Juniperus virginiana as an Alternative to Pine Bark in Nursery Production[1]

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Abstract

Pine bark has been the standard container nursery substrate for nearly forty years. However, due to the decline in the timber industry and fluctuations in fuel prices, alternative substrates and amendments are being sought by growers and researchers. This study evaluated locally grown eastern red cedar (*Juniperus virginiana* L.) as a potential alternative to pine bark in nursery production of 10 ornamental species. For seven of the species evaluated, growth indices for plants in 100% cedar were similar to those in 100% pine bark. 'August Beauty' gardenia grown in up to 80% cedar was comparable to plants grown in pine bark. Species that have lower pH requirements did not perform as well in substrates amended with high cedar percentages. 'Premier' blueberry did not grow well in cedar above 20%. Root growth for seven of the species in cedar was similar to or greater than those grown in 100% pine bark. 'Formosa' azalea and 'Burgundy' loropetalum showed slight variations in root growth above 10% cedar. These data conclude that cedar has potential as an amendment to pine bark in nursery production.

Index words: substrate, amendment, container-grown, woody ornamentals.

Species used in this study: 'KnockOut' rose (*Rosa* × KnockOut®); Reeves spirea (*Spiraea cantoniensis* Lour.); 'August Beauty' gardenia (*Gardenia jasminoides* J. Ellis. 'August Beauty'); 'Wintergreen' boxwood (*Buxus microphylla* Siebold and Zucc. var. *japonica* 'Wintergreen'); Sargent's juniper (*Juniperus chinensis* L. var. *Sargentii*); 'Bugundy' loropetalum (*Loropetalum chinensis* (R. Br.) Oliv. var. *rubrum* Yieh 'Burgundy'); 'Recurve' ligustrum (*Ligustrum japonicum* L. 'Recurvifolium'); 'Premier' blueberry (*Vaccinium ashei* Reade. 'Premier'); 'Formosa' azalea (*Rhododendron indicum* L. 'Formosa'); 'Rose Glow' lantana (*Lantana camara* L. 'Landmark® Rose Glow'); and 'Bandana Pink' lantana (*Lantana camara* L.'Bandana® Pink').

Significance to the Nursery Industry

Recent instability in pine bark (PB) supplies has created concern for nursery growers about its future availability. Therefore, a need has developed to evaluate alternative components for a standard growing substrate. Growers are looking for locally available substrates. Eastern red cedar (*Juniperus virginiana* L.) has become a 'weed species' throughout many parts of the Great Plains, Midwest, and Southeast. This study demonstrated that most woody nursery crops grown in varying ratios of red cedar (RC) had similar growth to plants grown in a nursery standard of 100% PB.

Introduction

Increasing energy cost has led to the use of PB as an alternative resource of clean fuels (12). This increasing demand for bark coincides with the slowly declining timber industry (7). Without a decrease of energy cost in sight, bark shortages could occur. With energy cost having preference over the horticultural industry, the need of an alternative substrate for growing nursery crops increases (8).

Previous research on alternative nursery crop substrates has focused heavily on high wood fiber substrates; mainly evaluating whole pine trees, chipped pine logs, timber harvested residual material, and hardwood chips in both greenhouse and nursery production (1, 2, 4, 9, 10, 11, 13, 19). This study evaluated locally available RC as an amendment to PB. Cedar is a coniferous species native to the Southeastern United States, growing between 12.2–15.2 m (40–50 ft) tall, and reaching spreads of 2.4–6.1 m (8–20 ft) (3). Specific cultivars of RC are excellent landscape plants, but the species, found native to hardwood forests, are thought to have an invasive habit (6).

In 1975, Self et al. (14) evaluated the growth of two azalea species in substrates composed of RC, mahogany, and pine shavings. Results revealed best plant growth in pine shavings followed by RC shavings. Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) seedling production was evaluated by Griffin (6) using PB amended with 0, 5, 10, 20, 40, and 80% RC. Four fertilizers were also analyzed: 0.81 kg $N \cdot m^{-3}$ (1.37 $lbs \cdot yd^{-3}$) control release fertilizer (CRF), 1.6 kg $N \cdot m^{-3}$ (2.70 $lbs \cdot yd^{-3}$) CRF, 0.4 kg $N \cdot m^{-3}$ (0.67 $lbs \cdot yd^{-3}$) Urea (46-0-0) or no fertilizer. Response was similar within each species. Plants growing in 5, 20, and 40% RC were similar to those grown in 100% PB; plants in 10 and 80% RC exhibited less height. Starr et al. (15) evaluated silver maple (*Acer saccharinum*) seed propagation in substrates composed of PB, RC, and 20% sand with two fertilizer rates [low = 4.5 kg $N \cdot m^{-3}$(7.58 $lbs \cdot yd^{-3}$), high = 8.9 kg $N \cdot m^{-3}$(15.0 $lbs \cdot yd^{-3}$)]. Fertilizer had no significant effect on plant height. Plants grown in 80% RC had the least amount of growth. Plants grown in up to 20% RC had similar growth to those grown in PB. Results conclude that RC could be a potential replacement for PB with further development of substrate physical properties.

Bald cypress (*Taxodium distichum*) was evaluated in PB:sand substrates amended with percentages of eastern RC; data concluded there was little difference in plant height between the treatments (16). Starr et al. (17) evaluated rudbeckia (*Rudbeckia fulgida*) in substrate mixes of PB and RC. RC chips were passed through a 0.5, 1, 1.3, or 1.9 cm (0.1875, 0.375, 0.50, or 0.75 in) screen. Plant growth indices were similar and all plants were marketable. Cedar chips proved efficient as a container grown substrate for rudbeckia at all 4 screen sizes; plants performed best in 0.5 cm screen

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size material. Recent data from Murphy et al. (13) has also shown that up to 50% fresh cut eastern RC has little to no difference when compared to a growers standard of 75:25 (v:v) peat:perlite in the production of petunia (*Petunia* × *hybrida* 'Dreams Sky Blue'), vinca (*Catheranthus roseus* 'Cooler Peppermint'), and impatiens (*Impatiens walleriana* 'Super Elfin Salmon'). Thus far, limited research with RC substrate has been conducted with woody nursery crops. The objective of this study was to evaluate eastern RC as an alternative substrate to PB in the nursery production of 10 woody ornamental crops.

Materials and Methods

Experiment 1 (Exp. 1) was initiated May 16, 2011, and Experiment 2 (Exp. 2) was initiated April 25, 2012, at the Paterson Greenhouse Complex, Auburn University, AL. Seven substrate treatments were evaluated: 100% PB, 95:5 PB:RC, 90:10 PB:RC, 80:20 PB:RC, 60:40 PB:RC, 20:80 PB:RC, and 100% RC. All treatments were incorporated with sand at a 6:1 (v:v) substrate:sand. Cedar used for Exp. 1 was harvested at ground level and de-limbed on April 7, 2011, at the Auburn Piedmont Research Station, Camp Hill, AL. Cedar was chipped through a (Vermeer BC1400XL, Vermeer Co., Pella, IA) on April 12, 2011, then stored until processing through a hammer-mill (Williams Patent Crusher & Pulverizer Co., St. Louis, MO) on May 10, 2011. Cedar used for Exp. 2 was harvested and de-limbed April 3, 2012, chipped on April 17, 2012, then processed through a hammer-mill on April 23, 2012. All RC, for both experiments, was milled to pass a 9.5 mm (3/8 in) screen size. Substrates were amended with 8.31 $kg \cdot m^{-3}$ (14 $lbs \cdot yd^{-3}$) 15.0N-2.64P-9.96K (15-6-12) Polyon (Harrell's Fertilizer, Inc., Lakeland, FL) control release fertilizer (8–9 months), 3.0 $kg \cdot m^{-3}$ (5 $lbs \cdot yd^{-3}$) dolomitic limestone, and 0.9 $kg \cdot m^{-3}$ (1.5 $lbs \cdot yd^{-3}$) Micromax (The Scotts Company, Marysville, OH) prior to potting.

Species in Exp. 1 consisted of 'KnockOut' rose (*Rosa* × KnockOut®); Reeves spirea (*Spiraea cantoniensis* Lour.); 'August Beauty' gardenia (*Gardenia jasminoides* J. Ellis. 'August Beauty'); 'Wintergreen' boxwood (*Buxus microphylla* Siebold and Zucc. var. *japonica* 'Wintergreen'); Sargent's juniper (*Juniperus chinensis* L. var. *Sargentii*); 'Bugundy' loropetalum (*Loropetalum chinensis* (R. Br.) Oliv. var. *rubrum* Yieh 'Burgundy'); 'Recurve' ligustrum (*Ligustrum japonicum* L. 'Recurvifolium'); 'Premier' blueberry (*Vaccinium ashei* Reade. 'Premier'); 'Formosa' azalea (*Rhododendron indicum* L. 'Formosa'); and 'Rose Glow' lantana (*Lantana camara* L. 'Landmark® Rose Glow'). Exp. 2 was conducted similarly with the following exceptions: 'Bandana Pink' lantana (*Lantana camara* L. 'Bandana® Pink') was substituted for lantana species and substrate treatments were incorporated with 7.12 $kg \cdot m^{-3}$ (12 $lbs \cdot yd^{-3}$) 17N-2.2P-9.13K (17-5-11) Polyon (Harrell's Fertilizer Inc., Lakeland, FL) control release fertilizer (8–9 months). Liners were transplanted from cell pack trays into #1 containers, except for 'Premier' blueberry and 'Wintergreen' boxwood which were planted in trade gallons. All plants were watered with overhead irrigation [1.27 $cm \cdot day^{-1}$ (0.5 $in \cdot day^{-1}$)]. 'Formosa' azalea and 'Premier' blueberry were kept under a 30% shade structure; all other species were placed in full sun.

The experimental design was a complete randomized block design with 8 single pot replications per treatment, except in Exp. 2, Sargent's juniper had 6 single pot replications per treatment. Each species was treated as its own separate experiment. Data collected included physical properties [air space (AS), water holding capacity (WHC), and total porosity (TP)] (n = 3) (5). Bulk densities (BD) were determined using from same samples used to determine physical properties, and were obtained from 347.5 cm^3 (21.2 in^3) samples dried in a forced air oven at 105C (221F) for 48 hours (n = 3). Leachates were collected from 'Formosa' azalea using the Virginia Tech PourThru Method (n = 4) (18). Substrate pH and Electrical conductivity (EC) ($mS \cdot cm^{-1}$) was measured at 7, 30, 60, and 180 days after potting (DAP). Growth indices (GI) [(height + width1 + width2) / 3] (cm) were also measured at termination (n = 8). Root growth ratings (RR) were taken at 180 DAP on a scale from 1 to 5, where 1 was less than 20% root ball coverage, and 5 was between 80 to 100% root ball coverage (n = 8).

All data were subject to analysis of variance using the general linear models procedure and multiple comparison of means, conducted using Tukey's Honest Significant Test at $\alpha = 0.05$ (SAS® Version 9.2; SAS® Institute, Inc., Cary, NC).

Results and Discussion

Physical properties. The recommend range of physical properties for a standard growing substrate is 10–30% air space (AS), 45–65% water holding capacity (WHC), and 50–85% total porosity (TP) percent per volume (20). In Exp. 1, substrate treatments containing 80% RC (25.0%) and 100% RC (29.5%) had higher AS than 100% PB (15.3%), while all other treatments were statistically similar (Table 1). Exp. 2 substrate AS exhibited no difference among substrates, all being within the recommended range. All substrate treatments for Exp. 1 had similar WHC to the 100% PB (46.3%). However, 80:20 PB:RC (44.0%) and 90:10 PB:RC (42.0%) were below the WHC optimal range. In Exp. 2, substrate WHC values of all treatments containing RC were similar to or greater than 100% PB (43.1%), with 20:80 PB:RC (57.5%) having the greatest WHC. Those not within the recommended range include: 100% PB (43.1%), 95:5 PB:RC (40.7%), and 90:10 PB:RC (44.4%). Total porosity varied throughout the treatments in Exp. 1, but was greatest for 20:80 PB:RC (71.3%) and 100% RC (78.0%) treatments. In Exp. 2 TP was greatest for 20:80 PB:RC (79.7%), with 100% PB (62.1%) having the least. All substrates for both Exp. 1 and Exp. 2 were within the optimum range for TP. Values for BD varied between the recommended ranges of 0.19–0.70 $g \cdot cm^{-3}$ for all treatments for both experiments. In Exp. 1, BD varied with 100% PB (0.45 $g \cdot cm^{-3}$) having the greatest and 100% RC (0.35 $g \cdot cm^{-3}$) the least. In Exp. 2, there was no difference in BD among substrate treatments.

pH and EC. Substrate pH levels ranged from 6.18 to 7.01 in Exp. 1 (Table 2). Each substrate was similar to the 100% PB at 7 (6.32), 30 (6.68), 60 (6.25), and 180 (6.40) DAP. In Exp. 2, substrate pH levels ranged from 5.04 to 7.56. pH at 7 DAP tended to increase with increasing RC; 100% PB (5.04) having the lowest pH level and 20:80 PB:RC (6.05) having the highest. At 30 DAP, pH levels were similar among all substrate treatments. At 60 DAP, all pH levels were greater than the 100% PB (6.35), with 80:20 PB:RC (6.95) having the highest. By 180 DAP, pH had returned to increasing with increasing RC, reaching the highest in 100% RC (7.23). In general, pH levels tended to increase with the increasing percentages of RC in the substrates. EC levels for Exp. 1 had no

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Table 1. Physical properties of seven substrates containing pine bark and cedar[z].

Substrate[u]	Air space[y] Exp. 1 (% vol)	Air space[y] Exp.2 (% vol)	Water holding capacity[x] Exp. 1 (% vol)	Water holding capacity[x] Exp.2 (% vol)	Total porosity[w] Exp. 1 (% vol)	Total porosity[w] Exp.2 (% vol)	Bulk density[v] Exp. 1 ($g \cdot cm^{-3}$)	Bulk density[v] Exp.2 ($g \cdot cm^{-3}$)
100% PB	15.3b[t]	19.0[ns]	46.3ab	43.1bc	62.7c	62.1c	0.45a	0.31[ns]
95:5 PB:Cedar	22.3ab	24.4	45.0ab	40.7c	67.3bc	65.1bc	0.36de	0.39
90:10 PB:Cedar	21.3ab	25.0	42.0b	44.4abc	63.3c	69.4abc	0.39bcd	0.32
80:20 PB:Cedar	20.3ab	21.1	44.0ab	47.1abc	64.3bc	68.2abc	0.40bc	0.43
60:40 PB:Cedar	22.7ab	19.4	46.3ab	49.1abc	69.0bc	68.6abc	0.37cde	0.38
20:80 PB:Cedar	25.0a	22.2	46.0ab	57.5a	71.3ab	79.7a	0.41b	0.37
100% Cedar	29.5a	21.4	48.5a	54.2ab	78.0a	75.6ab	0.35e	0.40
Recommended range[s]	10–30%		45–65%		50–85%		0.19–0.70	

[z]Analysis performed using the North Carolina State University porometer (http://www.ncsu.edu/project/hortsublab/diagnostic/porometer/).
[y]Air space is volume of water drained from the sample / volume of the sample.
[x]Water holding capacity is (wet weight – oven dry weight) / volume of the sample.
[w]Total porosity is substrate water holding capacity + air space.
[v]Bulk density after forced-air drying at 105C (221.0F) for 48 hrs; 1 $g \cdot cm^{-3}$ = 62.4274 $lb \cdot ft^{-3}$.
[u]PB = pine bark; all treatments 6:1 (v:v) ratio of substrate:sand.
[t]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range Test at $\alpha = 0.05$ (n = 3).
[s]Recommended ranges as reported by Yeager, et al., 2007. Best Management Practices Guide for Producing Container-Grown Plants.
[ns]Means not significantly different.

difference among treatments at 7, 60, and 180 DAP. Although there were minor differences among treatments at 30 DAP, all treatments were similar to 100% PB (0.54 $mS \cdot cm^{-1}$). In Exp. 2, there was no difference in EC among substrates at 7 DAP. Levels varied at 30 DAP, although substrates with up to 40% RC were similar to the 100% PB treatment (0.37 $mS \cdot cm^{-1}$). All levels were similar to 100% PB (0.34 $mS \cdot cm^{-1}$) at 60 DAP. By 180 DAP, EC readings were similar among all substrate treatments.

Growth indices. In Exp. 1, there were no statistical differences among GI for juniper, spirea, loropetalum, and

Table 2. Effect of seven substrates containing pine bark and cedar on pH and electrical conductivity (EC) in azaleas[z].

Substrate[y]	Exp. 1 pH	Exp. 1 EC[x] ($mS \cdot cm^{-1}$)[w]	Exp. 2 pH	Exp. 2 EC ($mS \cdot cm^{-1}$)	Exp. 1 pH	Exp. 1 EC ($mS \cdot cm^{-1}$)	Exp. 2 pH	Exp. 2 EC ($mS \cdot cm^{-1}$)
	7 DAP[v]				30 DAP			
100% PB	6.32ab	0.34[u,ns]	5.04d	0.33[ns]	6.68ab	0.54ab	6.28[ns]	0.37c
95:5 PB:Cedar	6.29b	0.42	5.42c	0.14	6.23b	0.71a	6.66	0.35c
90:10 PB:Cedar	6.33ab	0.40	5.35c	0.14	6.18b	0.50ab	6.87	0.32c
80:20 PB:Cedar	6.64ab	0.38	5.42c	0.16	6.55ab	0.55ab	7.56	0.53c
60:40 PB:Cedar	6.58ab	0.37	5.74b	0.14	6.72ab	0.46b	6.78	0.38bc
20:80 PB:Cedar	6.48ab	0.37	6.05a	0.15	7.01a	0.66ab	6.76	0.52a
100% Cedar	6.68ab	0.34	5.99ab	0.23	6.99a	0.47ab	6.85	0.48ab
	60 DAP				180 DAP			
100% PB	6.25ab	0.39[ns]	6.35c	0.34ab	6.40abc	0.24[ns]	6.80c	0.23[ns]
95:5 PB:Cedar	5.66b	0.57	6.65b	0.38ab	6.24c	0.27	6.99b	0.23
90:10 PB:Cedar	6.22ab	0.34	6.90a	0.33b	6.20c	0.25	6.92bc	0.23
80:20 PB:Cedar	6.29a	0.36	6.95a	0.36ab	6.55abc	0.24	7.06ab	0.24
60:40 PB:Cedar	6.52a	0.37	6.90a	0.38ab	6.49abc	0.26	7.18a	0.24
20:80 PB:Cedar	6.71a	0.41	6.93a	0.38ab	6.74ab	0.27	7.19a	0.23
100% Cedar	6.73a	0.37	6.93a	0.40a	6.79a	0.27	7.23a	0.24

[z]pH and EC of solution determined using pour-through method on 'Formosa' azalea.
[y]PB = pine bark; all treatments 6:1 (v:v) ratio of substrate:sand.
[x]EC = electrical conductivity.
[w]1 $mS \cdot cm^{-1}$ = 1 $mmho \cdot cm^{-1}$.
[v]DAP = days after potting.
[u]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range (HSD) Test at $\alpha = 0.05$ (n = 4).
[ns]Means not significantly different.

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‘Rose Glow’ lantana (Table 3). Minor differences in GI were observed for boxwood, gardenia and rose. Boxwood grown in 100% RC (15.6) was slightly smaller, but all were similar to 100% PB (18.5). All gardenia GI were similar except for 100% RC (36.9) having 25% less growth than 100% PB (49.4). Rose GI for all treatments were similar to GI in 100% PB; plants grown in 80:20 PB:RC (60.3) were slightly larger than those in 100% PB (59.0). Species exhibiting the greatest difference in GI among treatments include azalea, blueberry, and ligustrum. Azalea growth generally declined with increasing RC levels. When RC levels exceeded 20%, azaleas were 36% smaller than those grown in 100% PB. Three substrates were similar to 100% PB (42.2) for azalea including: 95:5 PB:RC (44.3), 90:10 PB:RC (40.6), and 80:20 PB:RC (41.1). Growth for blueberry was similar to PB (36.9) in treatments with up to 20% RC (33.4); in treatments containing 40% or more RC, stunting was visible. Ligustrum exhibited differences among treatments; GI for all treatments containing RC were similar to or greater than 100% PB (30.3), with 80:20 PB:RC (42.4) having 40% greater growth 100% PB.

In Exp. 2, there was no growth difference among all substrate treatments for spirea, rose, loropetalum, and ‘Bandana Pink’ lantana. Juniper GI for all substrate treatments were similar to the 100% PB control (21.4) except for 20:80 PB:RC (13.7). All GI values were similar to the control (45.9) for azalea, except 80:20 PB:RC (37.6) and 100% RC (34.6), which had less growth. Boxwood GI were similar to 100% PB for all treatments. All treatments, with respect to gardenia, exhibited similar GI to the 100% PB (55.9), except for 100% RC (48.6) having 13% less growth. Treatments up to 20% RC (55.0) had similar GI to 100% PB (54.4) for blueberry. For ligustrum, all treatments’ GI were similar to or greater than the control.

Root ratings. RR for Exp. 1 exhibited no difference in root growth for 9 of the 10 species (Table 4). Juniper exhibited a slight variation in root growth in 5% RC; all substrates were comparable to the 100% PB treatment. In Exp. 2, spirea, gardenia and ‘Bandana Pink’ lantana showed no difference in RR between substrates. RR for all treatments, with respect to juniper, rose, and ligustrum, were similar to 100% PB (3.2, 4.1, 4.0 respectively). Most azalea RR were similar to the control (4.4); those that were not included 80:20 PB:RC (3.1) and 100% RC (2.8), which had 38% less root growth than 100% PB. Three substrate treatments for boxwood were similar to 100% PB (2.8) including: 95:5 PB:RC (3.4), 80:20 PB:RC (3.3), and 60:40 PB:RC (3.4); remaining treatments had higher RR. Blueberry RR were similar to 100% PB (4.6) except 60:40 PB:RC (3.0) and 100% RC (2.9). RR for loropetalum were similar to the control (4.8) for three

Table 3. Effect of seven substrates containing pine bark and cedar on growth indices[z] of 10 woody plant species at termination (180 DAP[y]).

	Sargent’s juniper		‘Reeves’ spirea		‘Formosa’ azalea		‘Wintergreen’ boxwood	
Substrate[x]	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**
100% PB	37.4[w,ns]	21.4ab	61.6[ns]	89.4[ns]	42.2a	45.9a	18.5ab	14.9ab
95:5 PB:Cedar	34.6	21.0abc	64.9	101.8	44.3a	46.6a	17.2ab	18.8a
90:10 PB:Cedar	36.4	20.2abc	58.7	97.5	40.6a	42.0ab	18.4ab	16.9ab
80:20 PB:Cedar	40.4	20.5abc	65.2	112.3	41.1a	37.6bc	19.0ab	13.3b
60:40 PB:Cedar	36.8	24.8a	59.2	96.1	32.7b	43.4ab	19.7a	14.6ab
20:80 PB:Cedar	32.4	13.7c	59.4	93.9	27.4b	45.8a	17.7ab	18.0ab
100% Cedar	33.3	14.2bc	56.5	92.8	26.9b	34.6c	15.6b	16.5ab

	‘August Beauty’ gardenia		‘KnockOut’ rose		‘Premier’ blueberry		‘Burgundy’ loropetalum	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**
100% PB	49.4a	55.9a	59.0ab	62.0[ns]	36.9a	54.4a	46.8[ns]	49.0[ns]
95:5 PB:Cedar	49.8a	50.8ab	53.2ab	64.4	32.3abc	42.6abc	47.7	48.4
90:10 PB:Cedar	50.2a	50.9ab	55.4ab	65.4	36.1ab	48.8ab	50.0	51.6
80:20 PB:Cedar	47.5a	50.8ab	60.3a	57.8	33.4abc	55.0a	47.6	52.7
60:40 PB:Cedar	47.9a	55.6a	54.6ab	64.8	27.1cd	39.4bcd	46.8	53.6
20:80 PB:Cedar	44.2a	53.3ab	50.3b	63.4	28.0bcd	33.0cd	43.8	53.1
100% Cedar	36.9b	48.6b	50.9ab	63.1	20.8d	27.6d	43.4	48.0

	‘Recurvifolium’ ligustrum		‘Rose Glow’ lantana	‘Bandana Pink’ lantana
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**
100% PB	30.3cd	56.5b	55.1[ns]	48.4[ns]
95:5 PB:Cedar	34.3bcd	58.6b	56.9	49.9
90:10 PB:Cedar	40.9ab	70.0a	55.1	48.8
80:20 PB:Cedar	42.4a	58.6b	56.0	46.8
60:40 PB:Cedar	35.0abcd	55.9b	57.3	50.8
20:80 PB:Cedar	37.7abc	62.1ab	56.9	46.8
100% Cedar	29.3d	59.3ab	47.6	50.6

[z]Growth index = [(height + width1 + width2) / 3] (cm).

[y]PB = pine bark; all treatments 6:1 (v:v) ratio of substrate:sand.

[x]DAP = days after potting.

[w]Means within column followed by the same letter are not significantly different based on Tukey’s Studentized Range Test at α = 0.05 (n = 8).

[ns]Means not significanly different.

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Table 4. Effect of seven substrates containing pine bark and cedar on root growth[z] of ten woody plant species at termination (180 DAP[y]).

	Sargent's juniper		'Reeves' spirea		'Formosa' azalea		'Wintergreen' boxwood	
Substrate[x]	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB	3.3ab[w]	3.2ab	5.0[ns]	5.0[ns]	4.5[ns]	4.4a	3.4[ns]	2.8b
95:5 PB:Cedar	2.5b	2.5b	5.0	5.0	4.6	4.6a	3.4	3.4ab
90:10 PB:Cedar	3.1ab	2.8ab	5.0	5.0	4.0	4.0ab	3.5	4.1a
80:20 PB:Cedar	3.6ab	4.0a	5.0	5.0	4.4	3.1bc	3.5	3.3ab
60:40 PB:Cedar	3.1ab	4.2a	5.0	5.0	4.0	3.6abc	4.0	3.8ab
20:80 PB:Cedar	3.3ab	3.0ab	5.0	5.0	3.8	4.0ab	3.1	4.5a
100% Cedar	3.8a	2.0b	5.0	5.0	4.0	2.8c	3.0	4.1a
	'August Beauty' gardenia		**'KnockOut' rose**		**'Premier' blueberry**		**'Burgundy' loropetalum**	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**
100% PB	5.0[ns]	5.0[ns]	3.8[ns]	4.1ab	4.9[ns]	4.6a	4.0[ns]	4.8a
95:5 PB:Cedar	5.0	5.0	3.9	4.1ab	4.6	3.6ab	3.9	3.8abc
90:10 PB:Cedar	4.9	5.0	4.1	4.8a	5.0	4.1a	4.4	4.1ab
80:20 PB:Cedar	5.0	5.0	4.4	3.5ab	4.4	4.4a	3.9	3.5bcd
60:40 PB:Cedar	4.9	4.9	3.6	3.9ab	4.6	3.0b	3.8	4.1ab
20:80 PB:Cedar	4.9	5.0	4.3	3.0b	4.1	3.9ab	3.8	3.0cd
100% Cedar	4.6	4.0	4.5	2.8b	4.1	2.9b	3.6	2.7d
	'Recurvifolium' ligustrum		**'Rose Glow' lantana**		**'Bandana Pink' lantana**			
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**		**Exp. 2**			
100% PB	4.0[ns]	4.0ab	5.0[ns]		5.0[ns]			
95:5 PB:Cedar	4.3	4.3a	5.0		5.0			
90:10 PB:Cedar	4.4	4.3a	5.0		5.0			
80:20 PB:Cedar	4.4	4.0ab	5.0		5.0			
60:40 PB:Cedar	4.3	3.0b	5.0		5.0			
20:80 PB:Cedar	4.3	4.0ab	5.0		5.0			
100% Cedar	3.8	4.0ab	5.0		5.0			

[z]Root Growth was on a scale 1 to 5 (1 = 20% root ball coverage, 5 = 80 to 100% root ball coverage).

[y]DAP = days after potting.

[x]PB = pine bark; all treatments 6:1 (v:v) ratio of substrate:sand.

[w]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range Test at $\alpha = 0.05$ (n = 8).

[ns]Means not significanly different.

treatments: 95:5 PB:RC (3.8), 90:10 PB:RC (4.1), and 60:40 PB:RC (4.1); the remaining treatments were up to 44% less [100% RC (2.7)].

Overall, physical properties exhibited an increase in AS and TP with an increase in RC. Values for BD varied, and while BD values in Exp. 1 exhibited a decrease with increasing RC, BD values in Exp. 2 showed no difference among substrates. In general, seven of the 10 species grew equally well in substrates with up to 100% RC when compared to PB in Exp. 1. Gardenia growth was similar to PB in substrates amended with up to 80% RC. Blueberry and azalea did not grow as well in RC above 20%. Exp. 2 exhibited similar trends in growth among species. Blueberry did not grow as well in RC above 40%. However, azalea grew similar in PB as in substrates with up to 80% RC. The other 8 species performed similar to those in Exp. 1 with the exception of juniper, which had a decrease in growth in substrates amended with above 40% RC. These results agree with previous research by Starr et al. (16), where bald cypress had similar growth in 40 and 80% RC chips compared to those grown in PB. Results from Murphy et al. (13) showed that up to 50% RC may be amended to peat moss without a decrease in the growth of three annual species. Overall, data shows that PB amended with RC provides a suitable substrate for woody nursery crops, except with the two acid loving species evaluated. In conclusion, RC has potential for production of ornamental species.

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