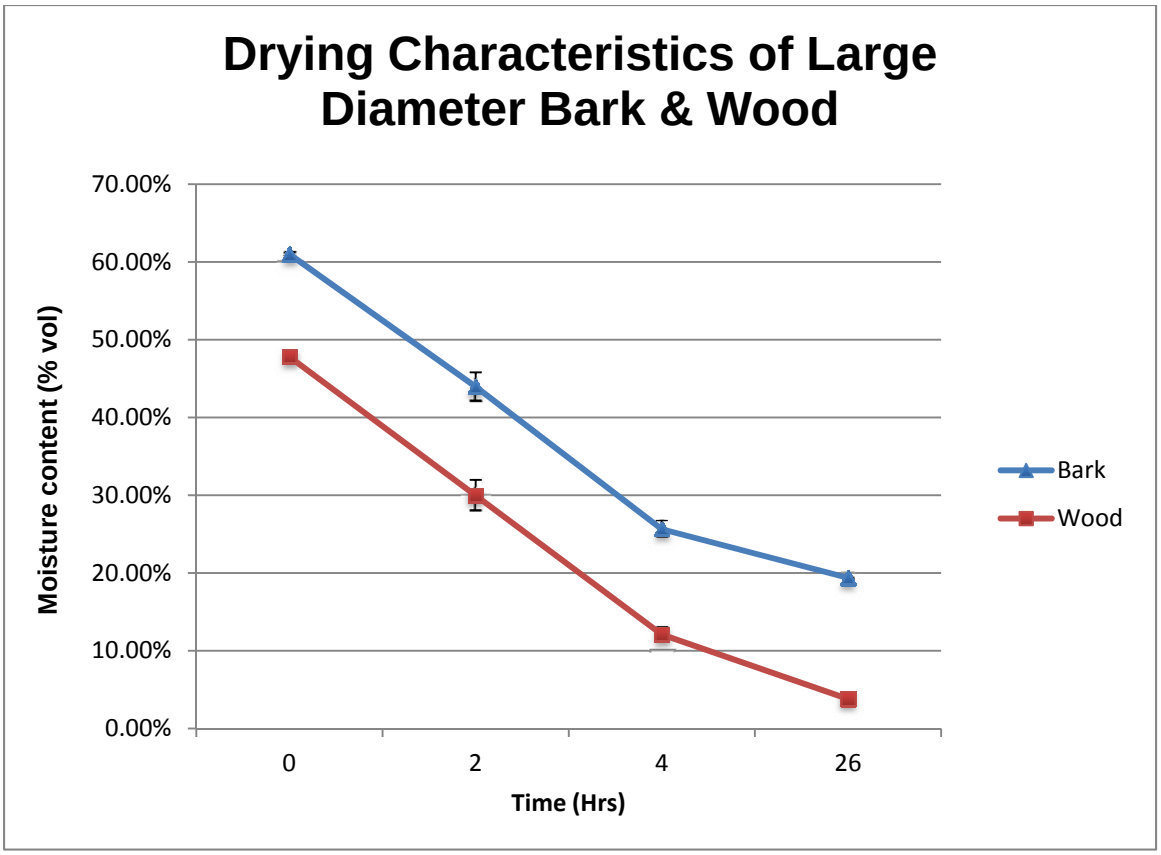

Figure 1: Drying characteristics of large (< 6.3mm > 2mm in diameter) pine bark and pine wood particles during oven drying. Vertical bars represent standard errors.

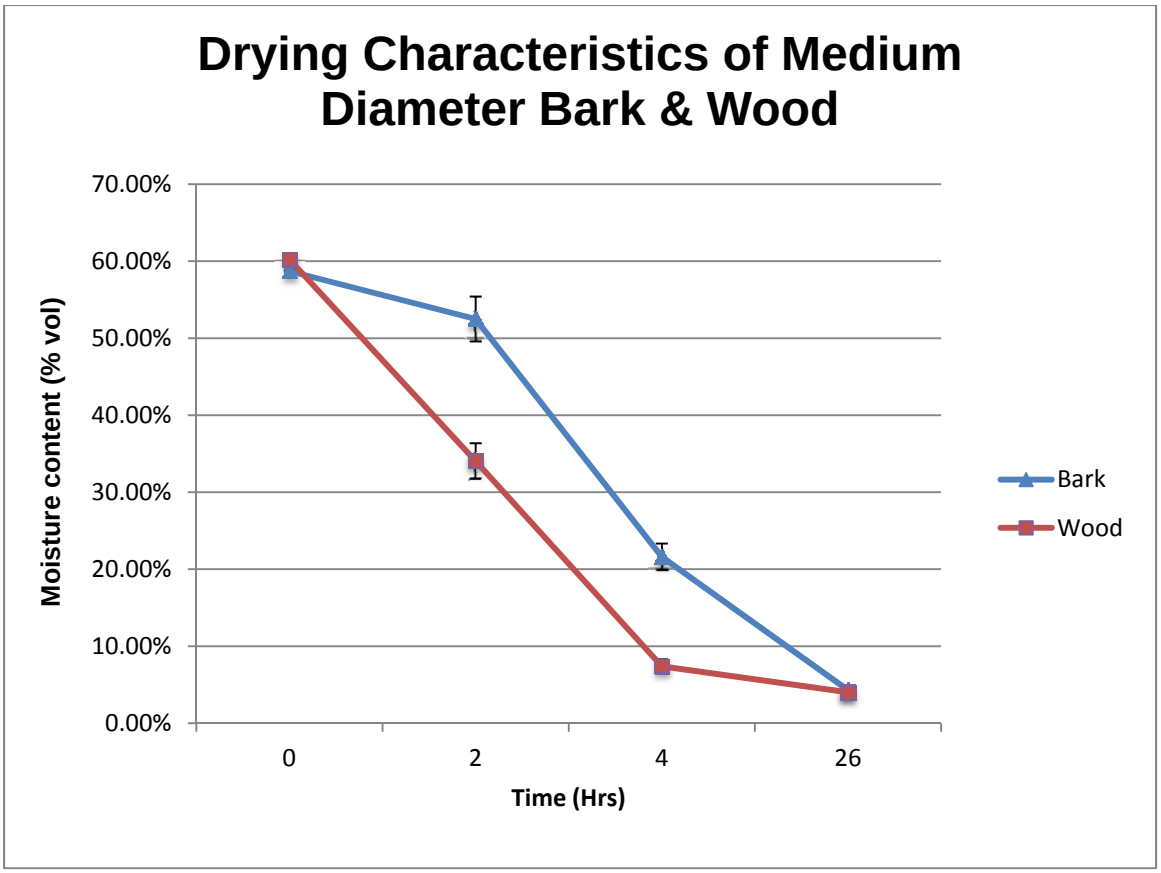

Figure 2: Drying characteristics of medium (< 2 > 0.5mm in diameter) pine bark and pine wood particles during oven drying. Vertical bars represent standard errors.