Composted Cotton Stalks and Cotton Gin Trash Substrate Amendments and Irrigation/Ground Cover Management I. Effect on Physical and Chemical Properties of Pine Bark and Pine Tree Substrates[1]

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Abstract

This project evaluated two cotton waste products (cotton stalks and cotton gin trash) as amendments to pine bark (PB) and pine tree (PT) substrates for their impact on substrate physical and chemical properties. PB or PT substrates were amended (v/v) with cotton stalks composted with a N source (CSN), cotton stalks composted without an N source (CS), or aged cotton gin trash (CGT) at 4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1 PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN) and 4:1 PT:CGT (PT:CGT) (by vol). In 2010, PB-amended substrates had larger percentages of coarse (> 2.0 mm) and fine (< 0.5 mm) particles while PT-amended substrates had larger percentages of medium (0.5–2.0 mm) particles. In 2011, PB-amended substrates again had larger percentages of coarse particles, while PT-amended substrates had more medium and fine particles. Generally, most physical properties were within adequate ranges and were better than or comparable to the 100% PB control. Substrate solution pH was generally higher in the PT- than the PB-based substrates. Electrical conductivity (EC) of the substrate solution was also generally higher in the PT-based substrates compared to the PB-based substrates. Inorganic nitrogen ($NH_4 + NO_3 + NO_2$), urea, P, K, Ca, and Mg concentrations in all substrate solutions, regardless of compost addition, were all below the recommended ranges by the last sample time (October 4, 2011) for the study indicating that nutrients supplied by the composts were depleted or below detection limits. However, CGT increased substrate solution P concentrations in both PB- and PT-based substrates with both overhead, sprinkler irrigation with black geotextile weed fabric covering the ground (OH) and low-volume, spray stake irrigation with gravel covering the ground (LV).

Index words: total porosity, air space, container capacity, bulk density, available water, unavailable water, alternative substrates, pH, EC, substrate solution.

Species used in this study: azalea [*Rhododendron obtusum* (Lindl.) Planch. 'Sunglow'], juniper (*Juniperus conferta* Parl. 'Blue Pacific').

Significance to the Horticulture Industry

This study evaluated the effect on substrate physical and chemical properties for the addition of cotton stalks composted with a N source, cotton stalks composted without a N source, or aged cotton gin trash to pine bark or whole pine tree nursery substrates. Plant production in a container environment is very dynamic. In order to optimally produce a plant, physical properties such as container capacity (water holding capacity), air space, and bulk density need to be within acceptable ranges. These various physical properties are impacted by the differing particle sizes of components within a substrate. Also, the substrate needs to have satisfactory chemical properties such as pH, electrical conductivity, and nutrient retention. The addition of various amendments, such as compost, can impact these physical and chemical properties. The addition of the composted cotton stalks, composted cotton stalks with N, and cotton gin trash amendments to pine bark and pine tree substrates generally created substrates with physical properties better than or comparable to the industry standard of 100% pine bark. Substrate affected the concentration of P in the substrate solution of both azalea and juniper irrigated by overhead and low-volume irrigation throughout the majority of the experiment. Pine tree:cotton gin trash generally maintained higher P concentrations in the substrate solution with overhead and low-volume irrigation. Leaching of P from nursery crop production practices is a concern due to the negative impacts it can have on water quality and should be kept at a minimum; however, by the final sample time the P concentrations in all the substrates were low. By utilizing local substrate amendments such as cotton waste products, the nursery industry can assist another industry in disposing of an unutilized waste while also reducing the nursery industry's dependence on pine bark. Composted cotton stalks and cotton gin trash can be used to reduce the amount of pine bark needed by nurseries but does not supply sufficient nutrient levels to warrant a reduction in fertilizer rate. However, to be cost effective, nurseries should choose potential alternative substrates and amendments based on proximity and availability to the nursery.

Introduction

Currently, 60% of the nursery industry in the United States is represented by container production of plants (Bilderback et al. 2013). Pine bark (PB) has been considered a useful resource for the nursery industry since the 1970s and makes up 75 to 100% (by vol) of container substrates used in the eastern U.S. (Lu et al. 2006). Recent issues regarding the availability, quality, and consistency of the PB supply for the nursery industry have arisen. Previous research evaluated the use of alternative substrates and pine bark extenders (amendments) including cotton gin compost (Cole et al. 2005,

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Jackson et al. 2005), turkey litter compost (Tyler et al. 1993), composted poultry litter (Marble et al. 2010), vermicompost (McGinnis et al. 2010), eastern redcedar (Murphy et al. 2011), switchgrass (Altland and Krause 2009), clean chip residual (Boyer et al. 2008) and whole pine tree substrates (Jackson et al. 2008, Jackson et al. 2009a, b, and c; Rau et al. 2006). Researchers found that all of these alternatives were appropriate substrates, with good water holding capacity and air space, and often have greater nutrient retention than a 100% PB substrate. Alternative substrates and amendments need to be reproducible and have consistent chemical and physical properties in order for them to be acceptable in a nursery's production system.

There are several factors that influence the distribution of air, water, and solids within a substrate: pore space, bulk density, particle size distribution, container height, and substrate settling (Argo 1998). However, particle size and pore space distribution have the most impact on the ratio of water to air held in a substrate after drainage (Argo 1998). PB substrates have low moisture retention properties (Warren and Bilderback 2004). Due to this low moisture retention, daily irrigation is applied to achieve maximum plant growth in the southeastern U.S. nursery industry (Warren and Bilderback 2004). According to Stetson and Mecham (2011) substrate selection is one of the key factors for irrigation management and to optimize crop production, conserve water and protect the environment.

Utilization of composts as substrate components may also contribute to different chemical properties in the container substrate environment. Benefits from utilizing a composted organic material as a substrate amendment include: (1) providing plant available nutrients like P, Ca, Mg, and micronutrients and (2) increasing pH (Warren et al. 2009). However, high EC and pH levels can also be concerns with these materials and need to be continually monitored (Warren et al. 2009).

Cotton is a very important agricultural crop in the southeast United States; it comprises 2% of North Carolina's $9.7 billion farm cash receipts (NCDA 2009). Best management practices (BMP) for cotton production include the use of 'no-till' methods that recommend leaving cut cotton stalks and debris in the field after cotton is harvested. However, this practice leads to a buildup of debris after several crop cycles (due to the woody nature of the cotton stalks), making it difficult for new crops to be planted and fertilized (Bilderback and Warren 2010). Instead, after cotton is harvested, cotton stalks can be collected and chopped into smaller pieces [< 3.81 cm (1.5 in)] using a silage cutter (preventing them from touching the ground) then composted in a moist pile for 3 to 6 months at temperatures near 60C (140F) to assure compost maturity. Cotton gin trash (CGT) (produced during the ginning process of lint removal from the cotton burr) results in 1.2–2.5 million metric tons of CGT, which creates a significant disposal problem in the ginning industry (Buser 2001, Fava 2004). Cotton gin waste has been reported to be an effective substrate amendment for the production of *Buxus microphylla* Sieb. & Zucc. 'Winter Gem', *Coleus* x *hybridus* 'Golden Bedder', *Nandina domestica* Thumb 'Firepower', and *Rhododendron indicum* L. & Sweet 'Formosa', 'Midnight Flare', and 'Renee Mitchell' (Cole et al. 2005, Jackson et al. 2005, Owings 1993).

Another approach to eliminating the nursery industry's dependency on PB is with the use of whole pine tree substrates (PT) produced from freshly-harvested loblolly pine trees, which are chipped or ground with or without the bark, limbs, and needles then sent through a hammer mill to achieve a suitable particle size (Jackson et al. 2009b). Research addressing pH, fertility, N immobilization, and changes in chemical and physical properties during long-term nursery crop production of PT substrates has been conducted (Jackson et al. 2009a, b, and c). However, the effect on substrate chemical and physical properties of blending PT with composts has not been evaluated.

The objectives of this research were to evaluate two cotton waste products (cotton stalks and cotton gin trash) as amendments to PB- and PT-based substrates for the production of two species under two different, commonly utilized, irrigation/ground surface management regimes for their impact on substrate physical and chemical properties. This project was repeated over two summers (2010 and 2011).

Materials and Methods

General conditions. Black plastic containers 2.8 liter (0.7 gal) were filled with either pine bark- (PB) or whole pine tree- (PT) based substrates that were amended by volume with cotton stalks composted at a ratio of 5:1 with a nitrogen (N) source (Daddy Pete's Plant Pleaser, 0.5N-0.5P-0.5K, Stony Point, NC) (CSN), cotton stalks composted without an N source (CS), or aged cotton gin trash (CGT). The PT substrate base was produced from freshly harvested twelve-year-old loblolly pine trees (*Pinus taeda* L.) that were delimbed and chipped (Morbark, Horizontal Grinder, Model 5600, Mobark Inc., Winn, MI). The PT chips were combined with CS (Fork L Farms, Norwood, NC), CSN, or CGT (Roanoke Tar Cotton Co., Williamston, NC) and then hammer-milled with a 9.52 mm (0.375 in) screen (10 horse power, Model 5, Meadows Mills, Inc., North Wilkesboro, NC).

Substrate treatments were designed as a factorial treatment combination of the substrate bases (PB and PT) and amendments (CS, CSN and CGT) resulting in a total of six substrates: 4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1 PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN) and 4:1 PT:CGT (PT:CGT) (by vol), along with a control of 100% PB. Ratios of CS, CSN or CGT were adjusted for PB- and PT-based substrates to achieve similar container capacities (water holding capacities).

PB-based substrates were amended with 1.4 $kg \cdot m^{-3}$ (3 $lbs \cdot yd^{-3}$) of dolomitic lime incorporated at mixing; while, PT-based substrates had no lime added based on recommendations by Jackson et al. (2009c). PB-based substrates and the 100% PB control were top-dressed with 2.6 g N [15 g (0.52 oz)] and PT-based substrates were top-dressed with 3.4 g N [20 g (0.71 oz)] per recommendations from Jackson et al. (2009a) using a polymer-coated, slow-release fertilizer, 17-5-10 (17N-2.2P-8.3K) (Harrell's, Lakeland, FL). The 6-month polymer-coated fertilizer contained all macro- and micronutrients derived from ammoniated phosphate, ammonium nitrate, calcium phosphate, potassium nitrate, sulfate of potash, copper sulfate, iron chelate, iron sulfate, magnesium oxide, magnesium sulfate, manganese sulfate, sodium molybdate, and zinc sulphate.

Plants in all substrate treatment combinations were grown with two irrigation/ground surface conditions: 1) overhead, sprinkler irrigation with black geotextile weed fabric covering the ground (OH) or 2) low-volume, spray stake irrigation with gravel covering the ground (LV). These irrigation/

ground surface conditions are commonly used in the nursery industry. However, the irrigation/ground covering conditions were not replicated in this study. Therefore, substrate effects were analyzed separately for each irrigation/ground covering situation. OH was supplied using rotary spray nozzles (961-P Part Circle, AGRIDOR Ltd., Rosh Ha'ayin, Israel) that delivered 120 liter·h^{-1} (32 gal·h^{-1}). LV was applied by a spray stake (PC Spray Stake, Netafim, Ltd., Tel Aviv, Israel) that delivered 12.1 liter·h^{-1} (3.2 gal·h^{-1}). Irrigation was applied cyclically at 8 am, 12 pm, and 4 pm for the duration of the study.

Total porosity (TP), airspace (AS), container capacity (CC), available water (AW), unavailable water (UW), bulk density (BD) and particle size distribution analyses were conducted in the Horticultural Substrates Laboratory, Department of Horticultural Science, N.C. State Univ., Raleigh, NC. Substrate physical properties were determined from fallow containers filled at potting. Irrigation was applied to the fallow containers with LV only.

Three replications of each substrate from the fallow containers were packed into 347.5 cm^3 cylindrical aluminum rings (7.6 cm diameter, 7.6 cm height) and used to determine TP, AS, CC, and BD according to procedures outlined in Tyler et al. (1993). Five replications of each substrate were packed into 101.4 cm^3 cylindrical aluminum rings, (7.6 cm diameter, 2.2 cm height) to determine UW using modified procedures of Bilderback et al. (1982). Unavailable water was determined using the 101.4 cm^3 rings following procedures described in Klute (1986), and AW was calculated as CC – UW. To determine particle size distribution, three replications of each substrate of approximately 100 g (3.53 oz) were dried at 105C (221F) for 48 hours and placed in a Ro-tap Shaker (Model B, W.S. Tyler, Mentor, OH) fitted with six sieves [6.3, 2.0, 0.71, 0.5, 0.25, and 0.106 mm (0.25, 0.08, 0.03, 0.02, 0.009, and 0.004 in)] for 5 minutes. The sample from each sieve was weighed, and particle size was expressed as a percentage of the total weight of the sample.

In both 2010 and 2011, studies were conducted at the Horticulture Field Laboratories, Raleigh, NC (longitude: 35°47'29.57"N; latitude: 78°41'56.71"W; elevation:136 m). In 2010 and 2011, for each irrigation/ground cover, all variables were analyzed using PROC GLM and least significant difference mean separations where appropriate and were considered significant at $P \leq 0.05$ (SAS 2011).

Summer 2010. 'Sunglow' azalea [*Rhododendron obtusum* (Lindl.) Planch.] and 'Blue Pacific' juniper (*Juniperus conferta* Parl.) were potted on May 7, 2010. Substrate solution was collected every two weeks for each substrate and species grown under both OH and LV irrigation using the pour-through nutrient extraction method (Wright, 1986). Electrical conductivity (EC) and pH of the collected substrate solutions were measured using a Hanna pH/EC meter (HI 8424, Hanna Instruments, Ann Arbor, MI). Substrate solution samples were collected on May 19, June 3, June 29, July 13, and July 28 for OH and on May 19, June 3, June 18, July 2, July 15, and August 10, 2010 for LV. Irrigation volume was managed for each irrigation system (OH and LV) and substrate base (PB and PT) and adjusted to maintain a 0.20 leaching fraction (leaching fraction = volume leached ÷ volume applied). Substrate physical properties were determined from fallow containers filled at potting and measured 4 and 22 weeks after filling using the same procedures as described above.

Summer 2011. On May 26, 2011 the experiments were repeated with the addition of a 100% PT control, hammermilled through a 6.35 mm (0.25 in) screen. Due to concerns over uniformity, a new OH system was constructed with sprinklers (R13-18, Rainbird, Tucson, AZ) that applied 363.6 liter·h^{-1} (96 gal·h^{-1}) and provided better application uniformity. The LV irrigation was the same used in 2010. Physical properties were analyzed from fallow containers at potting (0 weeks) and at the termination of the study (22 weeks after potting), using the same procedures as described above.

Substrate solution samples were collected on June 16, June 30, July 14, August 4, August 25, and October 4, 2011, for OH and on June 21, June 30, July 14, August 4, August 25, and October 4, 2011 for LV. Substrate solution samples collected on June 16, June 21, June 30, July 14, and August 25, 2011, were measured for pH and EC using a Hanna pH/EC meter (HI 8424, Hanna Instruments, Ann Arbor, MI). Substrate solution samples collected on June 30, August 4, and October 4, 2011, were submitted to the North Carolina Dept. Ag. and Consumer Services Agronomic Division (Raleigh, NC) for inorganic nitrogen (IN–N = NH_4–N + NO_3–N + NO_2–N), urea, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn analyses. NO_3–N was determined on a homogenized sample (~20 mL) by nitrate-hydrazine reduction (Kempers 1988, Skalar 1995b) and NH_4–N was determined by a modified Berthelot reaction (Krom 1980, Skalar 1995a), with an auto-flow spectrophotometric analyzer (San^{++} Segmented Flow Auto-Analyzer, Skalar Instruments; Breda, The Netherlands). Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B were determined with an inductively coupled plasma (ICP) spectrophotometer (USEPA, 2001) (Optima 3300 DV ICP emission spectrophotometer; Perkin Elmer Corporation; Shelton, CT).

Results and Discussion

Physical properties: In 2010 and 2011, throughout the production period, most of the PB- and PT-based substrates amended with CS, CSN, and CGT maintained acceptable physical properties (Bilderback et al. 2013) (Table 1). The sample time by substrate interaction was significant for TP, CC, AS, UW, AW, and BD for both years; therefore the data are presented by sample time.

In 2010, TP, AS, CC, and UW decreased for most of the substrates after 22 weeks. PB-based substrates had greater decreases in TP than the PT-based substrates. There were no differences in TP between the PB substrates amended with any of the cotton wastes for either sample time. TP and AS for all PT-based substrates were greater than the PB-based substrates at both sample times. Similarly, Jackson et al. (2009b) reported that TP and AS initially was higher in PT substrates (TP: 91%, AS: 36%) when compared to PB (TP: 83%, AS: 26%). After 22 weeks, PT:CS had the greatest TP (93%), the same level observed at the initial 4 week measurement (Table 1).

Similar to TP, AS was numerically lowest in PB:CGT and PB:CSN while PT:CS and PT:CSN had the greatest AS at 4 weeks in 2010 (Table 1). PB:CGT had the numerically lowest AS at both sample times. Similarly, Jackson et al. (2005) reported that at planting (initial) a 1.5:4.5:1 PB:CGC:sand had a lower AS (13%) than a 6:1 PB:sand and a 1:1 PB:CGC substrate. Container water-holding capacity decreased in four of the substrates and increased in three of the substrates between 4 and 22 weeks (Table 1). CC was numerically lowest

Table 1. Effect of pine bark- (PB) and pine tree- (PT) based substrates amended with composted cotton stalks (CS), cotton stalks composted with a nitrogen source (CSN) and aged cotton gin trash (CGT) on total porosity (TP), air space (AS), container water-holding capacity (CC), available water (AW), and unavailable water (UW) (2010 and 2011).

	TP (% vol.)				AS (% vol.)				CC (% vol.)				AW (% vol.)				UW (% vol.)			
	2010		2011		2010		2011		2010		2011		2010		2011		2010		2011	
Substrate (v/v)[z]	4 wks[y]	22 wks	0 wks	22 wks	4 wks	22 wks	0 wks	22 wks	4 wks	22 wks	0 wks	22 wks	4 wks	22 wks	0 wks	22 wks	4 wks	22 wks	0 wks	22 wks
PB	91	77d	80	84	32b	20cd	34ab	27abc	56c	57a	46e	57de	17c	29a	16c	28d	39ab	27ab	30b	29bc
PB:CS	89	76d	70	87	32b	20cd	35a	34a	57bc	60a	45e	53e	24bc	29a	17c	22e	36bc	27abc	28c	32a
PB:CSN	89	75d	80	89	29bc	24bc	32ab	31ab	59ab	51b	47e	58cd	24bc	22b	17c	26d	35c	30a	30b	32a
PB:CGT	86	75d	72	80	26c	17d	29bc	23c	60ab	58a	51d	63b	21bc	35a	17c	34b	39a	23c	35a	30b
PT:CS	93	93a	86	84	39a	36a	15e	24bc	54c	57a	71b	60c	17b	34a	43a	32bc	29de	23bc	28c	28c
PT:CSN	93	80c	89	82	38a	37a	15e	24bc	55c	43c	74a	58cd	25b	18b	44a	28cd	31d	25bc	31b	30b
PT:CGT	92	86b	88	89	31b	28b	27cd	22c	61a	58a	61c	57a	34a	35a	34b	41a	27e	23bc	27cd	26d
PT	—	—	84	90	—	—	24d	22c	—	—	60c	69a	—	—	34b	43a	—	—	26d	26d
Substrate[w]	NS	0.001	NS	NS	0.002	0.001	0.001	0.02	0.007	0.001	0.001	0.001	0.005	0.004	0.001	0.001	0.001	0.04	0.001	0.001
BMP Guidelines[v]	50–85%				10–30%				45–65%				25–35%				25–35%			

[z]The substrates consisted of: 100% PB, 4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1 PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN), 4:1 PT:CGT (PT:CGT) and 100% PT. 100% PT was not included in 2010.

[y]The substrates were sampled twice for physical property analyses at 4 weeks after planting and again at 22 weeks after planting, in 2010 and at potting (0 weeks) and again at 22 weeks after planting in 2011, fallow containers were irrigated with low-volume irrigation only.

[x]Means within a column for each year with different letters are significantly different from each other based on lsd mean separation ($P \geq 0.05$). N = 3.

[w]ANOVA effect of substrate within each sample date. NS = $P \geq 0.05$, P-value given otherwise.

[v]BMP = Best Management Practices recommended ranges (in percentages) for substrates used in general nursery production (Bilderback et al. 2013).

in PT:CS, PT:CSN, and PB initially, while PT:CSN continued to have the lowest CC after 22 weeks.

AW increased and UW decreased in most substrates from 4 to 22 weeks except PB:CSN and PT:CSN which both had decreased AW (Table 1). At four weeks after potting, AW was the highest in the PT:CGT and numerically lowest in the PB substrate while UW was numerically lowest with PT:CGT and highest with the PB:CGT and PB substrate. By 22 weeks after potting, PB:CSN and PT:CSN had the lowest AW with all other substrates having greater and similar AW. At 22 weeks, UW was numerically greater in all the PB substrates (except PB:CGT) than the PT substrates. BD did not change over time substantially amongst the different substrates (data not shown). All of the PB-based substrates had higher BD (0.23 to 0.27) than all of the PT-based substrates (0.11 to 0.16), a trend that continued through the final measurements and was similar to the results of Jackson et al. (2009b).

For particle size analyses, the sample time by substrate interaction was significant for most sieve sizes; therefore, data are presented by sample time (Table 2). Drzal et al. (1999) classified particle sizes into three main groups: coarse (> 2.0 mm), medium (0.5–2.0 mm), and fine (< 0.5 mm). Such groupings of particle sizes also make these data easier to interpret; therefore, data were re-analyzed with particle size data grouped according to Drzal et al. (1999) and are presented in this manner. Substrates that contain larger amounts of coarse particles have greater air filled pore space (Drzal et al. 1999). Substrates that have more medium and fine size particles have more small pores and can hold more water against the pull of gravity (Drzal et al.1999). Blending a coarse substrate with a substrate that has more medium or fine particles can increase container capacity as smaller particles nest in the pores created by the larger particles (Drzal et al. 1999). At both 4 and 22 weeks, all PB-based substrates generally had larger amounts of coarse and fine particles than any of the PT-based substrates (Table 2). PT-based substrates generally had higher amounts of medium particles at 4 and 22 weeks. These data support the TP, AS, and CC results (Table 1).

Similar to 2010, in 2011 TP was not significantly affected by substrate at 0 weeks (at potting); however, unlike 2010, it was also not affected by substrate after 22 weeks (Table 1). In contrast to 2010, PT:CS and PT:CSN had the lowest AS in 2011. In fact in 2011, all the PT substrates had lower AS than the PB at 0 weeks while there were less clear distinctions between substrates in AS after 22 weeks. In 2011, CC increased over time for all PB-based substrates. In both years, AW tended to increase and UW tended to decrease over time. As in 2010, at 22 weeks, AW in 2011 was highest with PT:CGT and the added 100% PT control and was lowest with PB:CS. After 22 weeks, UW was higher with PB:CS and PB:CSN and continued to be lowest with PT:CGT and PT. PB:CGT and PB had the highest BD at 0 and 22 weeks. PT:CS and PT:CSN had the lowest BD at 0 weeks while PT:CS had the lowest at 22 weeks.

For 2011, the sample time by substrate interaction was again significant for most sieve sizes (data not shown). Thus, data are presented by sample time (Table 2). PT-based substrates generally had a higher percentage of fine and medium particles at 0 and 22 weeks than PB-based substrates. In both 2010 and 2011, PB-based substrates had the largest amounts of coarse particles. In 2011, the trend in percentage of fine particles was opposite from 2010 and was due to the inconsistencies in PB supplies. In 2011, the PB was not well aged and did not have an appropriate particle size distribution. Over the 22 weeks of production, the PB continued to age in the container as evidenced by the increase in CC and decrease in AS (Table 1). Cotton stalk compost (CS and CSN) may have helped maintain AS in the PB substrates as the PB broke down. AS in the PB:CS and the PB:CSN substrates did not decrease as much as the 100% PB; however, these substrates were not statistically different from each other (Table 1).

CS and CSN added to the PB base did not change AS and CC or AW and UW of the blended substrate compared to 100% PB. When added to the PT base, CS and CSN decreased initial AS, increased initial CC, and did not dramatically alter AW and UW of the blended substrates compared to 100% PT. CGT blended with either PB or PT had little impact on

Table 2. Percent particle size distribution of pine bark- (PB) and pine tree- (PT) based substrates amended with composted cotton stalks (CS), cotton stalks composted with a nitrogen source (CSN), and aged cotton gin trash (CGT) (2010 and 2011).

	2010						2011					
	4 wks[y]			22 wks			0 wks			22 wks		
Substrate[z] (v/v)	Coarse[x]	Med.	Fine	Coarse	Med.	Fine	Coarse	Med.	Fine	Coarse	Med.	Fine
PB	17a[w]	72cd	11b	19a	54b	27ab	17cd	74cd	9c	17b	68c	16d
PB:CS	13b	75c	13a	16ab	63b	21ab	21a	70e	10c	18ab	73b	10e
PB:CSN	18a	70d	13a	17ab	54b	30a	19ab	70e	12c	20b	70bc	11e
PB:CGT	17a	73cd	11ab	13b	58b	30a	18ab	71de	11c	16d	67c	17bcd
PT:CS	4c	88b	8c	5c	89a	4c	0c	77bc	24a	0d	79a	21a
PT:CSN	3c	94a	4d	2c	84a	15bc	3c	82a	16b	0c	81a	20abc
PT:CGT	4c	91b	7c	3c	67b	21ab	0c	84a	17b	3c	81a	17cd
PT	—	—	—	—	—	—	0c	79b	22a	0d	80a	21ab
Substrate[v]	0.001	0.001	0.001	0.001	0.001	0.006	0.001	0.001	0.001	0.001	0.001	0.001

[z]The substrates consisted of: 100% PB, 4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1 PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN), 4:1 PT:CGT (PT:CGT) and 100% PT. 100% PT was not included in 2010.

[y]The substrates were sampled twice for physical property analyses at 4 weeks after planting and again at 22 weeks after planting, in 2010 and at potting (0 weeks) and again at 22 weeks after planting in 2011, fallow containers were irrigated with low-volume irrigation only.

[x]Means within a column for each year with different letters are significantly different from each other based on lsd mean separation ($P \geq 0.05$). N = 3.

[w]Particle size range: Coarse = > 2.0 mm, Medium = 0.5–2.0 mm, and Fine = < 0.5 mm (Drzal, 1999).

[v]ANOVA effect of substrate within each sample date. NS = $P \geq 0.05$, P-value given otherwise.

the air and water relations compared to either 100% PB or 100% PT.

Substrate solution analyses. In both 2010 and 2011, species and substrate affected the pH of the substrate solution while substrate solution EC was significantly influenced by sample time, species, and substrate regardless of irrigation/ground covering (OH and LV) (data not shown). In 2010, regardless of OH and LV, PT-based substrates maintained higher EC (0.3 to 1.4 $mS \cdot cm^{-1}$) and pH (5.7 to 6.4) levels throughout all sample times (May to August); while, 100% PB maintained the lowest EC (0.2 to 0.8 $mS \cdot cm^{-1}$) but similar pH (5.2 to 6.2) (data not shown). The PB-based amended substrates had intermediate EC (0.2 to 0.9 $mS \cdot cm^{-1}$) and pH (5.1 to 6.2) levels. The 100% PT substrate (added to the study in 2011) had the lowest pH levels (5.1 to 5.9) and the highest EC levels (0.3 to 1.3 $mS \cdot cm^{-1}$) throughout the entire growing season for both LV and OH when compared to the other substrates. Jackson et al. (2009b) reported similar results, where substrate solution pH remained higher in a PT substrate than a PB substrate. There was a general increase in pH and EC with substrates that had the CS, CSN, and CGT amendments compared to PB or PT alone. For the most part, substrate pH levels in this study were within recommended ranges (4.5 to 6.5); some, however, were slightly higher (e.g. 6.9, juniper, grown in PT:CGT under LV, 2010) (Bilderback et al. 2013).

To gain further insight into substrate nutrient composition, leachates were analyzed in 2011. The three way sample time by species by substrate interaction was largely non-significant. The other two-way interactions of sample time by substrate and sample time by species were more consistently significant so the data were reanalyzed by sample time and species for each irrigation/ground covering. Additionally, the June 30 and October 4 sample times adequately represent the trends in data; therefore only these dates are presented. With OH, substrate affected the concentration of IN–N in the substrate solution for juniper and azalea at all sample times except October 4 with azalea, but did not affect urea concentration (Table 3 and 4). With OH, IN–N levels were highest in the substrate solution samples collected on June 30 for azalea grown in PT:CSN and 100% PT (Table 3). Similarly, for juniper, with OH, IN–N was numerically highest in the substrate collected from 100% PT on June 30 and PT:CGT on October 4 (Table 4).

With LV, substrate did not affect IN–N concentrations in the substrate solution for either species except on October 4 for azalea where PT:CS was numerically highest (Table 3). The CGT substrate amendment or the addition of composted cow manure to the cotton stalks during composting (CSN) did not increase IN–N concentrations but did increase urea concentrations in both the PB- and PT-based substrates compared to the CS amended substrates with the exception of PT:CSN with azalea at the June 30 sampling. Substrate impacted urea concentrations at all sample times for both species with LV (Table 3 and 4). Pots containing azalea numerically had the most urea present in the substrate solution samples for June 30 when grown in PB:CGT and the lowest with PT:CS and 100% PB with LV. On October 4, PT:CGT had the highest amount of urea in the substrate solution for azalea with LV, while 100% PB, PB:CS, PB:CSN, PB:CGT, PT:CSN, and 100% PT had similar and lower amounts. For juniper grown with LV, urea was numerically highest in substrate solutions from PB:CSN and PB:CGT, while it was lowest with all of the PT-based substrates for the June 30 sample time.

Substrate affected the concentration of P in the substrate solution obtained from juniper and azalea with both ir-

Table 3. Effect of substrate on the substrate solution nutrient concentrations for azalea growing with overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH), or low-volume, spray stake irrigation and gravel covering the ground (LV) (2011).

	Inorganic N	Urea	P	K	Ca	Mg
	$mg \cdot L^{-1}$					
OH						
June 30[z]						
PB[y]	18.0b[x]	0.32	1.3d	38.2d	8.3b	6.7
PB:CS	25.8b	0.51	2.6cd	55.0bcd	10.0b	8.4
PB:CSN	24.5b	0.42	2.4cd	58.9bcd	9.6b	8.6
PB:CGT	22.0b	0.32	3.2c	73.6ab	12.7b	10.2
PT:CS	29.3b	0.48	3.1cd	73.9ab	11.8b	9.6
PT:CSN	61.5a	0.20	5.5b	83.9a	22.4a	20.0
PT:CGT	33.4b	0.13	10.0a	66.0abc	21.4a	14.4
PT	66.4a	0.53	3.5c	45.0cd	11.8b	9.6
Substrate[w]	0.003	NS	<.0001	0.0206	0.0175	NS
Oct. 4						
PB	5.5	0.10	1.8	8.2	3.5	2.0
PB:CS	6.2	0.06	1.7	8.7	3.2	2.0
PB:CSN	6.0	0.05	2.0	8.9	2.7	1.6
PB:CGT	6.3	0.10	2.0	10.4	3.7	2.0
PT:CS	5.3	0.16	1.5	6.6	3.4	1.7
PT:CSN	8.3	0.17	2.1	11.7	3.5	2.1
PT:CGT	4.2	0.09	1.7	6.6	4.5	2.0
PT	3.7	0.10	1.4	7.7	3.1	1.6
Substrate	NS	NS	NS	NS	NS	NS
LV						
June 30						
PB	30.7	0.20c	1.8c	57.2	16.7	14.9
PB:CS	32.4	0.78b	2.5bc	52.0	11.9	11.2
PB:CSN	42.8	0.85ab	3.4bc	67.5	15.3	14.7
PB:CGT	21.0	1.13a	2.2c	26.0	12.1	9.0
PT:CS	56.1	0.13c	5.4ab	80.8	25.3	23.5
PT:CSN	53.0	0.77b	5.5ab	96.5	23.6	20.1
PT:CGT	22.9	0.82ab	6.8a	86.5	22.9	14.0
PT	49.2	1.08ab	2.4bc	41.0	12.9	13.8
Substrate	NS	0.0001	0.0247	NS	NS	NS
Oct. 4						
PB	3.4b	0.01c	1.1	7.9b	2.8	2.3
PB:CS	2.8b	0.00c	1.1	5.3b	2.2	1.7
PB:CSN	3.0b	0.00c	1.1	6.1b	3.1	2.4
PB:CGT	2.8b	0.05c	1.3	6.5b	4.4	2.9
PT:CS	11.9a	0.16b	3.9	17.0a	7.5	5.8
PT:CSN	6.1b	0.00c	2.4	11.6ab	4.0	3.1
PT:CGT	5.6b	0.32a	4.7	12.5ab	7.0	4.5
PT	8.3ab	0.00c	3.1	17.6a	4.5	3.9
Substrate	0.0369	0.0001	NS	0.0289	NS	NS

[z]The substrate solution was collected and measured for nutrient concentrations on four dates, June 30, September 4, and October 4.

[y]The substrates consisted of 100% PB, 4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1 PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN), 4:1 PT:CGT (PT:CGT), and 100% PT.

[x]Means within a column with different letters are significantly different from each other based on lsd mean separation ($P \geq 0.05$). N = 3.

[w]ANOVA effect of substrate within each sample date. NS = $P \geq 0.05$, p-value given otherwise.

Table 4. Effect of substrate on the substrate solution nutrient concentrations for juniper grown with overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH), or low-volume, spray stake irrigation and gravel covering the ground (LV) (2011).

	Inorganic N	Urea	P	K	Ca	Mg
	mg·L^{-1}					
OH						
June 30[z]						
PB[y]	34.8c[x]	0.31	2.0d	60.8	14.1b	12.1bc
PB:CS	37.6c	0.39	3.3cd	50.3	12.7b	11.6bc
PB:CSN	43.1c	0.25	3.7cd	71.6	15.2b	13.5bc
PB:CGT	41.3c	0.43	4.5cd	89.7	13.5b	11.0c
PT:CS	93.5ab	0.38	8.1bc	62.6	17.8b	15.2bc
PT:CSN	81.3ab	0.21	10.9b	88.8	28.4a	24.4a
PT:CGT	67.5bc	0.31	16.7a	78.2	33.4a	19.3ab
PT	101.7a	0.53	6.7bcd	61.4	10.6b	10.0c
Substrate[w]	0.002	NS	0.0003	NS	0.0003	0.0196
Oct. 4						
PB	2.7b	0.16	1.3b	6.8b	5.1b	2.7b
PB:CS	3.1b	0.04	1.3b	6.1b	5.2b	2.8b
PB:CSN	2.6b	0.09	1.3b	5.7b	5.2b	2.9b
PB:CGT	3.4b	0.10	1.5b	6.4b	5.3b	2.8b
PT:CS	5.9b	0.11	2.0b	9.4b	5.5b	3.4b
PT:CSN	4.3b	0.08	1.8b	6.7b	5.8b	3.1b
PT:CGT	14.8a	0.23	6.0a	20.7a	12.7a	5.9a
PT	5.0b	0.22	2.2b	10.3b	5.7b	2.8b
Substrate	0.0154	NS	0.0006	0.0017	0.0109	0.0348
LV						
June 30						
PB	34.3	1.03ab	2.2b	42.4	12.2c	10.4c
PB:CS	70.1	0.86b	3.9b	99.2	28.8ab	29.1ab
PB:CSN	40.8	1.27a	3.4b	56.5	14.4bc	13.9bc
PB:CGT	43.6	1.28a	4.0b	85.7	16.4bc	14.1bc
PT:CS	108.6	0.34c	15.0a	186.9	35.3a	33.2a
PT:CSN	78.3	0.12c	10.3a	114.2	33.3a	30.3ab
PT:CGT	66.2	0.37c	15.1a	95.6	33.7a	22.8abc
PT	52.3	0.22c	3.3b	37.4	10.9c	9.4c
Substrate	NS	0.0001	0.0002	NS	0.0117	0.0382
Oct. 4						
PB	4.1	0.00	1.4c	8.8	4.2ef	3.1c
PB:CS	2.8	0.00	1.6c	7.4	3.7f	3.2bc
PB:CSN	4.6	0.06	2.1bc	9.7	5.2cde	4.2ab
PB:CGT	5.2	0.00	2.7b	10.6	7.0ab	5.0a
PT:CS	3.3	0.00	2.2bc	9.6	5.8bcd	4.0abc
PT:CSN	2.7	0.00	2.2bc	9.1	6.1bc	4.2abc
PT:CGT	3.3	0.03	4.2a	10.3	8.3a	3.5bc
PT	5.0	0.06	2.5b	15.3	4.4def	3.6bc
Substrate	NS	NS	0.0004	NS	0.0001	0.0362

[z]The substrate solution was collected and measured for nutrient concentrations on four dates, June 30, September 4, and October 4.

[y]The substrates consisted of 100% PB, 4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1 PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN), 4:1 PT:CGT (PT:CGT), and 100% PT.

[x]Means within a column with different letters are significantly different from each other based on lsd mean separation ($P \geq 0.05$). N = 3.

[w]ANOVA effect of substrate within each sample date. NS = $P \geq 0.05$, p-value given otherwise.

rigations throughout the experiment except azalea at the last sampling (October 4) (Table 3). Most of the substrates remained below the recommended range (5 to 10 mg·L^{-1} P), especially for PB-based substrates (Bilderback et al. 2013). However, PT-based substrates generally were within the recommended 5 to 10 mg·L^{-1} P range, with some exceptions. PT:CGT maintained higher P concentrations in the substrate solution for both juniper and azalea irrigated with OH and LV compared to the other substrates, except for juniper grown in PT:CSN on June 30 with LV. At the final sample time, October 4 all of the substrate solutions for each substrate, species, and irrigation were below the recommended ranges (Bilderback et al. 2013).

The substrate effect on K concentration in solution from azalea and juniper irrigated with OH and LV was not as clearly defined. Substrate did not affect substrate K concentrations except for azalea on June 30 and juniper on October 4 with OH, and azalea on October 4 with LV (Table 3). Generally, PT-based substrates tended to have higher levels of K in the substrate solution when compared to the PB-based substrates. The June 30 substrate solution samples for all substrates, for both azalea and juniper, and for both irrigations were above the recommended range (10 to 20 mg·L^{-1}); however, by October 4, they were mostly below the recommended range (Bilderback et al. 2013).

Substrate also had a varied effect on substrate solution concentrations of Ca and Mg in juniper and azalea with OH, affecting substrate Ca concentrations on June 30 for both azalea and juniper and on October 4 for juniper only (Table 3). With LV, Ca concentration in the substrate solution was impacted by substrate for juniper at all sample times. Mg substrate solution concentrations were only significantly impacted by substrate for juniper on June 30 and October 4 for OH and LV. With OH, PT:CSN and PT:CGT generally had higher Ca and Mg concentrations in the substrate solution. Similarly, McGinnis et al. (2010) reported that vermicomposted pig manure amended with PB had a linear increase of Ca and Mg in the substrate solution with incorporation rates from 10 to 40% (by vol). In this study, Ca and Mg substrate solution levels were generally below the recommended ranges (20 to 40 mg·L^{-1} Ca and 15 to 20 mg·L^{-1} Mg) for the majority of the study for both species in most substrates with both irrigations (Bilderback et al. 2013).

Under both irrigation treatments PB-based substrates maintained higher Fe concentrations, while PT-based substrates maintained higher S, Mn, and B concentrations (data not shown). Substrate solution Zn concentration was not affected by substrate (data not shown).

The substrate combinations used in this study are viable alternative substrates and PB extenders for production of crops in the nursery industry. Amending PB and PT substrates with CS, CSN, or CGT resulted in substrates with appropriate physical properties that were comparable to or better than the 100% PB industry standard. In 2010, PB-based substrates had larger percentages of coarse (> 2.0 mm) and fine (< 0.5 mm) particles while PT-based substrates had larger percentages of medium (0.5–2.0 mm) particles. In 2011, PB-based substrates again had larger percentages of coarse particles, while PT-based substrates had more medium and fine particles. The difference between the percentages of fines is due to an inconsistency in the PB supply from 2010 to 2011. TP and AS of PT-based substrates were greater (and decreased less over time) than PB-based substrates. PT:CS has the greatest TP and AS but the lowest CC and low AW. PB-based substrates tended to have greater UW than PT-based substrates regardless of amendment. AW increased in most substrates over time.

By October 4, 2011, substrate solution nutrient concentrations in all substrates for both species (azalea and juniper) with both irrigation types (OH and LV) were below the recommended ranges (Bilderback et al. 2013) indicating the composts were not supplying any additional nutrition. Urea and P concentrations were higher in PB- and PT-based substrates amended with CGT, however IN–N was not impacted by substrate amendment. Amending PB and PT substrates with CS, CSN, and CGT may be viable to extend the use of PB in the nursery industry but may not provide the plant with additional nutrition. Before an alternative substrate or amendment can be incorporated into the production system of a nursery it needs to be trialed and tested to ensure that it will not hinder crop production (Boyer et al. 2008). Also, it needs to be continually consistent and available within a close proximity to prevent any increases in crop production price.

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