Composted Cotton Stalks and Cotton Gin Trash Substrate Amendments and Irrigation/Ground Cover Management II. Effect on Growth and Disease Suppression for Azalea and Juniper[1]

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Abstract

'Sunglow' azalea and 'Blue Pacific' juniper were grown in pine bark (PB) and pine tree (PT) substrates that were amended with cotton stalks composted with a N source (CSN), cotton stalks composted without an N source (CS), and cotton gin trash (CGT) to evaluate the substrate's effect on plant growth and disease suppression. The plants were grown under two different, commonly used, irrigation/ground surface management regimes — overhead, sprinkler irrigation with black geotextile weed fabric covering the ground (OH) or low-volume, spray stake irrigation with gravel covering the ground (LV). In 2010, with OH, all PB-amended substrates produced significantly larger azalea shoots than PT-amended substrates. In 2011, with OH, all azalea shoots were similar in size when grown in all substrates except for PT:CS, where plants were significantly smaller. With LV, in 2010 and 2011, azalea shoot growth was largest when grown in a PB substrate amended with CSN or CGT and lowest in PT:CS. Junipers with OH produced generally larger shoot growth with the PB-based substrates in both 2010 and 2011 compared to the PT-based substrates. With LV, PT:CGT produced the numerically smallest juniper shoot growth for both years. Overall, PT-based substrates appeared to produce greater consistency in growth, because responses were more similar in 2010 and 2011, however irrigation method and management can impact growth regardless of substrate composition. CGT added to PB- or PT-based substrates enhanced Ca and Mg uptake by both species but not P uptake. OH generally kept ground surface and substrate temperatures lower than LV regardless of substrate composition. The substrates tested neither enhanced nor deterred *P. cinnamomi* infection in azalea or juniper.

Index words: disease suppression, temperature, substrate amendments, plant growth, renewable amendments.

Species used in this study: 'Sunglow' azalea [*Rhododendron obtusum* (Lindl.) Planch.];'Hinodegiri' (Hino) azalea, (*Rhododendron* L.); 'Blue Pacific' juniper (*Juniperus conferta* Parl); and phytophthora root rot (*Phytophthora cinnamomi* Rands).

Significance to the Horticulture Industry

Both pine bark- and whole pine tree-based substrates amended with either composted cotton stalks, cotton stalks composted with an additional N source, or cotton gin trash can support plant growth well when the substrates are formulated to have appropriate air and water holding properties. In this study, when plants were grown with overhead, sprinkler irrigation with black geotextile weed fabric covering the ground, all pine bark-based substrates were generally comparable to the 100% pine bark control substrate. When plants were produced with low-volume, spray stake irrigation with gravel covering the ground, there was less consistency in the results; however, plant growth still tended to be similar to the 100% PB control. However, all substrate combinations produced good quality plants; which substrate works best will depend on production system management for fertility and irrigation. By utilizing local substrate amendments such as cotton waste products, the nursery industry can assist another industry in disposing of a waste while also reducing the nursery industry's dependence on pine bark. The composted cotton stalks and the cotton gin trash neither deterred nor enhanced root rot in either azalea or juniper. Generally, both the overhead sprinkler and the low volume irrigation produced good quality plants in all substrates. However, plants grown on black plastic using overhead irrigation produced numerically larger shoot and root systems regardless of substrate when compared to plants grown on gravel using low-volume irrigation. The type of irrigation/ground surface management regimes played a large role on the temperature of the environment surrounding plants in production. Overhead irrigation created a cooling effect for the production environment and may have contributed to the larger shoot and root systems produced. However, overhead irrigation may not be as economically or environmentally sound compared to low-volume irrigation due to the amount of water lost during application and runoff generated.

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Introduction

Due to its availability and beneficial air and water holding properties, pine bark (PB) makes up 75 to 100% (by vol) of container substrates used in the eastern United States (Lu et al, 2006). However, after nearly forty years of use by the nursery industry, many industries have begun to compete for a diminishing supply of pine bark, driving up price and limiting supply. Thus, research for alternative substrates to replace the use of PB by the southeastern nursery industry is becoming more critical.

Alternative substrates and pine bark extenders (amendments) such as cotton gin compost (Cole et al. 2005, Jackson et al. 2005), turkey litter compost (Tyler et al. 1993a), vermicompost (McGinnis et al. 2009), eastern redcedar (Murphy et al. 2011), switchgrass (Altland and Krause 2009), and whole pine tree substrates (Jackson et al. 2008, Jackson et al. 2009a, b, and c, Rau et al. 2006) have been shown to support plant growth well. However, some of these substrate amendments are expensive due to their preparation, handling, shipping weight, and associated costs, making their use cost prohibitive. Growers are seeking substrates that are reasonably priced and produce high-quality plants. One way to address these needs may be through alternative substrates that are locally and readily available. These substrates may help prevent profit margins from decreasing due to a rise in container substrate costs, and they could utilize waste materials that may otherwise end up in landfills.

Cotton is a very important agricultural crop in the southeast that generates two wastes that could be beneficial PB extenders — cotton stalks and cotton gin trash. Cotton stalks (CS) must be composted and may require an added N source during composting (CSN) to produce an acceptable substrate amendment (personal observation). Non-composted cotton stalks that were chopped by a silage cutter, still contained cotton seeds, which germinated when blended with PB and added to a production substrate (personal observation). Cotton gin trash (CGT) is produced during the ginning process of lint removal from the cotton burr (Buser 2001, Fava 2004). Previous research has reported CGT as a viable substrate amendment with container-grown boxwood (*Buxus microphylla* Sieb. & Zucc. 'Winter Gem'), *Coleus* x *hybridus* 'Golden Bedder', juniper *(Juniperus conferta* Parl. 'Blue Pacific'), Nandina *domestica* Thumb 'Firepower', azalea [*Rhododendron indicum* (L.) Sweet 'Formosa', 'Midnight Flare', and 'Renee Mitchell'] and *Rhododendron obtusum* (Lindl.) Planch. 'Sunglow' (Cole et al. 2005, Jackson et al. 2005, Owings 1993, and Riley et al. 2014). However, cotton stalks have not been evaluated as a composted substrate amendment. Additionally, whole pine tree substrates (PT) have been found to be an appropriate alternative substrate (Jackson et al. 2009a, b, and c, Riley et al. 2014); however, the effect on plant growth of blending PT with composts has not been evaluated.

Two potential benefits of using composts to amend substrates, besides the outlet for waste utilization, are suppression of soilborne plant pathogens and addition of plant nutrients. Microorganisms that can be present in compost and persist once the compost has been added as a substrate amendment could act as biocontrol agents against diseases, including ones that are caused by *Phytophthora* spp. (Hoitink et al. 1997). The activity of these beneficial microbes could inhibit germination of pathogen spores, thus preventing them from infecting the host (Hoitink et al. 1997). Pine bark substrate pH was increased by the addition of composted turkey litter (Tyler et al. 1993b) and by composted cotton stalks and cotton gin trash (Riley et al. 2014). Additionally, composted turkey litter increased concentrations of P, Ca, Mg, and micronutrients in the substrate solution, resulting in increased uptake of these nutrients by the plant (Tyler et al. 1993b, Warren et al. 2009). In both PB- and PT-based substrates, CGT increased substrate solution P concentrations 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); however, CS, CSN and CGT had little impact on the inorganic N (NH_4+NO_3), K, Ca, and Mg concentration in the substrate solution with either OH or LV (Riley et al. 2014). Therefore, composted cotton stalks and/or cotton gin trash may enhance the uptake of P by plants.

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 different irrigation/ground surface management regimes. Also, the effect of different irrigation/ground surface management regimes, overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH) and low-volume, spray stake irrigation with gravel covering the ground (LV), on production environment temperature was evaluated. Finally, this research evaluated the disease suppression of *Phytophthora cinnamomi* by composted cotton stalks and cotton gin trash. This project was repeated over two summers (2010 and 2011).

Materials and Methods

Summer 2010. 'Sunglow' azalea and 'Blue Pacific' juniper were potted on May 7, 2010, into 2.8 liter (0.7 gal) black plastic containers filled with a factorial treatment combination of substrate bases [pine bark (PB) or pine tree (PT)] and amendments [cotton stalks composted with a nitrogen (N) source (CSN), cotton stalks composted without N (CS), or aged cotton gin trash (CGT)] blended by volume. The resulting six substrates [4:1 PB:CS (PB:CS), 4:1 PB:CSN (PB:CSN), 9:1PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CSN (PT:CSN), and 4:1 PT:CGT (PT:CGT) (by vol), and a 100% PB industry control] and two species were arranged in a randomized complete block design with eight replications as reported by Riley et al. (2014).

Plants in all substrate treatment combinations were grown with one of two different, commonly used 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) as described in previous research (Riley et al. 2014). Irrigation volume was adjusted for each irrigation system (OH and LV) and substrate base (PB and PT) to maintain a 0.20 leaching fraction (leaching fraction = volume leached ÷ volume applied). Leaching fractions were collected on June 25, July 7, July 21, and August 14 for OH and on June 25, July 7, July 20, and August 4, 2010 for LV.

On August 26, 2010, plants were separated into shoots (stems and leaves) and roots. Roots of juniper were washed to remove substrate for dry weight determination; azalea root dry weight was not obtained. All plant parts were dried at 62C (144F) for 5 days, and then weighed. Leaves were ground using a Foss Tecator Cyclotec™ 1093 sample mill (Analytical Instruments, LLC, Golden Valley, MN) to pass a ≤ 0.5 mm (0.02 in) sieve. Foliar nutrient concentration was analyzed by the North Carolina Department of Agriculture and Consumer Services (NCDA&CS), Agronomic Division (Raleigh, NC) with four replications of each species with OH; foliar nutrient concentration was not analyzed for LV in 2010. Foliar N concentration was determined by oxygen combustion gas chromatography with an elemental analyzer (NA 1500; CE Elantech Instruments, Lakewood, NJ) (Campbell and Plant 1992). Foliar P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn concentrations were determined with an inductively coupled plasma (ICP) spectrometer (Donohue and Aho 1992) (Optima 3300 DV ICP Emission Spectrometer; Perkin Elmer Corp., Shelton, CT) following open-vessel nitric acid digestion in a microwave digestion system (CEM Corp., Matthews, NC) (Campbell and Plant 1992).

Summer 2011. In 2011, the experiments were repeated as described above and previously reported (Riley et al. 2014) with a potting date of May 26, 2011, and the addition of a 100% PT control, hammer-milled through a 6.35 mm (0.25 in) screen. Additionally, juniper liners came from a different source and were smaller than in 2010. Leaching fractions were measured on June 10, June 25, July 12, July 29, August 24, and September 2 for OH and on June 10, June 25, July 12, July 30, August 24, and September 15, 2011, for LV. On October 4, 2011, plants were harvested as described above with the following exceptions; eight replications were used and LV samples were included in foliar analyses.

To evaluate the effect of substrate and irrigation/ground surface conditions on the production environment, the temperatures of the substrates and production ground surfaces were measured using a thermocouple and datalogger (U12 Outdoor/Industrial, Onset Hobo Data Loggers, Bourne, MA). A thermocouple was placed on the south side of the container, approximately 25.4 mm (1 in) deep into each substrate for temperature measurements in each irrigation treatment from August 19, 2011, at 6:00 am to August 20, 2011, at 6:00 am. For irrigation ground surface temperature measurements, the thermocouple was laid on the surface of the ground from August 3, 2011, at 6:00 am to August 4, 2011, at 6:00 am. In both 2010 and 2011, the study was conducted at the Horticulture Field Laboratories, Raleigh, NC (longitude: 35°47'29.57"N; latitude: 78°41'56.71"W; elevation:136 m). The irrigation/ground cover production areas were not replicated. Therefore, substrate comparisons were only made within each irrigation/ground cover system. In 2010 and 2011, 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).

Assessment of disease suppression. Suppression of the root-rot fungus *Phytophthora cinnamomi* was evaluated in an area adjacent to the OH irrigation area used for the plant growth study. Inoculum of *P. cinnamomi* was produced on sterile rice grains in the laboratory and used to inoculate test plants (Holmes and Benson 1994). 'Sunglow' azalea, 'Blue Pacific' juniper, and 'Hinodegiri' azalea ('Hino') were inoculated. 'Hino' azalea was included because it is highly susceptible to *P. cinnamomi.* All three species were transplanted on the same days, and into the same PB- and PT-based substrates amended with CS, CSN, and CGT as well as the control substrate (100% PB), with the same amounts of lime and fertilizer applied as previously reported (Riley at al. 2014). Plants were grown in 2.8 liter (0.7 gal) black plastic containers and were allowed to establish for two weeks before inoculation. At inoculation two rice grains colonized by isolate 2386 of *P. cinnamomi* were placed in three holes around the edge of the root system to a depth of 3 cm (1.18 in) below the surface. Pots were arranged in a randomized complete block design. In 2010, there were five inoculated and five non-inoculated replications; in 2011 there were four replications of each. Plants were watered by overhead sprinkler irrigation [Impact Sprinkler 25JDA-C (2010) and 1800 Series (2011), Rainbird, Tucson, AZ]. Once symptoms of *P. cinnamomi* first developed, observations were made every two weeks thereafter during the growing season. Foliar disease symptoms were recorded on a disease rating scale where 1 = no disease, 2 = slight disease (slight chlorosis), 3 = stunting and necrosis, 4 = dead plant (Benson 1990). At harvest on September 8, 2010, and September 12, 2011, fresh shoot weight was taken and root rot was assessed with a standard rating scale where 1 = healthy, 2 = fine roots necrotic, 3 = coarse roots necrotic, 4 = crown rot, and 5 = dead plant (Benson 1987). The data were analyzed using PROC GLM and means were separated using single degree of freedom linear contrasts to compare non-inoculated and inoculated treatments for each species growing in each substrate individually where $P \leq 0.05$ was considered significant (SAS 2001).

Results and Discussion

Irrigation efficiency. Sample time and species affected leaching fraction (LF) in both 2010 and 2011 (data not shown). For the first measurement date (June 25, 2010), LF ranged from 0.13 (azalea, LV, PB:CS) to 0.81 (juniper, OH, PB:CS). Similar trends in LF continued throughout the study until the last measurement of the 2010 season (August 4) where LF ranged from 0.34 (azalea, OH, PB:CS) to 0.87 (juniper, OH, PT:CS). Juniper is classified as having a low to medium irrigation requirement, while azalea is classified as having a medium to high requirement. Both species were irrigated with the same volume, which is most likely why substrates planted with junipers maintained higher LF than those with azalea (Bilderback et al. 2013). Our goal was to maintain a 0.20 LF but they ranged from slightly below 0.20 to four times greater throughout the season.

In 2010, LV irrigation LF remained closer to the targeted 0.20 for the first two sample dates (June 25 and July 7) for both species and all substrates; however, LF was higher than the targeted LF for the last two sample dates (July 20 and August 4) (data not shown). OH irrigation LF remained higher than the targeted value throughout the experiment despite the fact that every two weeks, irrigation volume was adjusted. While a 0.20 LF was not consistently maintained throughout the experiment, there were no significant differences between substrate and species treatment combinations in LF at any sample date, except for juniper grown with LV on July 20, 2010. Efforts were continued in 2011 to correct LF inconsistencies.

In 2011, with LV irrigation, LF ranged from 0.05 (azalea, September 15, PT:CGT) to 0.40 (juniper, July 30, PB:CSN) and with OH irrigation, LF ranged from 0.08 (azalea, September 2, PB:CGT) to 0.95 (juniper, August 24, PB:CS) (data not shown). With the redesigned OH system, the average LF (0.28) was maintained much closer to the targeted 0.20 LF for both species and all substrates. Substrate did not significantly impact LF for either species irrigated with OH. However, with LV, substrate affected LF for azalea on June 10, July 30, August 24, and September 15, and June 10 and July 30, 2011 for juniper. For both species grown with LV, there were no clear trends for LF.

Plant growth and shoot nutrient concentration. In 2010, the species by substrate interaction was significant for shoot growth, but not in 2011, possibly due to the smaller juniper liners and poor juniper growth in 2011. However, for consistency, data are presented by species for each year. Azalea shoot growth tended to be larger with OH for all substrates compared to LV while irrigation/ground covering appeared to have less of an impact on juniper growth (Fig. 1a–d).

With OH, azalea shoot growth was greatest in all the PB-based substrates and 100% PB and was lowest in all the PT-based substrates during 2010 (Fig. 1a). Using OH in 2011, azaleas grown in PB, PB:CS, PB:CSN, PB:CGT, PT:CSN, PT:CGT, and PT all had similar growth with only

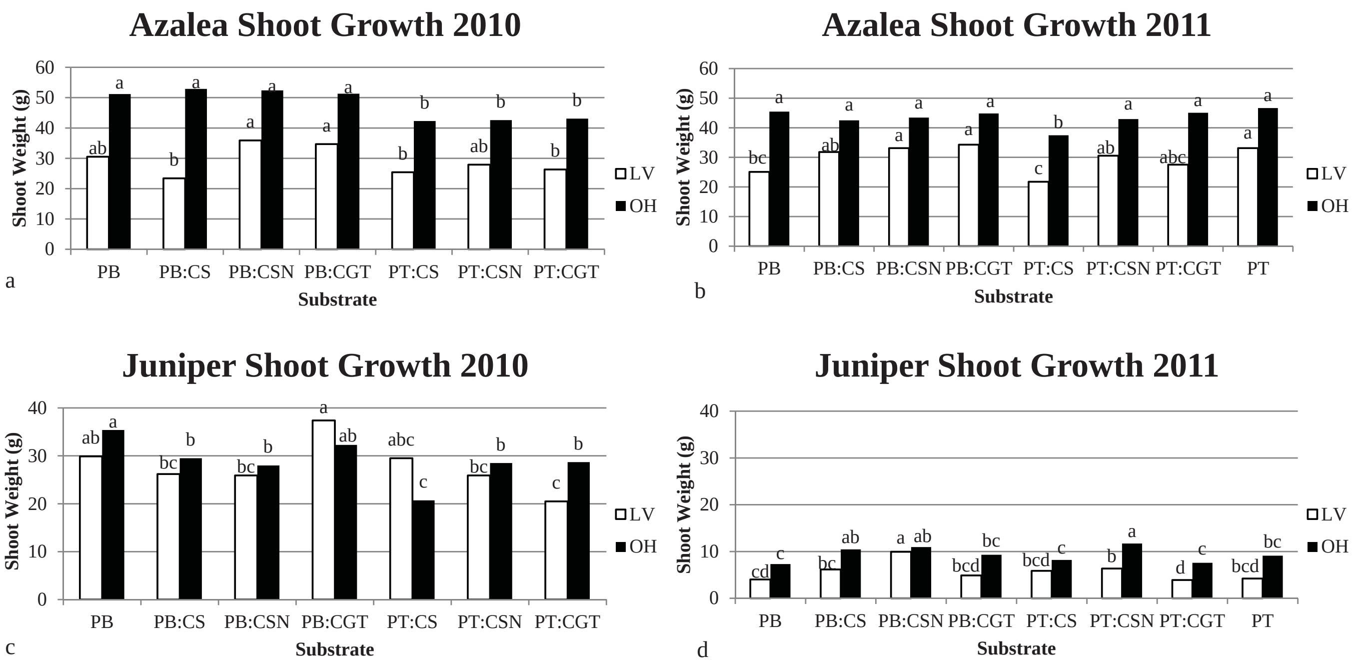

Fig. 1. Effect of substrate on azalea shoot growth in 2010 (a) and 2011 (b) and juniper shoot growth in 2010 (c) and 2011 (d) grown with overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH) or low-volume, spray stake irrigation with gravel covering the ground (LV). Means between substrates within an irrigation type with different letters are significantly different from each other based on lsd mean separation ($P \geq 0.05$). The substrates consisted of 100% PB, 100% PT, 4:1 PB:CS (PB:CS), 4:1 PB:CS+N (PB:CSN), 9:1PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CS+N (PT:CSN), and 4:1 PT:CGT (PT:CGT) where PB = pine bark, PT = whole pine tree, CS = composted cotton stalks, CS+N = composted cotton stalks with a nitrogen source added during composting, and CGT = aged cotton gin trash.

plants grown in PT:CS being significantly different and producing the least amount of azalea shoot growth (Fig. 1b). Shoot growth in azalea with LV irrigation was numerically greatest in PB:CSN and PB:CGT and was numerically lowest in PT:CS in 2010 and 2011 (Fig. 1a, 1b). In 2011 with both OH and LV, PT:CS produced numerically the smallest azalea shoots (Fig. 1). In contrast, Owings (1993) reported that shoot dry weights were higher in coleus grown in 40% CGT amended with 60% PB than in those amended with 20, 60, or 80% CGT. In this study, with LV, the 100% PB tended to produce equivalent growth to all of the PB- and PT-based amended substrates. Additionally, with LV, the 100% PT control that was included in 2011 supported azalea shoot growth as well as PB:CSN and PB:CGT. Thus, either PB or PT can be blended with CSN at a 4:1 ratio or CGT at a 9:1 to produce acceptable azalea growth. Similarly, growth indices of Winter Gem boxwood, Fire Power dwarf nandina, and Formosa, Midnight Flare and Renee Mitchell azalea were not significantly different for plants produced in substrates mixed with cotton gin compost (CGC) and a 3 PB:1 peat mix or PB:Sand (Cole et al. 2005, Jackson et al. 2005).

Due to the liners being much smaller, juniper growth was much less in 2011 compared to 2010. Similar to azalea, juniper shoot growth was smallest with OH and PT:CS in 2010 (Fig. 1c). However, in 2011, PB, PT:CS, and PT:CGT produced similar juniper shoot growth with OH but plants were smaller than in 2010 (Fig. 1d). With OH, PB:CS, PB:CSN, PB:CGT, and PT:CSN showed similar trends for juniper shoot growth in 2010 and 2011 (Fig. 1c, 1d). With LV, juniper shoot growth was numerically least with PT:CGT in both 2010 and 2011. Juniper root growth was not significantly different between substrates when grown with OH in 2010, but in 2011 root

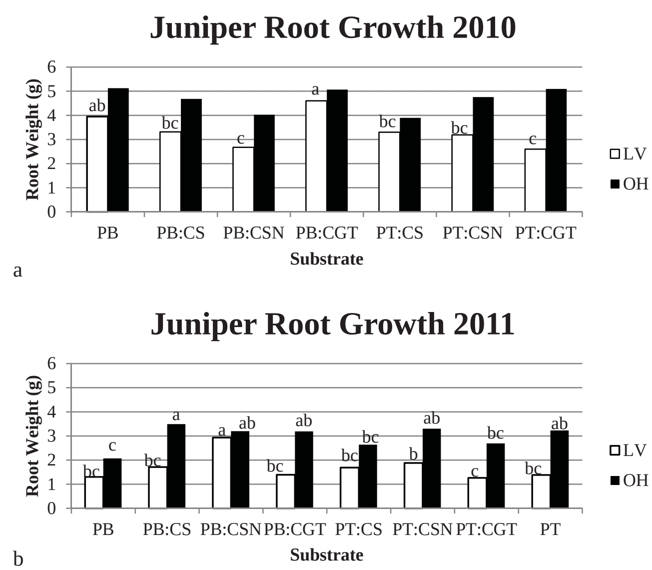

Fig. 2. Effect of substrate on juniper root growth grown with overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH) or low-volume, spray stake irrigation with gravel covering the ground (LV) in 2010 (a) and 2011 (b). Means between substrates within an irrigation with different letters are significantly different from each other based on lsd mean separation ($P \geq 0.05$). The substrates consisted of 100% PB, 100% PT, 4:1 PB:CS (PB:CS), 4:1 PB:CS+N (PB:CSN), 9:1PB:CGT (PB:CGT), 1:1 PT:CS (PT:CS), 1:1 PT:CS+N (PT:CSN), and 4:1 PT:CGT (PT:CGT) where PB = pine bark, PT = whole pine tree, CS = composted cotton stalks, CS+N = composted cotton stalks with a nitrogen source added during composting, and CGT = aged cotton gin trash.

growth was numerically least with PB (Fig. 2a, 2b). With LV, root growth was affected by substrate in both years. In 2010, numerically greater root growth occurred with LV in PB:CGT and PB and in 2011, root growth was highest with PB:CSN. With LV, numerically lowest root growth occurred with PB:CSN and PT:CGT in 2010 and PT:CGT in 2011. Both PB- and PT-based substrates amended with CSN or CGT produced acceptable azalea and juniper growth with OH. However, with LV, PT:CGT produced the numerically lowest juniper shoot and root growth in both years. Substrate solution EC levels were higher in PT:CGT but not above levels considered damaging as reported by Riley et al. (2014). Additionally, air and water holding capacities of PT:CGT were not below or above recommended ranges (Riley et al. 2014)

Foliar N concentrations in 2010 were affected by substrate for junipers but not azaleas, while substrate affected foliar P concentrations for both species (Table 1). Azalea growing in all PT-based substrates had numerically higher foliar P concentrations than substrates containing PB, likely due to the higher rate of fertilizer applied to these substrates. Juniper growing in the PT:CS substrate had significantly higher foliar N and P concentrations than all other substrates. Substrate affected Ca concentration in leaves of azalea but not juniper. PT-based substrates generally resulted in lower shoot Ca concentration numerically than PB-based substrates, even though PT substrates had higher levels of Ca in the substrate solution as previously reported (Riley et al. 2014). Juniper growing in PT:CS were generally numerically smaller in size than in the other substrates, so the higher N and P concentrations in the foliage may be due to a lesser amount of water present in the tissues compared to the larger plants (Fig 1c, 1d). Substrate did not affect S or any foliar micronutrient concentrations (data not shown).

Table 1. Effect of substrate on foliar nutrient concentrations of azalea and juniper grown in containers under overhead irrigation in 2010.

Substrate[z]	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)
Azalea				
PB	1.37	0.15c[y]	0.89	0.76a
PB:CS	1.36	0.15bc	0.88	0.75a
PB:CSN	1.35	0.15bc	0.87	0.75a
PB:CGT	1.43	0.15c	0.86	0.69ab
PT:CS	1.49	0.17ab	0.85	0.63abc
PT:CSN	1.63	0.18a	0.90	0.56c
PT:CGT	1.54	0.18ab	0.83	0.60bc
Substrate[x]	NS	0.04	NS	0.02
Juniper				
PB	1.51b	0.19b	1.16	0.61
PB:CS	1.71b	0.19b	1.15	0.63
PB:CSN	1.70b	0.20b	1.14	0.67
PB:CGT	1.71b	0.19b	1.13	0.60
PT:CS	2.37a	0.26a	1.29	0.54
PT:CSN	1.74b	0.19b	1.13	0.62
PT:CGT	1.75b	0.20b	1.10	0.55
Substrate	0.002	0.009	NS	NS

[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), and 4:1 PT:CGT (PT:CGT).

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

[x]ANOVA effect of substrate within each sample date.

NS = $P \geq 0.05$, p-value given otherwise.

In 2011, similar trends in foliar N and P concentrations were observed in both species and under both irrigation methods. Under LV irrigation, foliar N and P concentrations of both species were affected by substrate while foliar K was not affected by substrate for either species (Table 2). The PT-based substrates tended to produce numerically higher foliar P and K concentrations for both azalea and juniper, again most likely due to the higher fertilizer rates applied to these substrates. There were no apparent differences between the CS and CSN or CGT substrate amendments to supply N or P to plants grown under LV even though urea was higher in the substrate solution as previously reported (Riley et al. 2014). As in 2010, substrate also affected foliar Ca levels of azalea and juniper. Foliar Ca concentrations with LV were significantly higher for azalea grown in PB:CGT and highest in juniper grown in PT:CGT than other substrates. Foliar Mg levels were highest in PB:CGT than other substrates with azalea grown under LV irrigation. Substrate solution Ca and Mg concentrations were generally numerically highest in PT-based substrates blended with CGT which appears to have enhanced Ca and Mg accumulation by both species (Riley et al. 2014). Foliar S and micronutrient levels were largely unaffected by substrate (data not shown).

With OH in 2011, substrate affected foliar N, P, K, and Ca concentrations of both azalea and juniper. Plants grown in PT:CS substrates had the highest foliar N, P, and K concentrations in both azalea and juniper (Table 2) but the smallest growth (Fig. 1a, 1b), indicating that nutrient concentrations were not limiting growth. Additionally, plants grown in PT:CS had the lowest foliar Ca concentration in azalea while there were no significant differences between substrates for juniper, with the exception that 100% PT was the lowest but was similar to PB:CSN. Foliar micronutrient levels were largely unaffected by substrate with OH (data not shown). In contrast, Tyler et al. (1993b) reported that composted turkey litter increased the foliar concentrations of N, P, Mg, Mn, Cu, Fe, and B and adequately replaced the requirement for dolomitic limestone, micronutrients, and some of the macronutrients that were added to the commercial substrate used for comparisons.

Temperature effect. Irrigation method and ground coverings, as well as the substrate's container water holding capacity (CC), air space (AS), and bulk density (BD), can impact the temperature of the production environment which can impact the ability of a substrate to conduct heat (Tyler et al. 1993a). An 8% addition of composted turkey litter (CTL) to a PB substrate increased bulk density and container capacity and decreased the air space and resulted in an increase in thermal load and reduced ability to dissipate heat compared to the 100% PB when low volume irrigation was applied (Tyler et al. 1993a). As a result, a substrate containing 8% CTL had the least difference between the highest and lowest points on the diurnal temperature curve and maintained high temperatures longer than the 100% PB (Tyler et al. 1993a). Similar trends are shown in Figs. 3a and 3b. The PT:CS substrate, which had one of the highest CC and the lowest AS and BD (Riley et al. 2014), reached higher substrate temperatures and had the greatest swing in temperature from 37.2 to 27.8C (99 to 82F) with OH (Fig. 3a). Also, PT:CS substrates generally

Table 2. **Effect of substrate on the foliar nutrient concentrations of azalea and juniper grown in containers with overhead and low-volume irrigation in 2011.**

	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)
Azalea					
LV[z]					
PB[y]	1.57c[x]	0.13e	0.76	0.53b	0.25cd
PB:CS	1.73c	0.15bc	0.87	0.53b	0.28ab
PB:CSN	1.70c	0.15bcd	0.78	0.52b	0.26abc
PB:CGT	1.61c	0.14cde	0.77	0.68a	0.28a
PT:CS	2.26a	0.20a	0.87	0.42c	0.26bcd
PT:CSN	2.05ab	0.17b	0.91	0.48bc	0.26bcd
PT:CGT	1.98b	0.21a	0.86	0.45c	0.24d
PT	1.73c	0.13de	0.79	0.53b	0.24d
Substrate[w]	0.0001	0.0001	NS	0.0001	0.0007
OH					
PB	1.64cd	0.14d	0.74de	0.71a	0.27
PB:CS	1.73c	0.17bc	0.83bc	0.60cd	0.26
PB:CSN	1.76c	0.15cd	0.78cde	0.58de	0.25
PB:CGT	1.56d	0.15cd	0.71e	0.64bc	0.25
PT:CS	2.17a	0.21a	1.00a	0.52f	0.27
PT:CSN	1.98b	0.17bc	0.89b	0.54ef	0.26
PT:CGT	1.80c	0.18b	0.81bcd	0.63bc	0.26
PT	1.79c	0.17bc	0.86bc	0.65b	0.26
Substrate	0.0001	0.0001	0.0001	0.0001	NS
Juniper					
LV					
PB	1.77b	0.16cd	1.11	0.72bc	0.18
PB:CS	1.76b	0.16d	1.1	0.64c	0.17
PB:CSN	1.79b	0.18cd	1.09	0.64c	0.17
PB:CGT	1.79b	0.16cd	1.12	0.74b	0.18
PT:CS	2.61a	0.22ab	1.13	0.68bc	0.17
PT:CSN	2.32a	0.19bc	1.14	0.70bc	0.17
PT:CGT	2.44a	0.22ab	1.09	0.83a	0.16
PT	2.55a	0.24a	1.08	0.69bc	0.17
Substrate	0.0001	0.0001	NS	0.001	NS
OH					
PB	1.44c	0.15d	1.10c	0.66a	0.14
PB:CS	1.67c	0.17cd	1.17abc	0.66a	0.14
PB:CSN	1.67c	0.18bc	1.13c	0.64ab	0.14
PB:CGT	1.70c	0.17cd	1.15bc	0.72a	0.14
PT:CS	2.66a	0.22a	1.28a	0.68a	0.15
PT:CSN	2.34b	0.21a	1.29a	0.68a	0.14
PT:CGT	2.27b	0.20ab	1.30a	0.69a	0.13
PT	2.16b	0.21a	1.27ab	0.56b	0.14
Substrate	0.0001	0.0001	0.005	0.04	NS

[z]Plants were grown with overhead sprinkler irrigation black geotextile weed fabric covering the ground (OH), or low-volume, spray stake irrigation and gravel covering the ground (LV).

[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 = 8.

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

produced the smallest shoots, especially with LV (Fig. 1a–d). Additionally, substrate temperatures were numerically higher with LV than OH (Fig. 3a, 3b). Overall, PB:CS generally had a lower substrate temperature throughout the day regardless of irrigation/ground cover combination than PT:CS or PB, possibly because PB:CS had a lower CC with higher BD and AS (Riley et al. 1993) (Fig. 3a, 3b). PB:CS also produced some of the highest azalea and juniper shoots. Tyler et al. (1993a) reported that the substrate with the greatest CC and BD had the lowest fluctuation in temperature due to water's greater ability (compared to air) to retain heat. PB, which had the highest AS and BD and lowest CC (Riley et al. 2014), reached higher substrate temperatures and maintained them longer than PB:CS or PT:CS with LV (Fig. 3a, 3b).

Irrigation also played a role on ground surface temperatures (Fig. 4). OH appeared to maintain lower ground surface temperatures than LV, with lower air temperature during each irrigation event. This cooling may be responsible for the larger shoots of azaleas and junipers when grown with OH compared to LV (Fig. 1a–d). However, OH irrigation used for container production contributes to large volumes of runoff (Stetson and Mecham 2011), and containment and possible

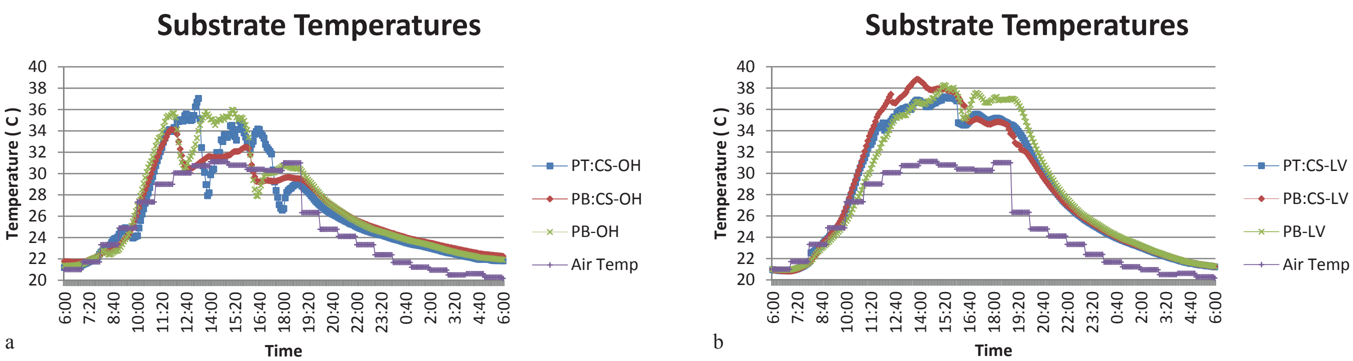

Fig 3. Effect of substrate on substrate temperatures of, pine bark-based (PB) and pine tree-based (PT) substrates amended with cotton stalks (CS) with overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH) (a) or low-volume, spray stake irrigation with gravel covering the ground (LV) (b) on substrate temperatures from 6:00 am August 19, 2011, to 6:00 am August 20, 2011.

treatment requirements of the runoff need to be considered when deciding between OH and LV.

Disease suppression. By September 2, 2010, and throughout the study in 2011, all of the highly susceptible 'Hino' azalea plants in inoculated treatments showed significant increases in foliar disease ratings when compared to non-inoculated plants growing in the same substrate (data not shown). These results indicate that in both years *Phytophthora cinnamomi* was successfully established in all substrates. Sunglow azalea and Blue Pacific juniper showed no significant differences in foliar disease symptoms and root rot ratings at all dates in both 2010 and 2011 (data not shown), indicating that substrate neither enhanced nor deterred *P. cinnamomi* infection in these susceptible species. Additionally, soilborne pathogens appear to not have been transferred with the cotton stalks.

Summer 2010 and 2011 comparisons. When comparing results from the two experiment years, there were some differences in growth outcomes (Fig. 1a–d). In 2010, all the PB-based substrates produced significantly larger azalea shoots when grown under OH than the PT-based substrates, but this was not the case in 2011. In 2011, under OH, azalea shoot growth was similar for plants grown in all substrates except for PT:CS, where plants were smaller (Fig. 1a–d). For both years, azalea plants grown under LV irrigation had larger shoot growth when grown in both PB- and PT-based substrates amended with CSN or CGT compared to the other substrates (Fig. 1a, 1b). The lowest azalea shoot growth was produced when PB- and PT-based substrates were amended with CS and irrigated with LV in both 2010 and 2011, possibly due to the higher temperatures maintained in this production environment. Junipers irrigated by OH generally produced larger shoot growth with the PB-based substrates compared to the PT-based substrates in both years (Fig. 1c, 1d). With LV, juniper shoot growth tended to be numerically smallest with PT:CGT (Fig. 1c) in both years. Surprisingly, 100% PB produced growth similar or better to the other substrate combinations in 2010, while in 2011 growth was comparable or smaller than the rest of the substrates, most likely due to the inconsistency in particle size of the PB from 2010 to 2011 (Riley et al. 2014). As reported previously (Riley et al. 2014), the PB in 2011 had fewer fines and a lower water holding capacity at potting than in 2010. In 2010 there were no significant differences amongst substrates for juniper root growth with OH, but in 2011 root growth was greatest with PB:CS (Fig. 2a, 2b). In both years PT:CGT with LV resulted

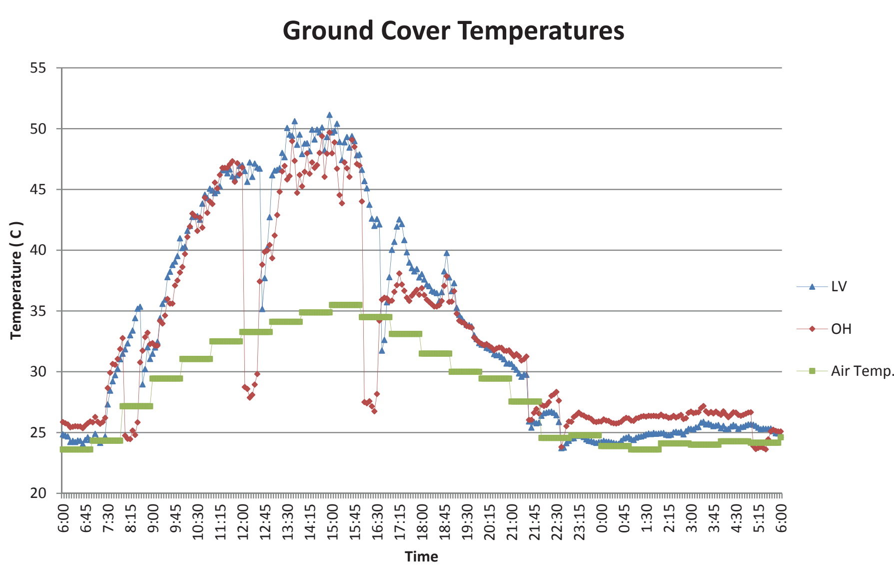

Fig. 4. Effect of overhead sprinkler irrigation with black geotextile weed fabric covering the ground (OH) or low-volume, spray stake irrigation with gravel covering the ground (LV) on ground covering temperatures from 6:00 am August 3, 2011, to 6:00 am August 4, 2011.

in one of the substrate combinations with the least amount of juniper root growth. Growth difference in both species and both years seemed to be affected more by the physical property differences between the substrates rather than the chemical property differences. As previously reported (Riley et al. 2014), pH, EC, substrate nutrient concentrations and foliar nutrient concentrations (Tables 1, 2) were more impacted by liming and fertilizer application rate than by compost addition.

Both species were numerically larger when grown under OH than LV in 2011 but growth differences were not as large as they were in 2010 (Fig. 1a–d). Juniper growth differences were not as great as they were with azalea. Similarly, Neal and Henley (1992) reported overhead, drip, capillary mats, and ebb and flow irrigation produced good quality plants; however, *Dieffenbachia maculata* (Lodd.) G. Don produced under overhead irrigation was significantly larger and received higher quality ratings.

The substrate combinations, PT:CS and PT:CSN, generally produced lower shoot growth for junipers and azaleas when compared to the other substrates. Also, even though PT-based substrates tended to have greater total porosity and air space than the PB-based substrates (Riley et al. 2014), the PT-based substrates did not improve root growth for junipers nor affect *P. cinnamomi* infection. PB:CGT had lower air space over the growing season (Riley et al. 2014) but still produced a juniper root system with one of the greatest masses with LV in 2010 and a root system comparable to or better than the 100% PB control in 2011 with both OH and LV.

PB processing is critical as growth results were altered in 2010 and 2011 by particle size and resulting water holding capacities (Riley et al. 2014). PT-based substrates appeared to produce greater consistency in growth, as responses were more similar in 2010 and 2011. However, irrigation method and management can impact growth regardless of substrate composition when substrates have similar physical characteristics. Azalea and juniper had numerically larger shoots and roots when grown with OH irrigation than with LV irrigation, probably due to the cooling effect created from OH compared to LV.

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