Container Grown
Plant Production

Derald Harp

Section Editor

Plant Growth and Nutrient Leaching Losses from Protein Byproduct-based Fertilizers

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Significance to Industry: Commonly-used fertilizer formulations and application methods have changed little over the past 40 years. As fossil fuel prices rise and the global energy landscape changes, many industries are exploring new applications for renewable resources. Here we report on the use of an underutilized industrial waste stream (rendered animal materials) to produce effective slow-release fertilizer materials. This technology will benefit both first-world and developing nations by increasing plant nutrient use efficiency, decreasing dependence on fossil fuels, and reducing the environmental impacts of fertilizer production. The material has practical applications for nursery operations where nutrient runoff can negatively impact water quality and a gradual release of plant nutrients is desirable.

Nature of Work:

Background and Rationale

Our long-term goal is to develop new fertilizers and soil amendments that maximize plant nutrient use efficiency (NUE), minimize nutrient leaching and employ economically-feasible source materials. Current fertilizer formulations rely primarily on inorganic and simple organic forms of nitrogen (N), including urea, ammonium salts, and nitrate salts. This approach results in relatively high nitrogen delivery over a short period of time, often exceeding the plant's uptake capacity and promoting low NUE.[1] Such nitrogen forms are readily released into runoff, increasing the risk of offsite environmental impacts such as accelerated eutrophication. As an alternative to these commercial fertilizers, we have revisited a historically-employed fertilizer matrix: rendered animal proteins. Animal wastes and byproducts have been used as fertilizers since antiquity but were generally phased out in the 20th century due to the availability of low-cost inorganic fertilizers. Here we present the results of several trials comparing the performance of protein by-product fertilizers with those of typical inorganic fertilizers. We focus in particular on plant growth, tissue nitrogen content, and nutrient leaching losses.

Materials and Methods

Poultry meal was obtained from several southeastern US rendering plants through the Animal Co-products Research Center at Clemson University. The rendered material was extracted to remove fatty acids and triglycerides and combined with various binders to produce first- and second-round experimental fertilizer formulations (Table 1). The effect of these formulations on plant growth and nutrient leaching was tested using *Zea mays* (corn), *Triticum aestivum* (wheat) and *Petunia* X *hybrida* 'Plum Madness' (petunia). Two non-poultry meal formulations prepared with urea, potash, and phosphate were also tested. The "commercial" formula mimicked a typical 5-5-5 commercial fertilizer, while the "custom" fertilizer mimicked the NPK content of the rendered material.

Corn experiment -- Three corn seeds were sown into ½-gallon nursery pots filled with a 4:1 volumetric mixture of calcined clay (Turface MVP ®, Buffalo Grove, IL) and unsterilized Cecil sandy loam field soil. Fertilizer materials were applied as a top dressing prior to seed sowing. The experiment used a randomized complete block design with 17 treatments (8 first-round formulations applied at 0.105 oz. or 0.525 oz. per pot, plus an untreated control) and 8 replicates per treatment. Data from 0.105 oz. and 0.525 oz. rate plants were analyzed separately by analysis of variance using the R statistical software package, and mean separations were performed using Tukey's HSD with $P < 0.05$.

Seedlings were thinned to one per pot after germination. Greenhouse temperatures were maintained between 68 and 77 °F, and high pressure sodium lamps were used to provide a minimum of 200 W m^{-2} of light during a 16-h photoperiod. Pots received 1.7 fl oz. of water daily, increasing to 2.5 fl oz. as the plants matured. Twice every week, pots were flushed with 6.8 fl oz. of distilled water and the first 1.7 fl oz. of pot leachate was collected for nutrient analysis[2] using a Dionex ® ion chromatography system (Sunnyvale, CA) and an Orion 9512® ammonia electrode (Thermo®, Waltham, MA). Plants were harvested 8 weeks after sowing for height and dry weight measurement, and tissue samples were sent to the Clemson University Agricultural Service Lab for determination of tissue nutrient concentrations.

Wheat and petunia experiments – Wheat and petunia experiments were conducted as above, with the following modifications. For wheat, soil was a 4:1 mixture of field soil and perlite, and fertilizer materials were incorporated throughout the soil profile prior to seed sowing. The experiment used a randomized complete block design with 7 treatments (6 round two formulations applied at 0.105 oz. per pot, plus an untreated control) and 8 replicates per treatment. Five wheat seeds were sown in each pot and thinned to the strongest seedling following germination. For petunia, 3-wk-old *Petunia* X *hybrida* 'Plum Madness' plugs have been potted up into 6-in nursery pots filled with Fafard 3B potting mix into which fertilizer materials had been mixed at a rate of 0.018 oz. or 0.071 oz. per pot. The experiment uses a randomized complete block design with 8 replicates of 4 treatments: 2 rates raw rendered material (RM), commercial 15-5-15 water-soluble fertilizer applied at a 200 ppm N rate with each irrigation, and an untreated control.

Table 1. Descriptions and NPK mass percentages of first- and second-round experimental fertilizer formulations.

First-round Formulations	% N	% P_2O_5	% K_2O
Raw Material (Poultry meal; RM)	11.39	5.93	1.2
Extracted RM (ERM)	10.2	4.25	0.85
ERM + Rice Flour (ERMR)	9.43	5.16	0.85
ERM + K_2SiO_3 (ERMK)	8.7	4.65	2.8
ERM (5-5-5) (ERM5)	4.96	6.74	5.79
ERM (20-20-20) (ERM20)	8.66	16.7	10.98
Commercial 5-5-5 (CF)	5.68	10.16	5.56
Custom inorganic fertilizer (CU)	9.16	10.2	0.98
Second-round Formulations			
Raw Material (Poultry meal; RM)	9.23	6.57	0.8
Extracted RM (ERM)	9.92	8.64	0.8
ERM + Attapulgite clay binder (ERMA)	7.54	6.69	0.69
ERM + K_2SiO_3 (ERMK)	7.35	6.36	3.74
ERM + Neem cake (ERMN)	8.06	7.02	1.08
Custom inorganic fertilizer (CU)	26.22	34.88	1.64

Results and Discussion

Corn experiment -- Corn treated with both rendered material fertilizers and inorganic fertilizers grew approximately twice as tall as controls (Table 2). At both the 0.105 oz. and 0.525 oz. rates, plants treated with RM, ERM, and ERMK formulations produced plants of equal height to those treated with inorganic fertilizers. THE ERM20 formulation also performed well at the 0.525 oz. rate. Most fertilizer formulations produced plants with significantly higher foliar N% than controls, particularly at the 0.525 oz. rate. Results for other plant nutrients were similar (data not shown). These findings highlight the potential of rendered materials to serve as a viable source of plant nutrition.

Rendered material formulations generally produced plants of equal height and nitrogen content to inorganically-fertilized plants, while simultaneously releasing less nitrogen in the pot leachate (Table 2). This effect was most pronounced early in the experiment, when release of ammonium from commercial and custom inorganic fertilizer pots was significantly higher than from all other pots. Corn plants treated with 0.105 oz. of all fertilizers released nutrients at a relatively constant rate throughout the experiment. Plants treated with 0.525 oz. of the commercial and custom fertilizers leached more ammonium at the beginning of the experiment. There were no significant differences in leachate nitrate concentrations over the course of the experiment.

Table 2. 8-week corn height, foliar nitrogen content (%), and ammonium and nitrate concentrations of pot leachate for first round of rendered material product trials. Within a column, means followed by different letters are significantly different (Tukey's HSD, $P < 0.05$).

0.105 oz. Rate	**Height (in.)**	**N%**	**Ammonium (PPM)**		**Nitrate (PPM)**	
			Jan. 31	**Mar. 18**	**Feb. 20**	**Mar. 17**
Control	13.9^{c}	0.95^{d}	24.48^{b}	18.18^{b}	2.97^{a}	5.32^{a}
Commercial	25.6^{ab}	1.44^{bc}	113.04^{a}	38.16^{ab}	4.32^{a}	10.38^{a}
Custom Inorganic	26.8^{a}	1.86^{a}	136.62^{a}	60.3^{a}	1.81^{a}	6.56^{a}
RM	25.2^{ab}	1.72^{abc}	30.96^{b}	28.26^{b}	9.28^{a}	6.19^{a}
ERM	27.2^{a}	1.97^{a}	38.34^{b}	38.88^{ab}	10.95^{a}	7.56^{a}
ERMK	24.2^{ab}	1.47^{bc}	46.44^{b}	33.48^{ab}	5.85^{a}	8.88^{a}
ERMR	22.0^{b}	1.27^{cd}	33.12^{b}	21.06^{b}	4.16^{a}	13.26^{a}
ERM5	25.4^{ab}	1.42^{bc}	23.94^{b}	54.18^{a}	8.12^{a}	5.61^{a}
ERM20	21.8^{b}	1.11^{cd}	38.34^{b}	23.762^{b}	4.83^{a}	8.79^{a}
0.525 oz. Rate	**Height (in.)**	**N%**	**Ammonium (PPM)**		**Nitrate (PPM)**	
			Jan. 31	**Mar. 18**	**Feb. 20**	**Mar. 17**
Control	13.9^{c}	0.95^{b}	24.48^{b}	18.18^{c}	2.97^{a}	5.32^{a}
Commercial	30.6^{a}	3.40^{a}	821.52^{a}	460.62^{a}	4.05^{a}	92.85^{a}
Custom Inorganic	30.7^{ab}	3.50^{a}	532.08^{a}	181.44^{b}	3.00^{a}	17.37^{a}
RM	28.9^{ab}	2.75^{a}	142.56^{b}	54.36^{c}	4.31^{a}	30.95^{a}
ERM	28.9^{ab}	3.03^{a}	205.2^{b}	111.78^{bc}	4.20^{a}	32.45^{a}
ERMK	30.8^{ab}	2.62^{a}	282.24^{b}	92.88^{bc}	6.34^{a}	15.48^{a}
ERMR	28.1^{ab}	2.98^{a}	125.28^{b}	95.04^{bc}	5.36^{a}	15.91^{a}
ERM5	24.1^{b}	2.36^{a}	42.48^{b}	224.10^{b}	10.64^{a}	34.89^{a}
ERM20	30.9^{ab}	3.04^{a}	365.04^{b}	271.08^{ab}	4.29^{a}	71.53^{a}

Wheat and petunia experiments – After three weeks, wheat treated with both rendered material fertilizers and inorganic fertilizers grew larger than controls (Table 3). Plants treated with RM are equal in size to those treated with inorganic fertilizers. Wheat treated with inorganic fertilizers leached more ammonium at the beginning of the experiment. This trend is still present after 3 weeks. There were no significant differences in leachate nitrate concentrations over the course of the experiment.

Initially, a 0.525 oz. rate was included, but due to poor germination and performance, was dropped from our analyses. Higher fertilizer rates in the clay field soil appeared to burn the plants and cause osmotic stress.

Table 3. 3-week 0.105 oz. rate wheat height and ammonium and nitrate concentrations of pot leachate for second round of rendered material product trials. Within a column, means followed by different letters are significantly different (Tukey's HSD, $P<0.05$). WAP = weeks after planting.

1 WAP	Height (in.)	Ammonium (mM)	Nitrate (PPM)
Control	--	3.9^{b}	12.0^{a}
Commercial	--	24.3^{a}	8.7^{a}
RM	--	5.0^{b}	11.7^{a}
ERM	--	10.0^{b}	6.3^{a}
ERMA	--	6.8^{b}	6.9^{a}
ERMK	--	7.9^{b}	10.1^{a}
ERMN	--	9.1^{b}	10.6^{a}
3 WAP	**Height (in.)**	**Ammonium (mM)**	**Nitrate (PPM)**
Control	9.1^{b}	17.8^{ab}	30.6^{a}
Commercial	9.8^{a}	29.6^{a}	40.6^{a}
RM	10.4^{a}	5.6^{b}	42.0^{a}
ERM	10.4^{a}	18.7^{ab}	52.9^{a}
ERMA	9.5^{a}	10.7^{ab}	44.5^{a}
ERMK	11.8^{a}	7.9^{b}	41.4^{a}
ERMN	10.5^{a}	8.5^{b}	26.5^{a}

Conclusions Preliminary results indicate that plants treated with the fertilizers made from rendered animal materials grew as well as those treated with inorganic fertilizers. Further, significantly less nitrogen was lost in leachate from the pots treated with the experimental fertilizers. These results suggest that animal byproduct-based fertilizers may be useful in nursery operations where nutrient loss from pots presents a significant water quality problem. Continued work with nursery and floriculture crops in typical soilless media will help us to optimize rates and formulations for nursery production.

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Nutrient Movement in a Bark-Based Substrate During Irrigation

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Index Words: controlled release fertilizer, incorporated, topdress, electrical conductivity, leachate, container-grown

Significance to the Industry: Minimizing the leaching of nutrients from a nursery production facility is of interest to growers as it makes more efficient use of fertilizer and economic resources and may improve compliance with local environmental regulatory standards. Yet little information is known about how nutrients move through a substrate column during irrigation or rainfall and which portion of these nutrients are lost at various increments throughout a leaching event. This study explores the bulk nutrient concentration in leachate throughout the duration of an irrigation event as affected by the placement of controlled-release fertilizer (CRF) within the container profile. Nutrient concentration in leachate proved to be dynamic, with the greatest contribution coming from CRF placed in the middle of the substrate profile followed by incorporated throughout and surface applied (topdressed). Such information may help growers make more informed decisions regarding fertilizer and irrigation management.

Nature of Work: Producers of containerized ornamental crops within certain regions of the U.S. face strict legal regulation on the nutrient content of water leaving nurseries (1). Consequently, nursery producers have an interest in minimizing the quantity of agrichemicals, such as nitrogen and phosphorus, that unnecessarily leave their production facilities. Planning to meet these regulatory standards is complicated for growers given the diversity in crop nutrient and water demand, production schedules, production techniques and the high plant density in a typical nursery (5). One approach is to improve nutrient use efficiency (percent of total fertilizer applied that is utilized by the crop) by reducing nutrient leaching from containers. This strategy not only has the potential to reduce pollutant load in runoff, but also to save money by reducing the need to reapply fertilizers or to treat runoff water.

Water residing in the pore spaces of a substrate contains dissolved salts from fertilizer which may be used for crop growth or leached during irrigation or a rain event. Current estimates of pore water nutrient content are typically measured by techniques such as a saturated media extract (SME) (7) or the pour through (PT) procedure (8). SME is destructive method that involves disturbing the root zone to collect substrate sample, which is then saturated in deionized water (DI). A PT involves pouring water over the substrate surface after irrigation to displace a portion of the pore water. Both methods produce a solution of which pH and electrical conductivity (EC) can be measured. Pure water does not conduct electricity. However, its conductivity increases proportionally with the quantity of dissolved salts. Therefore, EC is a measure of the total salts (nutrients) dissolved in a solution.

The possibility exists that the dissolved salt content of leachate may provide valuable information as to pore water nutrient content and CRF performance. Current understanding of how CRFs release nutrients into soilless substrates is based on aforementioned extraction methods or research that has quantified release throughout a production season (2,3) in an attempt to account for all applied nutrients (mass balance) (4). These methods have increased our understanding of long term nutrient use efficiency, but have not investigated the patterns in which nutrients are leached from soilless substrates during the short time span of a single irrigation. Therefore, the objective of this experiment was to measure the concentration of dissolved salts throughout the duration of an irrigation induced leaching event as affected by CRF placement.

Materials and Methods: On May 24th, 2013 a 9:1 bark:sand (v:v) substrate [bulk density = 0.19 oz•in^{-3} (0.32 g•cm^{-3})] amended with 3 lb•yd^{-3} (1.8 kg•m^{-3}) crushed dolomitic lime (Rockydale Quarries Corp., Roanoke, VA) and 3 lb•yd^{-3} (1.8 kg•m^{-3}) pelletized dolomitic lime (Kelly's Limestone LLC., Kirksville, MO) was potted into trade gallon (2.7 L) nursery containers (Myers Industries, Middlefield, OH). The study consisted of four treatments, all fallow (i.e.without a plant), including topdressed, incorporated, mid-profile and control (no CRF) fertilizer placements. A 16-6-11 + micronutrient CRF (Harrell's LLC, Lakeland, FL) was pre-weighed and applied to each container using the manufacturers recommended "medium" rate of 0.32 oz. (9 g) per container when topdressed and 0.48 oz (13.47 g) per container when incorporated and mid-profile. Methodology for filling each container varied depending on the CRF application method. Each used a slight variation of the method used to fill a fallow container in which the pot was loosely filled with substrate until heaping, leveled at the container rim and tapped twice on the table to settle, leaving approximately 0.5 inch (1.27 cm) head space. Topdressed containers used this exact method before applying CRF to the substrate surface. The mid-profile treatment was loosely filled and leveled at 50% of the total container height without tapping. The CRF was evenly distributed at this level after which, the remaining container volume was then loosely filled, leveled and tapped to settle as before. For the incorporated treatment, the desired volume of substrate was placed in a 3.5 gal (13.25 L) bucket along with the CRF which was then held at an angle and rolled for 30 seconds, completing 15 full revolutions. This rolling motion evenly distributed the CRF throughout the substrate which was then transferred to the container, leveled and tapped twice to settle. Containers were thoroughly watered in and moved to a greenhouse where they were hand watered daily with approximately 0.32 gal (1.2 L) of water.

Data were collected over a three-day period beginning on June 5th, 2013. Average substrate moisture content was 44% volumetric water content (VWC) at the time leaching was induced. Water was applied to each container using a custom platform which delivered DI at an average rate of 4.7 gal•hr^{-1} (300 mL•min^{-1}) through a diffuser mounted 10.6 in (27 cm) above the substrate surface. The diffuser evenly distributed DI over the substrate surface. As each container began to leach, the effluent (leachate) was fractioned sequentially by collecting (in order) five 1.7 oz (50 mL), five 3.4 oz (100 mL), five 6.8 oz (200 mL) and two 16.9 oz (500 mL) samples equaling 17 samples and 0.73 gal (2.750 L) leachate collected per container. This cumulative volume was chosen because it represents approximately three times the volume of water held within the substrate at the time of irrigation. Therefore, approximately three pore volumes were passed through the substrate over the course of data collection. Once the final sample had been collected, water application was terminated and containers were allowed to drain. Samples were refrigerated and analyzed on June 8th, 2013 for EC using an Orion 4 Star benchtop meter equipped with a DuraProbe^{TM} 4-Electrode Conductivity Cell (Thermo Fisher Scientific, Waltham, MA). The experiment was a completely randomized design with 4 replicates per treatment (n = 16).

Based on the soluble salt concentrations of individual leachate samples, as measured by EC, we are able to develop concentration curves which show salt concentrations as a function of the cumulative volume of leachate collected and calculate the area under the curve (AUC) for each treatment to evaluate the total salt load, and load at various increments along the curve. AUC data were subjected to one way analysis of variance ($\alpha = 0.1$) (6) and Tukey's HSD. Concentrations at each sampling interval were compared to control by means of Dunnett's Test. All data were processed in JMP® Pro version 10.0 (SAS Institute Inc., Carey, NC).

Results and Discussion: The total dissolved salt load in leachate collected over the entire duration of the leaching event and over individual pore volumes (Table 1) were affected by CRF placement ($p<0.0001$). Soluble salt concentration curves (Figure 1) and plotted p-values of comparisons between each treatment and control (Figure 2) reveal that leachate salt concentration changes as leaching progresses. All treatments decreased in concentration as leaching progressed. The mid-profile treatment produced the highest concentrations of all treatments and differed from control throughout the leaching event. The incorporated treatment produced the next highest contribution and differed through 0.46 gal (1750 mL) of cumulative leachate collected at which point it is no longer considered different from fallow. Topdressed did not differ from fallow in the first 0.01 gal (50 mL) of leaching, however did have a distinguishable salt contribution between 0.01 gal (50 mL) and 0.09 gal (350 mL).

This dataset suggests that the concentration of salts in leachate drained from a pine bark substrate varies with both the quantity of leachate produced and CRF placement. Knowledge of these nutrient leaching patterns during an irrigation event are pretext for future research to explore the use of leachate as an indicator of nutrients for crop growth in a similar manner to SME or PT procedures.

An additional implication of this research is that under conditions where water flow through a container profile is excessive, such as a heavy storm or mismanaged irrigation, the rate of nutrient discharge does not keep pace with the rate of water flow through the container, meaning that nutrient load changes with the quantity of leachate. This minimizes the total nutrient load which is contributed to collection ponds or local watersheds under these extreme conditions.

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Table 1. Area under each curve relating to total leachate salt load and load at various leachate collection intervals (pore exchanges) for three fertilizer application methods and control receiving no fertilizer.

		Pore exchange[z]		
Treatment	Total	1st	2nd	3rd
Mid-profile	269.3 a[y]	175.2 a	59.9 a	40.4 a
Incorporated	199.9 b	127.6 b	45.4 b	33.2 b
Topdressed	179.5 bc	112.7 bc	41.5 bc	30.6 b
control	154.4 c	92.9 c	36.6 c	29.9 b
p-value[x]	<0.0001	<0.0001	<0.0001	<0.0001

[z] Areas under the curves for pore exchanges 1,2 and 3 were calculated based on 0 to 0.25, 0.25 to 0.46 and 0.46 to 0.73 gal (0 to 950, 950 to 1750 and 1750 to 2750 mL) of cumulative leachate collected, respectively.

[y] Letters within columns not followed by the same letter indicate significant differences according to Tukey's HSD ($\alpha = 0.1$)

[x] Differences reported based on one way analysis of variance ($\alpha = 0.1$)

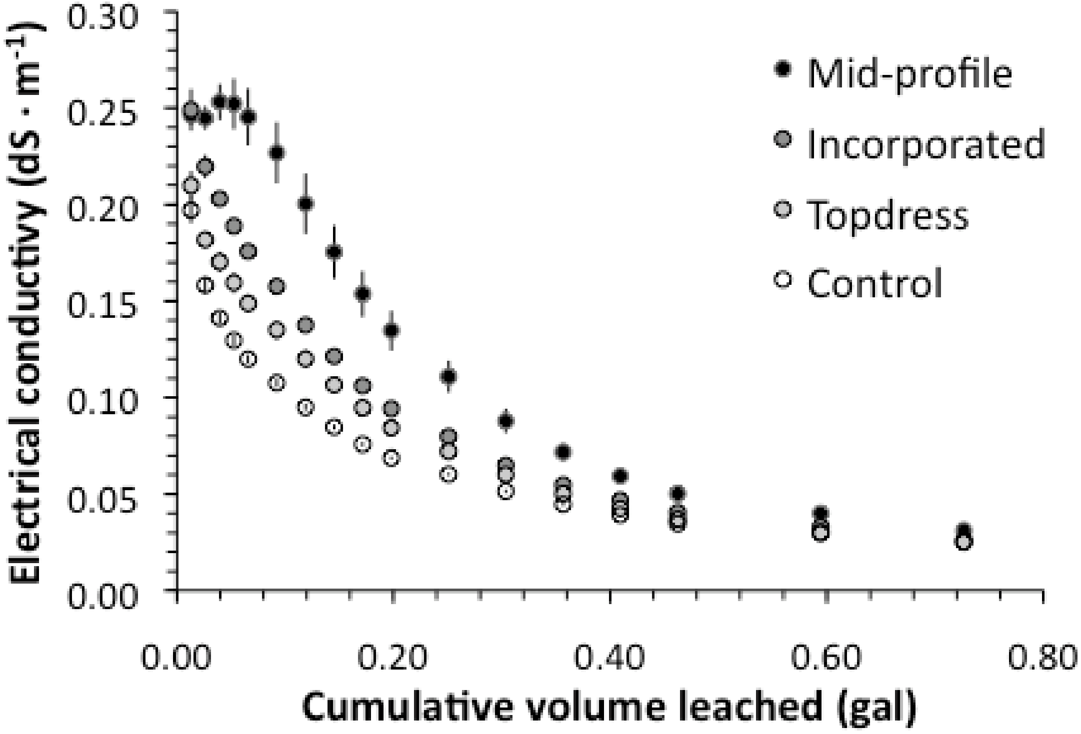

Figure 1. Soluble salt concentration, measured by electrical conductivity (EC), as a function of cumulative volume leached within a single irrigation event. Bars represent the standard error for each measurement. The control received no fertilizer.

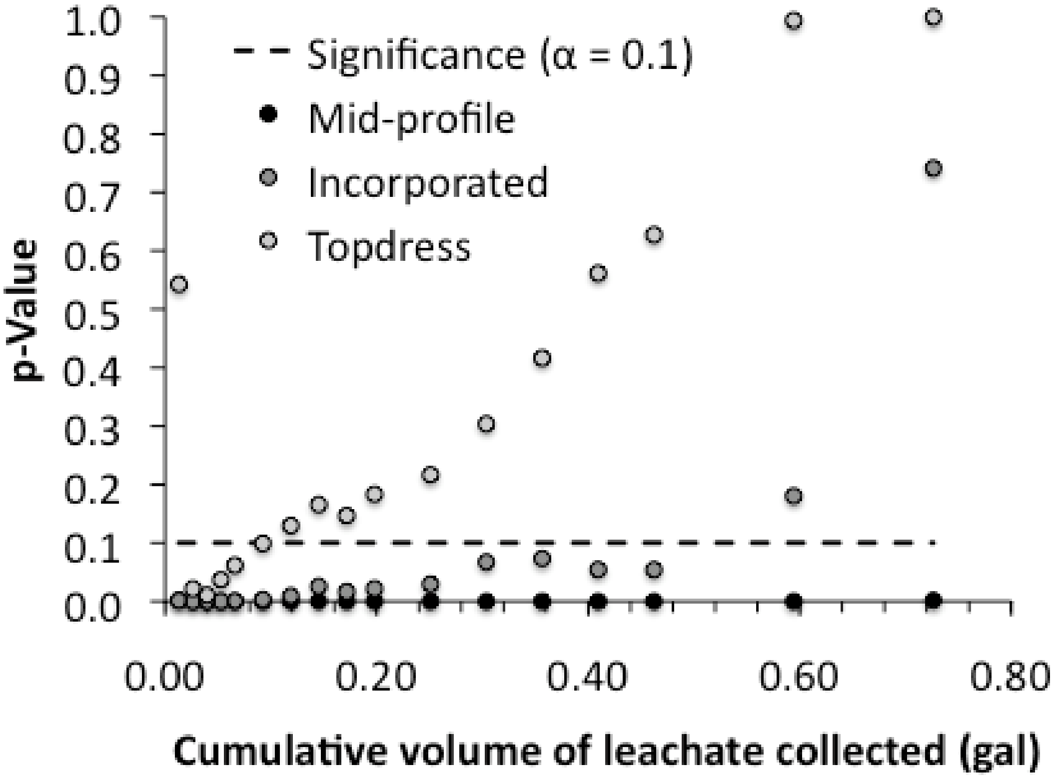

Figure 2. p-values for Dunnett's test comparing electrical conductivity at each sampling interval against the control (no fertilizer). All p-values below the α = 0.1 line are considered significantly different from the control.

Current Issues and Recent Advances in the Container Substrate Industry

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Index Words: nursery production, greenhouse production, potting media, pine tree substrate

Significance to Industry: There have been, are, and always will be issues relating to growing media that deserve attention and consideration by both growers and mix manufacturers. The upside to this reality is that there has been a lot of valid research conducted on the discovery, development and use of many successful alternative media components in the past 8-10 years. Looking forward, the biggest factors in determining if any new or alternative components are viable are: 1) location of the grower, 2) proximity of growing media components and 3) the transportation costs associated with them. Every grower and mix manufacturer must look at their own situation and assess what materials are cost effective to be worth their investment. Growers should be cautious when changing mixes or trying new components. Based on the broad range of local alternative components, most locations will have materials available to them that are viable options for cutting costs while maintaining proper growing media quality. After all, the goal of researching these new materials is not to change grower practices, but to provide stable, sustainable and cost effective alternatives to growers.

Nature of Work: Growing media selection and performance remain one of the most important factors in horticultural crop production. The Horticultural Substrates Laboratory (HSL) at NC State University has been working on soils and growing media-related issues since 1980 and at no time during that history has our industry had more interest in new discoveries in growing media research than now. In the past eight years there have been a record number of publications (trade magazine, extension bulletins, websites, scientific journals, etc) addressing issues with traditional growing media components and introducing alternative materials. Several factors have prompted the spike in grower and manufacturer interest in recent years, including:

1) Canadian peat shortage of 2011 due to unusually wet weather during the harvest months which resulted in the lowest peat supplies in decades. This saw a significant increase in growing media costs and in some cases the utilization of mixes containing peat extenders/alternatives.
2) Pine bark industry saw increased cost and lower supplies (2010-2011) due to proposed government subsidies for biofuel (Biomass Crop Assistance Program – BCAP). This threat prompted interest in alternatives for the nursery industry but also elicited concern from growing media manufacturers as well considering the heavy use of pine bark in many greenhouse mixes.

3) Variability in pine bark consistency, water holding capacity, and hydrophobicity from source to source (supplier to supplier). Partially as a result of the BCAP threat and partially due to trends in consumer demand, the processing and handling of pine bark has changed in recent years which has led to changes in product quality and performance in some situations.
4) High cost of perlite in growing media continues to warrant interest in alternatives. In most situations, perlite is the single most expensive media component (by volume). In addition, a more recent complaint of many growers and mix manufacturers has been the variability in perlite particle size and consistency from source to source (and from batch to batch). This variability and inconsistency leads to variable air and water properties in growing mixes.
5) General increase in transportation and fuel costs which have affected the cost of all growing media components, and as a result led to greater interest in locating and developing "local" growing media components. Transportation costs are, and will remain the biggest concern for the growing media industry. Not only do transportation costs influence peat, perlite and pine bark but these costs will also be the defining factor that determines the feasibility and success of any new or alternative media component in the future.
6) The growing public perception and demand of "green", "sustainable" and "local" concepts have made its way to growers and mix manufacturers attempting to meet these market trends/demands and offer products that fit these requirements. The interest in local alternative media components has the immediate advantage of reduced freight (transportation costs) to growers and distributors but a more broad-based and novel advantage may be the opportunity for new marketing strategies. Many growing mix manufactures are already promoting new product labels that include phrases like "all natural", "organic and sustainable", "environmentally friendly" to highlight the use of new alternative and sustainable components in their mixes.
7) Storage issues associated with long-term quality control of growing mixes that contain new alternative organic materials that are decomposing, consuming the starter charge, or experiencing substantial pH changes during storage. The rush to supply new growing mix formulations (or components) has sometimes precluded the long-term evaluations during storage (bulk or bags) that is needed for product quality assurance.
8) Lack of understanding of the processing requirements and variables that influence the manufacturing of organic materials (i.e. trees/wood) for use in growing media. With many growers and mix manufacturers currently developing their own new mixes, many are purchasing equipment to process raw organic materials and are not producing consistent products. The initial processing/harvesting of materials slated for use as growing media components is as important as any other factor or step in the production of and successful use of growing media. Processing is likely THE most important factor. If not processed correctly, other factors including blending, handling, storage, amendments (lime, starter charges, wetting agents, etc.) are of secondary importance in many cases. Processing is also the key to being able to consistently reproduce any growing media or media component from region to region, season to season or year to year. Currently, there is a tremendous void of relevant

information available to the horticulture industry aimed at addressing issues associated with the processing and engineering of raw organic materials for use as growing media components.

Results of Current Research with Wood Substrates

Perlite Replacements: Pine wood chips (PWC) made from loblolly pine (*Pinus taeda*) are one of the many wood-based growing media components that have been discussed in recent years. Through the extensive research of pine tree substrates (including WholeTree and clean chip residual) there have been many suggestions made that these materials provide the porosity to peat-based greenhouse mixes that would exclude the need for perlite. Until recently, no official experimental data or recommendations have existed on how wood chips can be used as aggregates (2). The main reason for this was due to a lack of consistency and knowledge about how pine wood is processed. Research at NC State University in 2011 and 2012 has provided a wealth of knowledge about using PWC as an alternative to perlite. When amended with peat at ratios of 10, 20 or 30% (by volume) compared to the same ratios of perlite, no differences were seen in 1) physical properties (air and water holding), 2) fertility requirements, 3) plant growth regulator rates/efficacy, 4) disease (*Pythium* sp. and *Rhizoctonia* sp.) occurrence or 5) shrinkage or decomposition (2). Based on these results (and at those ratios), no cultural changes in crop production are needed to switch from perlite to PWC. Even though perlite can be completely substituted with PWC with no change in cultural practices, the addition of 5% perlite to mixes is still advised because the general public (consumers) have the perception that the white particles of perlite are actually fertilizer! It is estimated that the cost of PWC, including the acquisition or pine trees, equipment to process the trees, and actual manufacturing (energy, man hours, etc.) will be ~50% cheaper than perlite. The broad geographic natural range of loblolly pine makes PWC available to local markets across much of the southeastern US with limited/minimal freight costs.

Peat Alternatives/Extenders: Many materials have been touted over the years as the “replacement for peat”, yet peat remains a good and viable material for containers. Despite some reports and beliefs, peat is an extremely abundant resource with approximately 270 million acres in Canada alone, of which only a tiny portion is being harvested for horticultural consumption. The peat producers (suppliers) are also going to great lengths (and expenses) to “lightly” harvest peat bogs and restore them after harvest in a way that has minimal impact on the environment. There are materials currently on the market that are able to be used like peat or in conjunction with peat. These we call alternatives or extenders, not “replacements” as it is not possible to “replace” peat due to its specific properties and success as a growing media, but instead only find suitable substitutions to it. Pine tree substrates (PTS) have made the biggest push in the industry in recent years. It was just a few short years ago when the first work was published (2005) on the concept of using fresh, non-composted pine wood as a viable alternative to peat moss in the production of greenhouse crops. At that time, the idea of using fresh wood in mixes was met with much skepticism (with good reason) by the industry, academics and manufacturers. As more and more researchers (university and mix manufacturer R&D folks) looked into this material and came to the same conclusions that there is indeed great potential with using wood, the perceptions have become more positive and now are very optimistic. Since 2005, more research has been conducted and reported on the use of wood-based substrates or substrates containing wood components, than any other alternative material. Reasons for the high interest in pine tree substrates include: 1) the availability of pine trees (specifically loblolly pine) in the United States, 2) the renewability and sustainability of using pine trees, 3) pine trees are fast growing and conceivably can be grown specifically for use as a substrate component - growing the media of the future - 4) wood/pine fiber has a low bulk density, light weight and can be easily compressed for shipment, 5) crops grown in mixes containing wood have consistently shown increased/improved root growth and 6) pine wood does not breakdown, shrink or really even lose its yellow color during crop production, not even long-term 3-4 month crops. It is important to point out that there is a difference in pine tree substrates (often referred to as pine/wood fiber) used as peat extenders and those that are used for aggregates (PWC described above). Pine wood processed in a fashion to be a peat extender (see section below on processing differences) will be more fiberous in nature, hold and release water similar to that of peat, and can be used up to 40% in a growing mix without many if any changes to irrigation and fertility practices. Above 40%, nitrogen tie-up will be a problem for some crops and increased fertilizer rates will be needed. Wood inherently has a high pH, ranging from ~5.0-6.0 most often, depending on the season of year the trees are harvested. Less lime may be required for mixes containing >30% wood to prevent pH levels from being too high during crop production. Root growth of greenhouse crops grown in mixes containing pine tree substrates (as peat extenders or perlite replacements) has been observed and reported for many years to be enhanced both in speed of rooting and overall root mass (1). Research in 2011-2013 at NC State University has proven this phenomenon to be factual and researchers there are now focusing on how to further modify and improve greenhouse mixes with wood for the specific purpose of enhancing root growth (1).

Pine Wood Chips & Pine Tree Substrate Processing: Recent processing technologies and discoveries have enabled manufacturers to produce different wood components that serve different roles when incorporated in growing mixes. As previously described, pine wood can be used as either a perlite or a peat replacement. Processing of freshly harvested pine trees is the key to make different products from the same trees. If trees are harvested and first passed through a “shredder” to reduce the log to smaller pieces before being further processed in a hammer mill the end result will be more “fiberous” (peat-like) compared to pine logs that are first passed through a “chipper” and then further processed through a hammer mill will produce “blockular” wood chips that have clean edges, no fibers and are sized similar to perlite particles. Many additional factors other than machine type are important in the processing of wood including 1) screen size of hammer mill, 2) size (horse power) of hammer mill, 3) air handling system of hammer mill, 4) moisture of wood at the time of grinding, 5) species of wood being ground as well as several others. To produce a consistent wood product these processing factors must be considered.

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Mini-Horhizotron: A Novel Technique for Observing and Quantifying Root Systems of Plants in Pot Culture

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Index Words: Rhizosphere, rhizometrics, root architecture, root growth, substrate

Significance to Industry: The mini-Horhizotron was developed to observe root growth and development, and root growth over time of small seedlings, herbaceous plugs, or woody liners in container production. The results of this study indicate faster root growth/root establishment of plants grown in substrates containing fresh pine wood chip (PWC) compared to plants grown in the peat:perlite substrate. For the second objective, only root growth of plants grown in PWC substrate were significantly different between mini-Horhizotrons filled completely with one substrate and mini-Horhizotrons with a different substrate in each quadrant. These experiments: 1) further test the usefulness of the mini-Horhizotron as a research tool in studying root growth; 2) show differences in root growth as influenced by different substrates; and 3) test the feasibility of utilizing a different experimental design in studying root growth across three treatments simultaneously.

Nature of Work: A large portion of the horticultural industry is involved with growing plants in pot culture. Root growth is a central element in overall plant performance, and therefore it is important to understand the factors that influence root growth. Quantifying root growth has ranged over the last several decades, including methods like root drawings, pin boards, rhizotrons, and minirhizotrons. More recently, computer programs have increased in use as technology advances and measuring root growth becomes easier.

Two of the most common methods that are accepted by the scientific community used for quantifying root growth are 1) subjective ratings and 2) root washing for determining dry biomass. Subjective root ratings can be a method to quantify root systems; however this method is completely dependent on the rater. Rating is a subjective measurement, and the person rating must first understand how to accurately rate the size of the root system (5). It is common to wash roots of container-grown plants to be able to view the root structure and assess root dry mass. Washing roots will reveal the root system to be viewed; however this removes the roots from their natural position/architecture and up to 20-40% of the fine roots (including root hairs) are often lost in the washing process (2, 4). This creates a need for new non-destructive methods that can measure the whole root system in situ and root growth/development over time.

In an effort to overcome some of the drawbacks on the techniques mentioned above, new root measuring methods have been created. The Horhizotron™, a non-destructive technique, was developed at Auburn University and Virginia Tech to measure horizontal root growth from the root ball of a container-grown nursery plant, allowing for post-transplant root growth assessment (6). The Horhizotron™ is constructed out of eight panels of glass attached to an aluminum base to form four quadrants and fits a range of nursery stock root balls. The substrate in each quadrant can be modified in various ways in order to examine the effects of different rhizosphere conditions (6). However, the size of the Horhizotron™ is restricted to large sized root balls, the glass panels are not permanent and can move and crack and the shade box does not restrict all light from the root system. More recently, a large-volume rhizotron was developed to observe root growth in an environment closer to natural soil conditions. This apparatus is aboveground which allows for relatively easy data collection (3). However, this design is even larger than the Horhizotron™ and is intended for woody plants, with large root balls, to imitate post-transplant conditions.

A new technique, the mini-Horhizotron, was developed in the Horticultural Substrates Laboratory at North Carolina State University to study root growth of seeds, plugs and woody liners during production (1). The mini-Horhizotron is a root box designed with three quadrants extending away from the center of the box, allowing for different substrates to be placed in the separate quadrants. Quadrants are clear sided which allows visible measurements to be taken from a plant/seed planted in the center, such as root length, speed of root growth, presence and quantity of root hairs, and root architecture/branching. Shade panels were constructed to fit snuggly against the plexiglass quadrants and completely block sunlight from the rhizosphere. The shade panels do not cover the substrate surface, allowing for irrigation to be directly applied to the substrate surface, same as normal watering practices of container-grown plants.

The quadrants allow for root growth observations in each separate quadrant, and the possibility of filling each quadrant with a different substrate in order to measure the effects of different substrates on one plant or lessen the number of replications needed. The objectives of this study were to use the mini-Horhizotron to: 1) observe and quantify the effects of different substrates on root growth of *Rudbeckia hirta* and 2) test the influence of experimental design on root growth of plants grown in mini-Horhizotrons that have either: A) all quadrants filled with the same substrate or B) each quadrant filled with a different substrate.

The study was executed on July 30, 2012 in greenhouses at North Carolina State University, Raleigh, NC. Three substrates were used, 70% (v/v) peat moss amended with either 30% perlite (PL), pine wood chips (PWC), or shredded-pine-wood (SW). Eight-year-old loblolly pine trees (*Pinus taeda* L.) were harvested on 4 July, 2012 at ground level and delimbed in Chatham County, NC and subsequently stored under shelter for protected from the weather. The delimbed pine logs were then chipped in a DR Chipper (18 HP DR Power Equipment, model 356447; Vergennes, VT) to produce small wood chips. The pine logs destined for shredding were processed in a Wood Hog shredder (Morbark® model 4600XL; Winn, MI). Both the chipped and shredded wood was then processed in a hammermill through a 6.35 mm (0.25 in.) screen (Meadows Mills, North Wilkesboro, NC) to produce two end products, PWC and SW. The substrates were mixed on 28 July 2012, all substrates were tested for initial pH and then amended with dolomitic limestone at 4.45 $kg \cdot m^{-3}$ (7.5 $lb \cdot yd^{-3}$) to achieve a desired pH of 5.8. On 30 July 2012 three mini-Horhizotrons were filled with an individual substrate and tapped three times, by lifting the mini-Horhizotron 10 cm (4 in.) from a hard surface and dropping, to settle the substrate and then filled to the top with substrate again, to accommodate for substrate settling which occurs after initial irrigation events during the beginning of normal crop production. Six mini-Horhizotrons were divided in the center with a cardboard divider and each quadrant was filled with one of the three substrates in random order and the same tapping and refilling procedure occurred. The cardboard divider was then removed, and one plug of *Rudbeckia hirta* 'Becky Yellow' (288-tray; C. Raker & Sons, Inc., Litchfield, MI) was planted into the center of all mini-Horhizotrons. Each of the mini-Horhizotrons that contained the same substrate in all quadrants was considered a single treatment. The six mini-Horhizotrons with a different substrate in each quadrant was considered a triple treatment. A total of 15 mini-Horhizotrons were used in this experiment. 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 were taken on the three longest roots appearing on the face of each quadrant on 15, 19, 23, 27, 31, and 35 days after planting (DAP). Each quadrant has two measureable faces giving a sum of six quadrant faces per mini-Horhizotron. Measurements were taken by placing a transparent sheet (3M Visual Systems Division, Austin, TX) with a printed on cm^2 (0.39 x 0.39 in.) grid on each face, and roots were measured from the start of the gridlines, which was at the center of one of the three sides, to the end of the gridlines, which reached the end of the quadrants. Data were subjected to the general linear model procedures and regression analysis (SAS Institute version 9.2, Cary, NC). Means were separated by least significant differences at $P \leq 0.05$.

Results and Discussion: Data taken from the single treatment mini-Horhizotrons showed that *Rudbeckia* roots grew faster in the SW and PWC substrates compared to plants grown in the PL substrate, until the fourth measurement date (27 DAP; Fig. 1). After 27 DAP, plants grown in SW had longer root lengths compared to plants grown in PWC or PL substrates. This study indicates there is enhanced root growth in substrates amended with pine components, and that the mini-Horhizotrons provide an effective method/technique for measuring root growth of small herbaceous plants in situ. These experiments provide results showing the ability to easily manipulate the root environment (rhizosphere) in the mini-Horhizotron, and to also have the capacity to detect and quantify the influence of the rhizosphere on root growth of plants. Root system development can easily be measured in the mini-Horhizotrons, as well as observations of root architecture/branching and root hairs.

The second objective of comparing the two experimental designs (mini-Horhizotron as a single versus triple treatment) by substrate, root growth in the SW and PL substrates were not significantly different across all measurement dates (Table 1). Root growth in the PWC substrate was different between the experimental designs from 15 DAP through 27 DAP, and it was observed that plants grown in PWC substrates in the replication design had greater root growth. At the end of the study, plants grown in PWC substrate did not have significant root growth differences between the experimental designs (Table 1).

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Table 1: Comparison of *Rudbeckia* root growth[z] in different experimental designs using the mini-Horhizotrons grown in peat amended with either perlite, pine-wood-chips or shredded-pine-wood.

		DAP[y]							
Substrate	Exp. Design[x]	15	19	23	27	31	35		
PL[s]	Block[w]	1.7 a[u]	2.9 a	5.2 a	6.7 a	8.5 a	10.9 a	L***[t]	Q***
	Rep[v]	1.4 a	2.7 a	5.7 a	7.4 a	8.9 a	10.0 a	L***	Q***
PWC[r]	Block	1.4 b	2.6 b	5.3 b	6.9 b	9.7 a	11.2 a	L***	Q***
	Rep	2.9 a	4.1 a	6.7 a	8.3 a	10.3 a	12.3 a	L***	Q***
SW[q]	Block	2.6 a	3.6 a	7.0 a	8.6 a	11.9 a	13.0 a	L***	Q***
	Rep	2.8 a	4.4 a	7.5 a	9.4 a	12.6 a	14.1 a	L***	Q***
	Significance	Exp. Design		***	Substrate	***	Interaction	NS	

[z] Root growth in cm (1 cm = 0.394 in.).

[y] DAP is day after planting.

[x] Experimental design was either block or replication of mini-Horhizotrons.

[w] Block was the experimental design with each quadrant of mini-Horhizotrons filled with an individual substrate.

[v] Rep was the experimental design with each quadrant of mini-Horhizotrons filled with the same substrate.

[u] Means separated by substrate within column by Duncan's multiple range test, $P \leq 0.05$. Means followed by the same letter are not significantly different.

[t] NS, L, and Q represent no significant response, linear, and quadratic response, respectively, over time of individual substrates and experimental design type, *, **, *** represent significant effects when $P \leq 0.05$, 0.01, and 0.001, respectively.

[s] PL substrate is 70:30 peat:perlite (v/v).

[r] PWC substrate is 70:30 peat:pine-wood-chips (v/v).

[q] SW substrate is 70:30 peat:shredded-pine-wood (v/v).

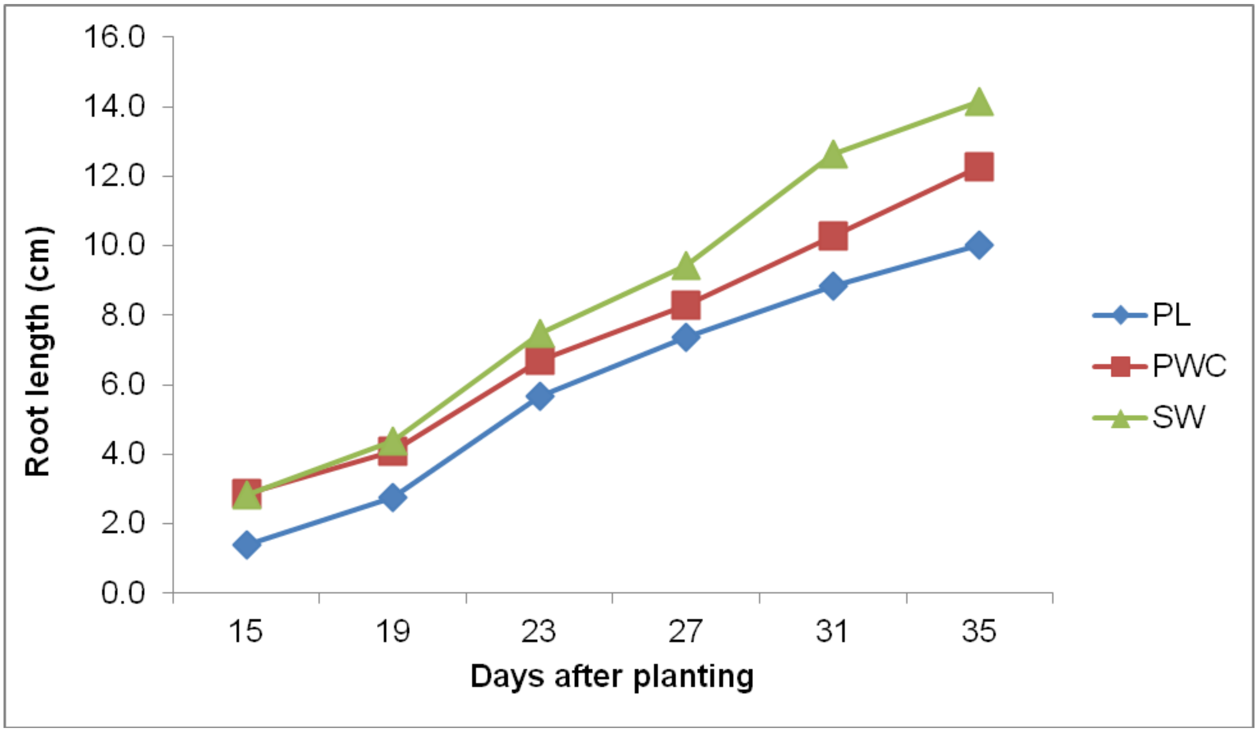

Figure 1. Root length measurements (1 cm = 0.394 in.) of Rudbeckia grown in 70% (v/v) peat amended with either 30% perlite (PL), pine-wood-chip (PWC), or shredded-pine-wood (SW).

Improving Nursery Sustainability Using New Extension Resources Featuring Grower-developed Strategies

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Significance to Industry: The website, Moving Nursery Producers Toward Sustainable Production Practices (http://blog.caes.uga.edu/snpp/), features new nursery sustainability resources including You Tube videos (http://blog.caes.uga.edu/snpp/sustainability-videos/), publications, categorized website links, and other information. Videos feature Georgia and Florida nursery growers showing sustainable practices already in use at their operations. These resources allow nursery growers to learn about and more easily adopt sustainable practices. The long-term goal of this project is to enhance the environmental sustainability of nursery production while maintaining economic sustainability.

Nature of Work: Conventional nursery production relies heavily on use of plastic containers, chemical pesticides, synthetic fertilizers and imported substrate ("potting soil") components (5). This reliance on non-indigenous and/or synthetic materials is costly as well as unsustainable. Social, economic and regulatory trends suggest nursery growers will be receptive to sustainable production methods. Higher oil prices are increasing the costs of fertilizers, pesticides, plastic containers and shipping (2). Climate change is becoming widely accepted and consumers are responding with the desire for all growers to reduce their carbon footprint. Federal regulations such as Worker Protection Standards, the Clean Water Act and regional irrigation restrictions have caused nursery growers to become more aware of and manage more judiciously their use of synthetic or resource-intensive production components such as pesticides, water and fertilizers. Regardless of environmental and regulatory considerations, the competitive nature of the nursery business requires growers to have a solid business plan to be financially sustainable.

Sustainable production is defined by the Floriculture Sustainability Research Coalition as one that aims to reduce environmental degradation, maintain agricultural productivity, promote economic viability, conserve resources and energy and maintain stable communities and quality of life (4). A survey of nursery and greenhouse growers found “going green” and “minimal or no negative impact on the environment” were concepts these growers wanted to implement in the future (3).

Results and Discussion: Funding from the Sustainable Agriculture Research and Education program (http://www.sare.org/) enabled us to compile and develop resources to help nursery growers become more sustainable (1, 6). Over a three year period, we visited growers in Georgia and Florida to view and learn about sustainable practices already successfully used by these growers. At each location, growers were asked to discuss and show practices they considered to be sustainable or added an element of sustainability to their current production practices. We also developed new resources to fill gaps in teaching about sustainable nursery production, including videos as well as publications and presentations. Environmental sustainability in nursery production will not be successful unless these practices are also economically sustainable; thus these resources emphasize both aspects. These sustainability resources are available for use from the website, Moving Nursery Producers Toward Sustainable Practices, http://blog.caes.uga.edu/snpp/.

Training and resource materials were developed in association with "sustainable” nursery growers and a nursery grower advisory group. Sites and individuals involved in advising, filming and interviews were: Athens Wholesale Nursery, Athens, GA; C & C Peat Company, Stephen Cook, Okahumpka, FL; Classic Groundcovers, Wally Pressey, Athens, GA; Clinton Nurseries of Florida, Kay Phelps, Havana, FL; Evergreen Nursery Inc., Will Ross, Statham, GA; Florida Department of Agriculture and Consumer Services, Gary Seamans, Tallahassee, FL; Florida Nursery, Growers and Landscape Association, Jim Spratt, Orlando, FL; Fraleigh Nursery, LLC, Jay Fraleigh, Madison, FL; Georgia Green Industry Association, Chris Butts, Bishop, GA; Grandiflora, Alan Shapiro, Gainesville, FL; Griffin Greenhouse and Nursery Supply, Ed Thornton, Ball Ground, GA; Hackney Nursery Co., George Hackney, Quincy, FL; James Greenhouse, Ken James, Colbert, GA; Monrovia, Stewart Chandler, Cairo, GA; O’Toole’s Herb Farm, Betty O’Toole, Madison, FL; Riverview Flower Farm, Rick Brown, Riverview, FL; Southeastern Growers Inc., Carol Seadale, Watkinsville, GA; and University of Florida/IFAS Information and Communication Services, Al Williamson and Michael Munroe, Gainesville, FL.

Thirteen captioned videos are currently available at the website, Moving Nursery Producers Toward Sustainability, http://blog.caes.uga.edu/snpp/sustainability-videos/. Video titles, lengths and descriptions are:

- Moving Nurseries Toward Sustainability: Project Introduction and Overview (2:27 min.): This is an overview of the project findings which are presented in documents and additional videos at the project website: http://snpp.caes.uga.edu.
- Why is Sustainability Important? (6:24 min.): Several growers provide their ideas on the need for container production nurseries to adopt sustainable practices.

- Sustainable Options for Nursery Containers (6:36 min.): Growers discuss re-using and re-cycling plastic containers as well as using eco-containers made from alternatives to oil-based plastics.
- Effective Overhead Irrigation (5:04 min.): This video reviews methods to improve uniformity and efficiency of overhead irrigation in container nurseries.
- Low Volume Irrigation (6:23 min.): Growers discuss the advantages of drip, trickle, ebb-and-flow and micro-irrigation systems for container nurseries.
- Use of Reclaimed Wastewater for Irrigation (2:11 min.): George Hackney of Hackney Nursery (Quincy, FL) explains how his nursery benefits from a supply of treated municipal wastewater.
- Managing Nursery Runoff to Remove Contaminants (5:06 min): Nursery sustainability can be improved by treating pesticide- and fertilizer-contaminated runoff with methods ranging from small scale bio-retention "rain gardens" to large sophisticated systems for collecting and purifying nursery runoff.
- Methods and Tools to Improve Nursery Production Efficiency (7:20 min.): "High tech" soil moisture sensors and robots as well as "low tech" methods relating to nursery design and production uniformity can improve production efficiency and sustainability by reducing input costs, labor and production time.
- Recycling and Re-purposing in the Nursery (7:00 min.): Creative recycling, re-purposing and reusing materials and supplies can lead to cost savings and improved sustainability of many nurseries.
- Improving Energy Efficiency in the Nursery (5:59 min.): Whether "low-tech" or "high-tech," improvements in energy efficiency almost immediately help your nursery become more sustainable while reducing costs.
- Sustainable Fertilizers for Nursery Production (7:12 min.): Nurseries can become more economically and environmentally sustainable by selecting an appropriate fertilizer and integrating fertilizer management with other aspects of production for efficient nutrient use.
- Integrated Pest Management (IPM) in the Nursery (8:30 min.): IPM is an effective and environmentally sensitive approach to pest management that relies on a combination of common sense practices, including sanitation, low hazard chemicals and "systems approaches."
- Sustainable Substrates for Nursery Production (4:30 min.): Locally available waste organic materials or composts can often substitute for costly and less sustainable substrate components.

In addition, a list of more than 350 publications and websites relevant to nursery sustainability were compiled and catalogued by topic (http://snpp.caes.uga.edu/snpp/sustainability-resources/).

As a result of our investigations and interviews, we identified five broad categories of practices that maximize environmental sustainability as well as financial sustainability (6). These are practices that 1) reduce energy and fossil fuel use, 2) reduce natural resource inputs, 3) reduce pest and disease problems, 4) successfully re-purpose materials currently on the nursery, and 5) reduce the amount of labor required to produce a crop.

In addition to these general topic areas, growers already using sustainable practices share notable characteristics: most of these growers are very proactive about searching for sustainable solutions. They recognize that sustainability is the right thing to do and they aren't waiting for government regulations to force them to become more sustainable. Moreover, most growers view sustainability as a financial opportunity; they seek out sustainable solutions that make economic sense as well as environmental sense. Growers found a tremendously wide array of practices are sustainable, from very easy and inexpensive practices like washing and reusing containers all the way to installation of new nursery systems like ebb-and-flow irrigation. Growers that implement sustainable practices find that these practices soon become a “way of life” on the nursery as opposed to a defined task. But above all, the most successful and sustainable nurseries found sustainable practices that best "fit" their nursery and they fully implemented these practices as soon as possible.

For more information on these topics, please view the videos and additional resources on the website, Moving Nursery Producers Toward Sustainable Practices, http://blog.caes.uga.edu/snpp/.

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Fertilizer Rates, Container Size and Sun Exposure Affect Growth of Container-grown Dogwoods

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Significance to industry: Container grown trees are an important product for the nursery and landscape industry. Flowering dogwoods are one of the most popular small flowering trees for landscape use. These data show that dogwoods can be successfully grown with low rates of fertilizer during the first year of container production from a bare root liner. The greatest amount of plant growth occurred when plants were grown under 50% shade regardless of the container size or fertilizer rate. In most instances, the plants grown in #7 containers under shade exceeded the height growth of those grown in #15 containers in full sun.

Key words: nursery production, *Cornus florida*, *Cornus kousa*

Nature of the work: Dogwoods are one of the most beautiful and important small flowering trees for the landscape use. It offers interest in every season of the year, but is most admired when in flower. Flowering dogwood is an aristocrat of native flowering trees of the U.S. and has a broad range extending through most of the eastern states and westerly through Iowa and south to Texas (1). Differences exist in climatic adaptation, flower size and color, leaf variegation, berry color, growth habit and precocity of bloom, thus about 90 cultivars have been named. The flowering dogwood has been in nursery cultivation a long time. However, as the demand for containerized trees has increased in the last 20 years, so has the demand for container-grown dogwood. The author has observed poor dogwood growth of many container-grown dogwoods. Anecdotal comments about the poor growth include overwatering, underwatering, poor root structure, environmental stress or the extended delay from the bare root harvest until the plants were potted. Often high electrical conductivity readings were observed with many of the dogwoods exhibiting poor growth. The Best Management Practices handbook (9) listed *Cornus florida* L. as a crop with a medium nutrient requirement. In contrast, Hubert Nicholson, an experienced dogwood producer, recommended low fertilization to prevent burning of the delicate root system (5). During the first year after transplanting a bare root liner, Nicholson recommended that no fertilizer be applied.

Tilt *et al*. (8) reported a 2-fold increase in dry shoot weight of three ornamental species (*Ilex cornuta* x *aquifolium* ‘Nellie R. Stevens’, x *Cupressocyparis leylandii* Jacks and Dall. ‘Haggerston Grey’, and *Rhododendron* sp. ‘Sunglow’) occurred as container volume increased from #1 (3.8 l) to #3 (11.4 l) with a coarse bark substrate. Smaller containers restrict root and subsequent shoot growth (2, 3, 6 and 8). Weeping fig (*Ficus benjamina* L.) and loquat (*Eriobotrya japonica* (Thunb.) Lindl.) both grew faster in larger #3 (11.3 l) containers than smaller #1 (3.8 l) containers with a commercial peat based substrate (3).

The effects of container size on growth of ornamentals have been studied in conjunction with fertilizer rates and substrate components. Green ash (*Fraxinus pennsylvanica* Marsh), birch (*Betula pendula* Roth.), and honey locust (*Gleditisia triacanthos* L.) produced greater shoot dry weight, root dry weight and stem diameter with controlled release fertilizer compared to controlled release plus liquid feed when grown in a pot-in-pot system in #20 (76 l) containers compared to #10 (38 l) containers (4). Poole and Conover (6) reported schefflera (Brassaia spp.) plants increased growth and quality as container size increased, but fertilizers rates had no effect on plant growth. In contrast, optimal growth of *Rhododendron indicum* L. 'Formosa' and *Ilex cornuta* x *aquifolium* 'Nellie R. Stevens' was obtained in #15 (45.4 l) containers compared to #3 (11.4 l) or #7 (22.7 l), but only when sufficient quantities of nutrients were applied (2).
Larger containers may provide more growing room, but the initial investment of substrate, fertilizer, and space is more expensive; and handling may be more difficult. Production costs may be recovered, though, with increased growth rates and better quality plants (7).

The objective of this project was to evaluate growth of three dogwood cultivars grown in #7 or #15 nursery containers with six fertilizer rates in conjunction with sun or shade exposure.

Uniform 3 - 4 ft (0.9 - 1.2 m) bare root liners of *Cornus kousa* 'Stellar Pink' and *Cornus florida* 'Cherokee Princess' and 'Cherokee Brave' were potted into either #7 (22 l) or #15 (50 l) nursery containers (Nursery Supplies, Chambersburg, PA) on 22 and 23 Feb 2012. Containers were filled with a pine bark substrate amended with Micromax (The Scotts Co., Marysville, OH) at 1 lb / yd^3 (0.6 kg / m^3) and one of the following fertilizer treatments: 1) 4.75 lbs (2.85 kg) (1/2x low), 2) 6.5 lbs (3.9 kg) (1/2x medium), 3) 8.5 lbs (5.1 kg) (1/2x high), 4) 9.5 lbs (5.7 kg) (1x low), 5) 13.0 lbs (7.8 kg) (1x medium) and 6) 17.0 lbs (10.2 kg) (1x high) of 19-5-9 (19N-2.2P-7.5K) Osmocote Pro controlled-release fertilizer (The Scotts Co., Marysville, OH) per yd^3 (m^3). Half of the plants of each container size and fertilizer rate were placed on a gravel bed in full sun and the other half placed in a shade structure with 50% shade. Irrigation was applied daily with three cyclic applications using micro-spray emitters. Weed control and pest management were maintained with traditional nursery practices during the growing season. Foliar ratings were recorded on August 12 and September 12 using a rating scale of 1=healthy, 2=slight chlorosis, 3=moderate chlorosis, 4=severe chlorosis and 5=dead and a rating scale of 1= healthy, 2=slight stunting, 3=moderate stunting, 4=severe stunting and 5=dead (data not presented). Leaf samples were collected immediately after foliar observations for foliar analysis. Leachate was collected on a bi-weekly schedule using the Virginia Tech pour through method (Yeager, 2007) within one hour of the last daily irrigation cycle. Leachate analysis was determined for nitrate-

N (N) and ortho-phosphate (P) levels using a Dionex DX-600 ion chromatograph (Dionex Corp., Sunnyvale, CA). Only cumulative levels from all sampling dates are presented.

On 26 Sept 2012, height and trunk diameter, measured 6 in (15 cm) above the substrate surface, were recorded. Growth was determined by subtracting the final growth measurement from the initial measurements made at potting. Three plants of each treatment were randomly selected and harvested for shoot and root dry weights by severing shoots from the roots at the substrate surface. Pine bark substrate was gently blown from the root mass using a compressed air system. Both roots and shoots were dried in a forced-air oven at 133 F (56C) (dry weight data not shown).

Treatments consisted of a 6x2x2 factorial (6 fertilizer rates x 2 exposures x 2 container sizes). The experiment was conducted as a completely randomized design by cultivar with 5 single plant replicates. Data was analyzed by cultivar using a generalized linear model with differences among treatments were separated by a Fisher's least significant difference, $P<0.05$.

Results and Discussion: Fertilizer rate, sun exposure and container size affected plant growth of the dogwood cultivars. Height growth was similar among plants receiving 1/2x low, 1/2x medium, 1/2x high and 1x low rates (4.75, 6.5, 8.5, and 9.5 lbs/yd^3) (Figs. 1-3). The greatest differences in height growth occurred with Cherokee Princess between the 1x medium and 1x high rate compared to plants that received the 1/2x rate. Cherokee Brave and Stellar Pink had reduced height growth with the 1x medium and 1x high compared to the other fertilizer rates.

Though foliar rating data is not presented, it is important to know that most plants receiving a 1x medium or 1x high rate had chlorotic and smaller foliage, as well as stunted shoot growth compared to plants receiving 1/2x fertilizer rates. Trunk diameter increased more with the 1/2x low, 1/2x medium and 1/2x high fertilizer rates compared to plants that received the 1x low, medium and high with all cultivars (Figs. 4-6).

All plants had more height increase when grown in shade compared to full sun. Increase in trunk diameter was observed with Cherokee Brave in full sun whereas Cherokee Princess and Stellar Pink trunk diameter growth was similar with plants grown in shade and sun. In native stands, flowering dogwood is considered an understory tree that is partially or fully shaded by larger trees. In this experiment, artificial shade provided a better growing environment than placing plants in full sun.

Container size had the greatest affect on plant growth. Height growth averaged 23, 33, and 32% more with Stellar Pink, Cherokee Princess and Cherokee Brave, respectively when plants were grown in #15 container compared to #7. Trunk diameter was 26, 24, and 21% larger with Stellar Pink, Cherokee Princess, and Cherokee Brave, respectively, in #15 container compared to plants grown in #7 containers.

Shoot dry weight was not affected by sun or shade which is indicative of the height increase under shade was a result of internode elongation rather than an increase in total shoot biomass. As fertilizer rates increased shoot dry weight decreased significantly with the three cultivars tested. Container size affected shoot weight with all cultivars. Stellar Pink, Cherokee Princess, and Cherokee Brave, had a 31, 33 and 32%, respectively, increase in shoot dry with plants grown in #15 compared to #7 (data not shown).

The cumulative N and P levels were similar in the #7 and the #15 nursery container and similar when grown in sun or shade, thus data was pooled for treatment means with all dogwood cultivars. The levels of N and P in the leachate increased in a linearly trend as fertilizer rate increased. With the exception of the 1x high rate from Cherokee Princess, Stellar Pink, Cherokee Brave and Cherokee Princes had similar N levels that leached from the containers (Fig. 7). The level of N was 95 mg/l leached compared to 81 mg/l and 77.1 mg/l from Cherokee Brave and Stellar Pink.

P levels in the leachate were similar with Cherokee Princess and Stellar Pink (Fig. 8). P uptake was greater with Cherokee Princess and Stellar Pink compared to Cherokee Brave (foliar analysis data not presented). Cherokee Brave had about 2.5 times more P in the container leachate than Cherokee Princes or Stellar Pink with all six fertilizer rates tested.

These data show that dogwoods can be grown successfully with low rates of fertilizer. However, the biggest gain in plant growth was with plants grown under 50% shade. In most instances, the plants grown in #7 containers under shade exceed height growth of those grown in #15 containers in full sun.

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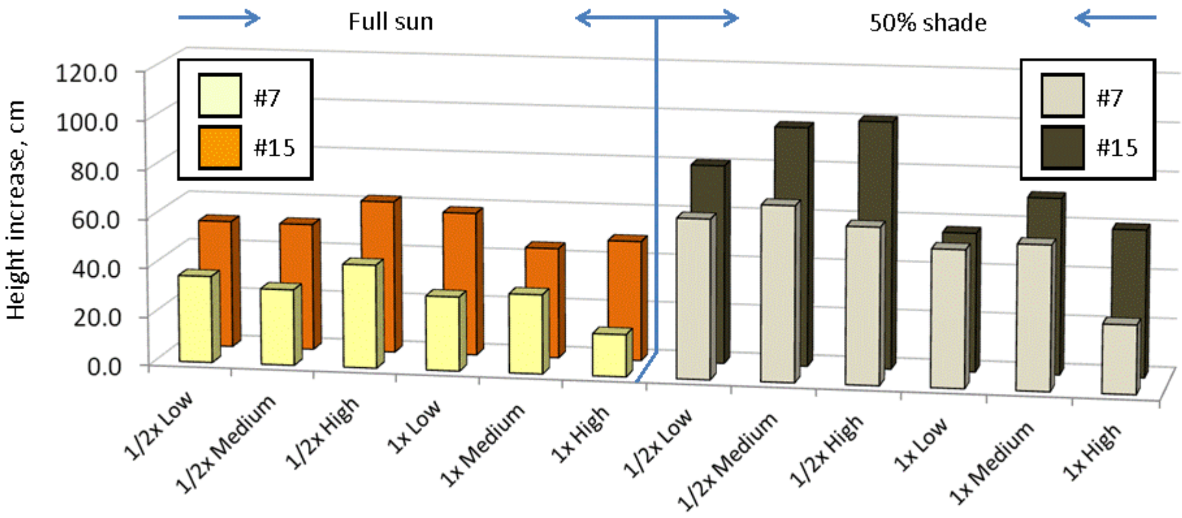
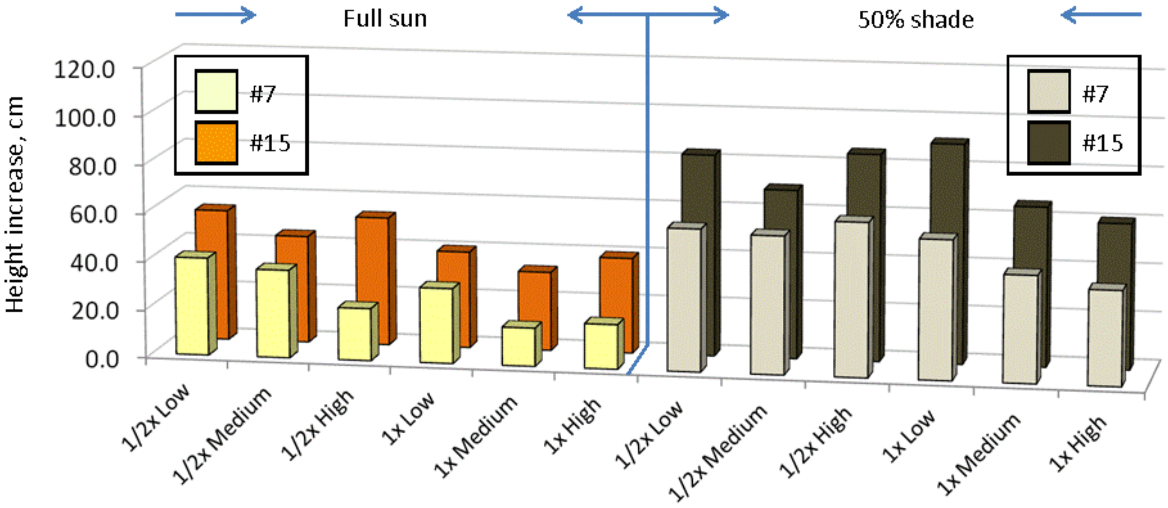
Fig. 1. Height increase of Cherokee Brave in #7 and #15 nursery containers grown in full sun or shade.



1/2x Low = 4.75 lbs
1/2x Medium = 6.5 lbs
1/2x High = 8.5 lbs
1x Low = 9.5 lbs
1x Medium = 13 lbs
1x High = 17 lbs

Fertilizer rates of Osmocote Pro 19-5-9 per yd^3.

Fig. 2. Height increase of Cherokee Princess in #7 and #15 nursery containers grown in full sun or shade.



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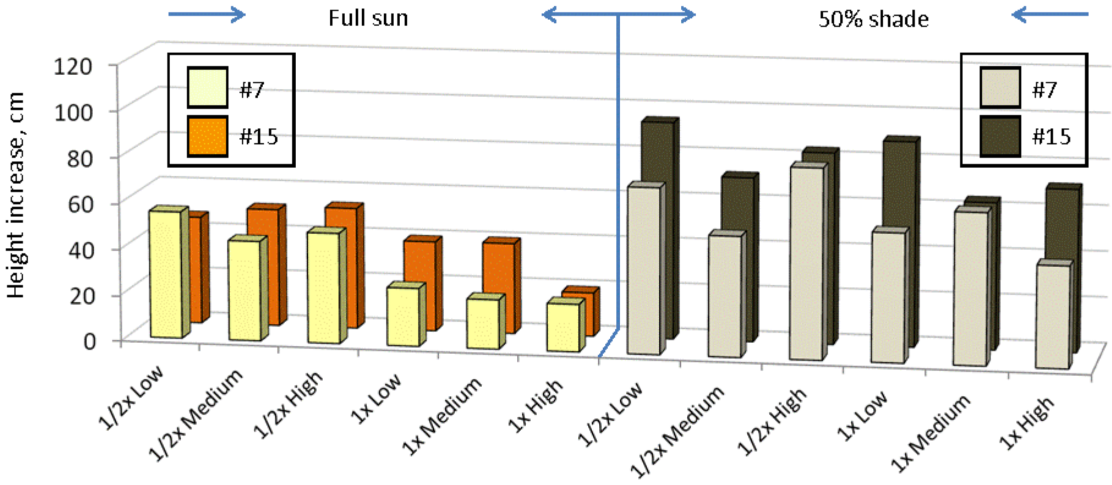
1/2x High = 8.5 lbs
1x Low = 9.5 lbs
1x Medium = 13 lbs
1x High = 17 lbs

Fertilizer rates of Osmocote Pro 19-5-9 per yd^3.

Fig. 3 Height increase of Stellar Pink in #7 and #15 nursery containers grown in full sun or shade.



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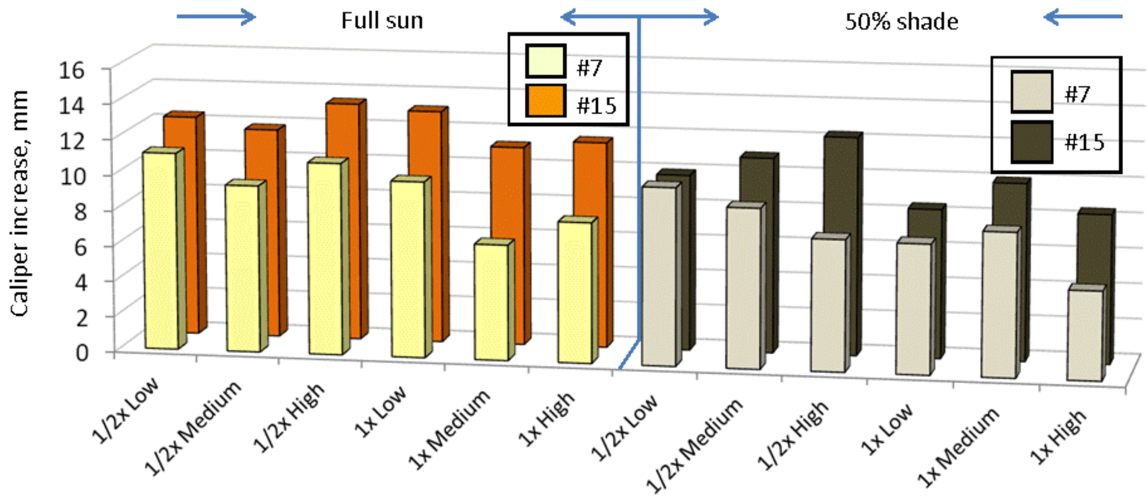
1/2x High = 8.5 lbs
1x Low = 9.5 lbs
1x Medium = 13 lbs
1x High = 17 lbs

Fertilizer rates of Osmocote Pro 19-5-9 per yd^3.

Fig. 4. Caliper increase of Cherokee Brave in #7 and #15 nursery containers grown in full sun or shade.



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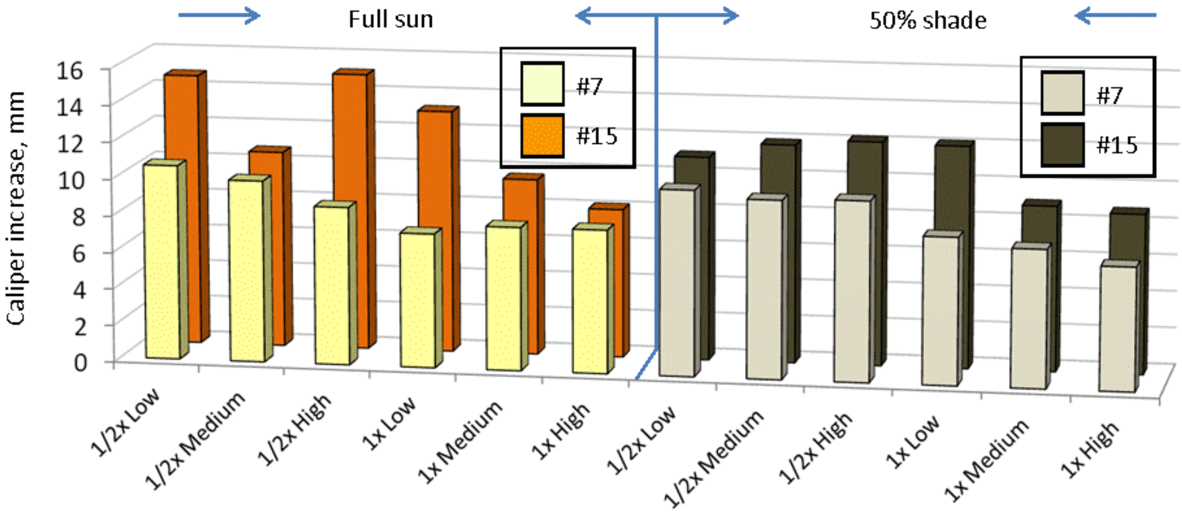
1/2x High = 8.5 lbs
1x Low = 9.5 lbs
1x Medium = 13 lbs
1x High = 17 lbs

Fertilizer rates of Osmocote Pro 19-5-9 per yd^3.

Fig. 5. Caliper increase of Cherokee Princess in #7 and #15 nursery containers grown in full sun or shade.



1/2x Low = 4.75 lbs
1/2x Medium = 6.5 lbs
1/2x High = 8.5 lbs
1x Low = 9.5 lbs
1x Medium = 13 lbs
1x High = 17 lbs

Fertilizer rates of Osmocote Pro 19-5-9 per yd^3.

Fig. 6. Caliper increase of Stellar Pink in #7 and #15 nursery containers grown in full sun or shade.

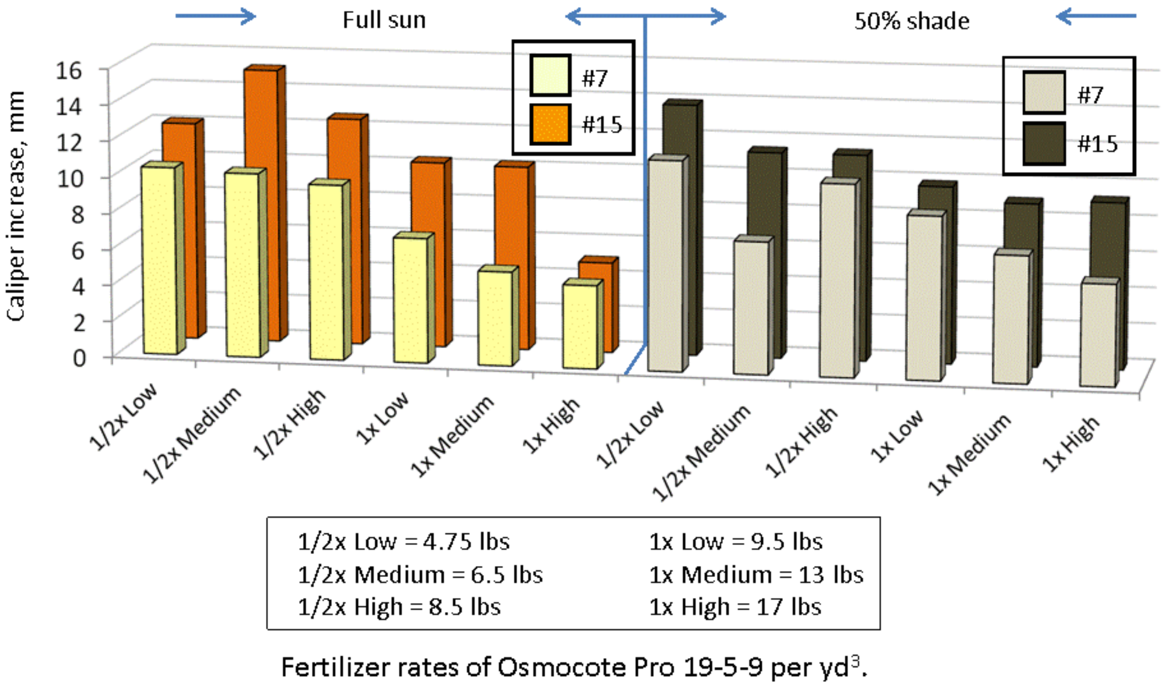


Fig 7. Cumulative nitrate-N leached from container grown Cherokee Brave, Cherokee Princess and Stellar Pink dogwoods.

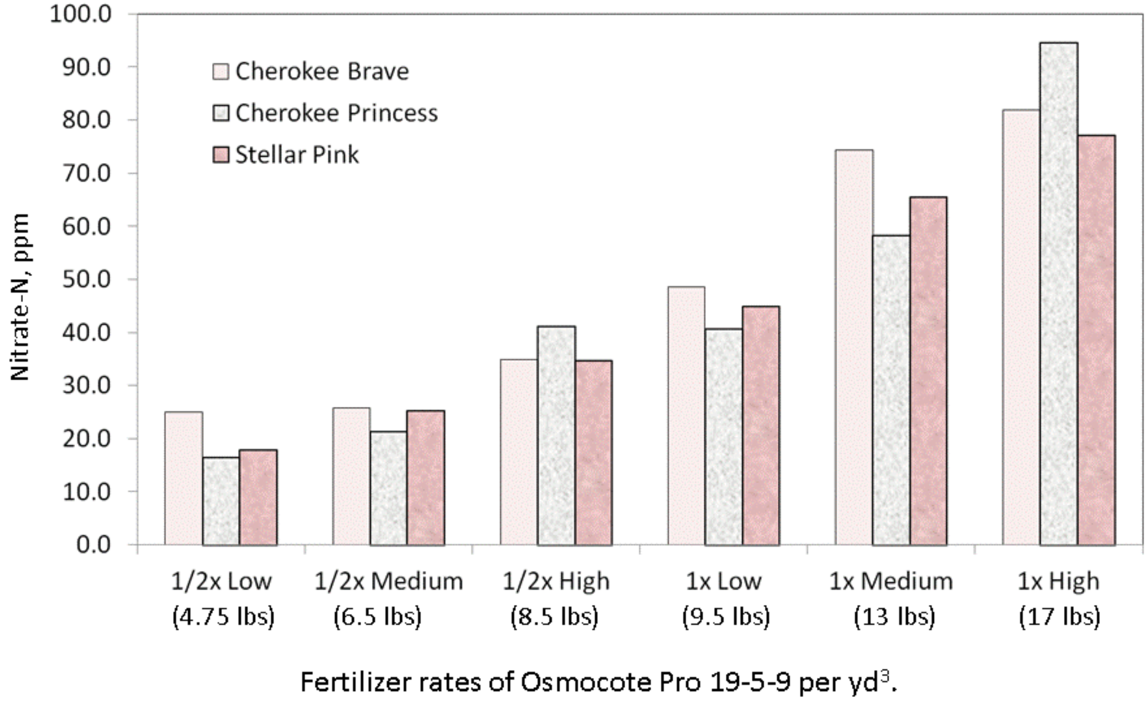
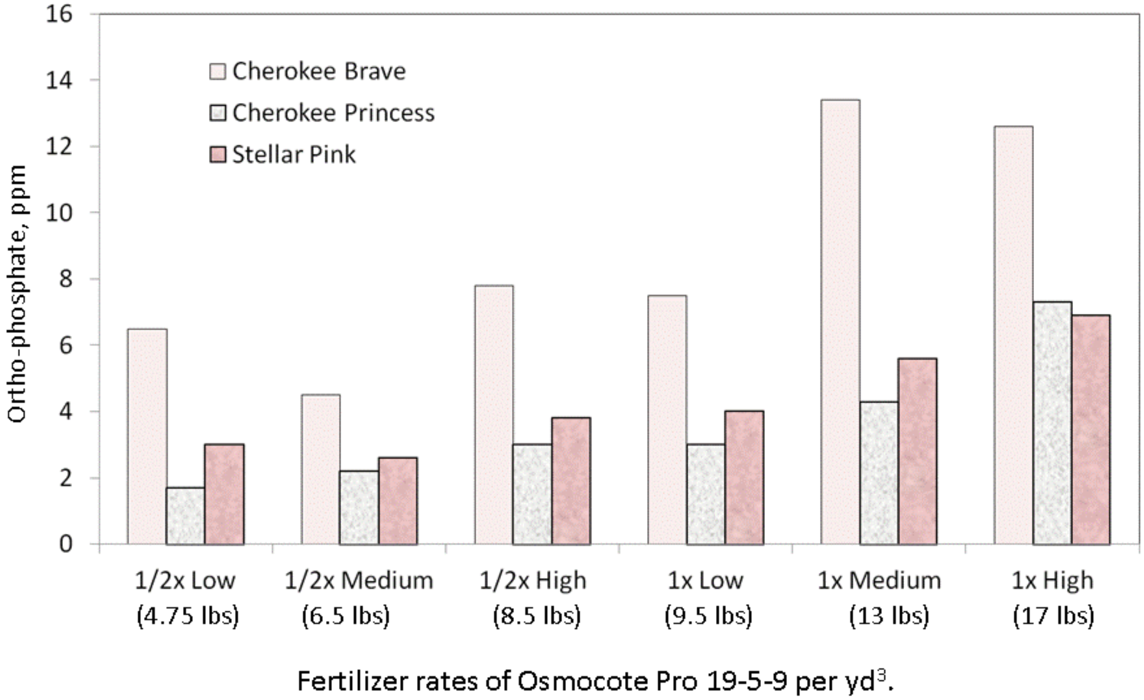


Fig 8. Cumulative ortho-phosphate leached from container grown Cherokee Brave, Cherokee Princess and Stellar Pink dogwoods.



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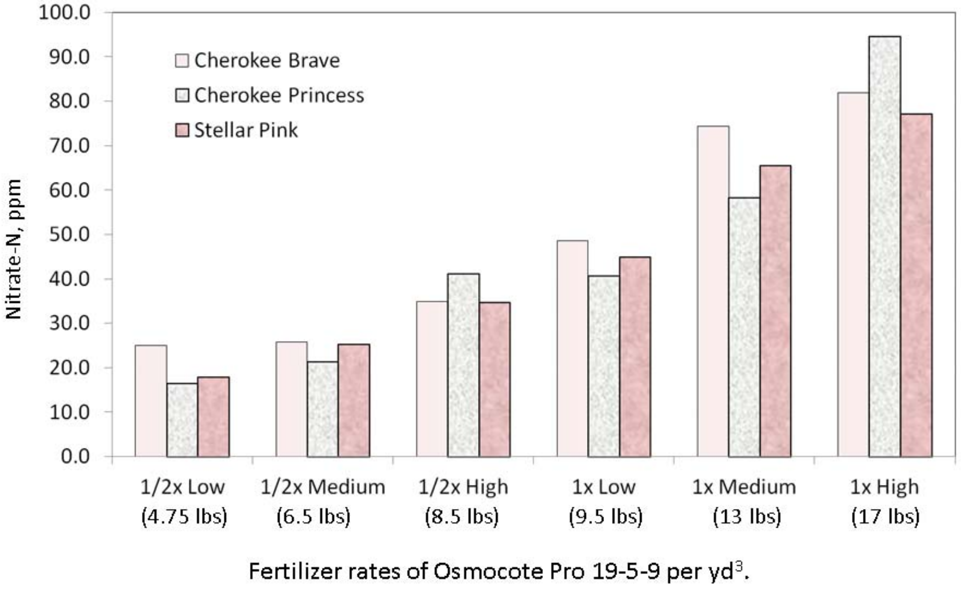

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