Production of Woody Nursery Crops in Clean Chip Residual Substrate[1]

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Abstract

Clean chip residual (CCR) is a potential replacement for pine bark (PB) in nursery crop substrates. It is a by-product of in-field forestry harvesting practices and has been shown to produce annual plants and perennials similar in size to plants grown in PB. Studies were conducted in two locations, Auburn, AL, and Poplarville, MS, to evaluate growth of woody ornamentals grown in CCR or PB. Five species were tested; *Loropetalum chinensis* var. *rubrum*, *Buddleja davidii* 'Black Knight', *Lagerstroemia indica* 'Hopi', *Lagerstroemia* × *fauriei* 'Natchez', and *Rhododendron indicum* 'Mrs. G.G. Gerbing'. There were few differences in plant growth indices, leaf chlorophyll content, and inflorescence number over the course of the year for all species at both sites. Percent rootball coverage was generally similar among treatments, though those grown in PB had the greatest percent rootball coverage for loropetalum and buddleja (at both sites) and azalea at Auburn. Shoot dry weight of loropetalum and crapemytrle grown in PB at Poplarville was greater than plants grown in CCR.

Index words: media, forest residuals, pine, loblolly, peat moss, pine bark, sustainable, alternative, loropetalum, crapemyrtle, azalea, buddleja.

Species used in this study: Loropetalum (*Loropetalum chinensis* var. *rubrum* R. Br.); buddleja (*Buddleja davidii* 'Black Knight' Franch.); crapemyrtle (*Lagerstroemia indica* L. 'Hopi' and *Lagerstroemia* × *fauriei* 'Natchez' Wallich ex Paxt.); azalea (*Rhododendron indicum* 'Mrs. G.G. Gerbing').

Significance to the Nursery Industry

As the expense of growing nursery crops continues to rise along with labor shortages and higher material prices, it has become increasingly important to search for production practices that will lower input costs for growers. With recent and continued trends in the reduced availability of pine bark (PB) (10) a promising avenue for reducing production costs has been the development of alternative substrates. Clean chip residual (CCR) is a forest residual material, a by-product of in-field harvesting of small-diameter (10–30 cm, diameter at breast height) pine trees for 'clean chips' used in paper manufacturing. Utilizing CCR as a nursery crop substrate could potentially lower costs to growers and provide a sustainable, local/regional substrate resource in the Southeast United States. Our data shows that plants grown in CCR had comparable growth to plants grown in PB.

Introduction

Safe, effective, and economical growth substrates are an important part of nursery crop culture. Growers have been searching for innovative ways to meet this need since the inception of container-grown crops on a large scale in the 1950s. The first container substrates were composed primarily of field soil which had poor physical properties and many soil-borne pathogens (4). For the last 30 years PB has been the primary component of nursery crop substrates. Unfortunately, PB is becoming increasingly expensive and less available due to in-field harvesting practices (rather than mill processing), alternative fuel uses, decreased domestic forestry production and increased foreign importation of logs (10).

Recent substrate research has identified CCR, a forest in-field harvesting residual material, as a possible replacement for PB-based substrates (2, 3). Clean chip residual is composed of a high percentage of wood-fiber (about 50%) though it also contains about 40% bark and approximately 10% foliage and other material (pine cones, etc.). Pine trees are passed though a total tree harvesting machine which de-limbs and de-barks the trees before sending remaining material through a chipper and into a chip truck/van. Residual material from this process (limbs, bark, needles, and chipper rejects) is then either sold for boiler fuel at the pulp mill or spread back across the harvested area. Clean chip residual acquired for this study could be obtained for approximately $3 to $4 per cubic yard within a 40-mile radius of the harvesting operation. Additional costs would be required for processing CCR through a hammer mill to reduce particle size. While forestry production, as a whole, is declining in the United States, the sale of CCR for boiler fuel is less than 50% of the available material. Horticultural use of CCR would not equal the amount left in the field and thus would remain a sustainable material.

Several studies have been conducted to evaluate the growth of nursery/perennial crops in high wood-fiber content substrates. Laiche and Nash (9) were the first to compare the growth of plants grown in PB, PB with wood chips or pine tree chips. Woody plants evaluated in their study included *Rhododendron indicum* 'President Clay' (L.) Sweet, *Ligustrum sinense* 'Variegata' Lour., and *Ilex crenata* 'Compacta' Thunb. They concluded that while the physical properties of

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the three media were variable, all exhibited very high hydraulic conductivity and low water holding capacity. Further, the capacity of the substrate materials to hold nutrients was very low. Nitrogen, potassium, and phosphorus were rapidly removed by leaching, while calcium and magnesium were retained longer because of the low solubility of dolomitic limestone. The authors concluded that, for all plants, the best growth was with plants grown in pine bark. Pine bark with wood was less satisfactory than PB and growth was poorest in pine tree chips.

In 2005, pine tree chips were once again evaluated as substrates for plant growth (13). Pine bark (100%), pine chips (100%) and a 75:25 (by vol) pine chip:PB blend substrate were assessed for plant growth during a 13-week growing cycle in a glasshouse. Woody species evaluated in this study included japanese holly (*Ilex crenata* 'Chesapeake' Thunb.) and azalea (*Rhododendron obtusum* 'Karen' Planch.). Plant dry weights of azalea were higher in 100% PB than both substrates containing chips. There were no differences in shoot dry weight for japanese holly between the three substrates. The authors speculated that greater nutrient leaching occurred with the more porous pine chips, resulting in lower electrical conductivity values for pine chip substrates. They attributed the nutrient leaching in pine chips to larger plants when grown in PB. However, nutrient analysis of pine chips revealed that there are no toxic nutrient levels present when loblolly pine (*Pinus taeda* L.) is used as the chip source. Pine chip pH was acceptable for plant growth and there was no substrate shrinkage due to decomposition over the course of the study. The results of this study demonstrated the potential of pine chips for use as container substrates, though further fertility work was necessary.

Later, a study by Wright et al. (14) showed that a wide range of woody species could be produced in a pine chip substrate. Many woody species were grown in either a 100% PB or 100% pine chip substrate over an average of four months. Two planting dates (April 4 and May 18, 2005) were employed to establish the study and plants were grown either in a glasshouse or outdoor container pad until late August. Shoot dry weight of 13 of 18 woody species in the April planting was not different between PB and pine chips, with shoot dry weight of four species being higher when grown in PB and one being higher when grown in pine chips. Shoot dry weight for 6 of 10 species in the May planting was higher in PB compared to pine chips. Instances of reduced growth with pine chips compared to PB were attributed to reduced nutrient availability in pine chips compared to PB. Results of this study suggest that pine chips can be a suitable substrate for container production of woody ornamental plants with adjustments to fertility. A later study by Jackson et al. (7) evaluated fertilizer requirements for two woody species: japanese holly (*Ilex crenata* Thunb. 'Compacta') in 2005 and 2007 and azalea (*Rhododendron obtusum* Planck. 'Delaware Valley') in 2007. Plants were grown in either PB (no fertilizer amendments) or pine chips with one of four pre-plant incorporated fertilizer rates for three months. Fertilizer used was Osmocote Plus (15N–3.9P–10K) at rates of 3.5, 5.9, 8.3, or 10.6 $kg \cdot m^{-3}$ for japanese holly and 1.2, 3.5, 5.9, or 8.3 $kg \cdot m^{-3}$ for azalea. Japanese holly plants required a fertilizer rate of 8.3 $kg \cdot m^{-3}$ or greater in order to have comparable shoot dry weights in both pine chips and PB in 2005. In 2007, shoot dry weights of both species were comparable in PB or pine chips when grown at the 5.9 $kg \cdot m^{-3}$ rate. This study demonstrated that plants grown in pine chip substrate have a higher fertilizer requirement than PB and fertilizer recommendations will need to be developed due to potential nutrient immobilization in pine chip substrate.

Another wood-fiber substrate material is *WholeTree*. *WholeTree* is composed of the entire shoot portion of the tree and is approximately 80% wood fiber depending on the age of the trees harvested. *WholeTree* can be obtained from low-value biomass acquired from forest thinning (making room for the remaining trees to grow larger) or salvage operations where young plantations have not been managed well and are harvested completely in order to replant (this material is then sold to pulp mills or sawmill operations for fuel). Fain and Gilliam (5) reported that annual vinca (*Catharanthus roseus* (L.) G.Don) grown in *WholeTree* had similar growth to plants grown in PB. While shoot dry weights were 15% greater for plants grown in 100% PB 60 days after planting, there were no differences in plant growth indices. Fain et. al (6) reported *WholeTree* composed of three species of pine could each be successfully used as a growth substrate for annual vinca.

In previous research with CCR as a substrate, Boyer et al. (2) evaluated the growth of eight perennial species at two locations (Auburn, AL, and Poplarville, MS). Two CCR particle sizes were used alone or amended with peat moss (4:1 by vol) and compared with control treatments PB and PB:peat moss. Substrates composed of 100% PB or 100% CCR had high air space and low water holding capacity which resulted in less available water to plants. Addition of peat moss lowered air space and increased water holding capacity. Leaf chlorophyll content was similar among all treatments for 3 of 4 species evaluated at 100 days after planting. Growth indices were similar at Poplarville for 6 of 8 species and for 3 of 7 species at Auburn. Shoot dry weight was greater in substrates amended with peat moss. Results of this study indicate that acceptable growth of perennial plants can be obtained in substrates composed of CCR when compared to PB and PB amended with peat moss. However, no tests have evaluated long-term container-grown woody crops with CCR. The objective of this work was to evaluate fresh CCR, processed to several screen sizes, as a substrate for production of container-grown woody crops over the course of one year.

Materials and Methods

CCR used in this study was obtained from a 10-year-old pine plantation near Evergreen, AL, on December 1, 2005. A loblolly pine plantation was being thinned and processed for clean chips using a total tree harvester (Peterson DDC-5000-G Portable Chip Plant, Peterson Pacific Corp., Eugene, OR). Further processing occurred through a horizontal grinder with 4 in (10.2 cm) screens (Peterson 4700B heavy duty grinder, Peterson Pacific Corp.) before the material was sold to a pulp mill for boiler fuel. Clean chip residual material was then stored in a pile outdoors before further processing through a swinging hammer mill (No. 30; C.S. Bell, Tifton, OH) to pass either a 3.18 cm (1.25 in), 1.91 cm (0.75 in), 1.27 cm (0.50 in), or 0.95 cm (0.38 in) screen on March 29, 2006. For our study these four CCR particle sizes were used alone (100%) and compared with a standard control, PB (Table 1).

This study was conducted at two locations: Paterson Greenhouse, Auburn University, Auburn, AL (June 6, 2006),

Table 1. Physical properties of pine bark and clean chip residual substrates[z].

Substrates[y]	Air space[x]	Water holding capacity[w]	Total porosity[v]	Bulk density (g·cm^{-3})[u]
	(% vol)			
3.18 cm (1.25 in) CCR	65a[t]	27c	92a	0.11d
1.91 cm (0.75 in) CCR	62a	29b	91a	0.12c
1.27 cm (0.50 in) CCR	52b	37a	89b	0.13b
0.95 cm (0.38 in) CCR	52b	38a	90b	0.13b
PB	47c	37a	84c	0.15a
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]PB = pine bark, CCR = clean chip residual, 1 cm = 0.0394 in.
[x]Air space is volume of water drained from the sample ÷ volume of the sample.
[w]Water holding capacity is (wet weight – oven dry weight) ÷ volume of the sample.
[v]Total porosity is container capacity + air space.
[u]Bulk density after forced-air drying at 105C (221.0F) for 48 h; 1 g·cm^{-3} = 62.4274 lb·ft^{-3}.
[t]Means within column follwed by the same letter are not significantly different based on Waller-Duncan k ratio t tests 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.

and at USDA-ARS Southern Horticultural Laboratory, Poplarville, MS (June 14, 2006). Each substrate blend was pre-plant incorporated with 8.3 kg·m^{-3} (14 lb·yd^{-3}) 18–6–12 Polyon® (Harrell's Fertilizer, Inc., Sylacauga, AL) control release fertilizer (9 month); 3.0 kg·m^{-3} (5 lb·yd^{-3}) dolomitic limestone and 0.9 kg·m^{-3} (1.5 lb·yd^{-3}) Micromax® (The Scotts Company, Marysville, OH). Five woody ornamental species, *Loropetalum chinensis* var. *rubrum*, *Buddleja davidii* 'Black Knight', *Lagerstroemia indica* 'Hopi' (Auburn) and *Lagerstroemia* × *fauriei* 'Natchez' (Poplarville), and *Rhododendron indicum* 'Mrs. G.G. Gerbing' were transplanted from standard 72-cell flats into #1 containers, placed outdoors on a gravel container pad and overhead irrigated twice daily (0.25 in + 0.25 in = 0.50 in total). Water quality between locations was similar. Irrigation water pH at Poplarville was 6.2, electrical conductivity (EC) (mmhos·cm) was 0.1 and alkalinity (HCO_3^- mg·L) was 41. Irrigation water pH at Auburn was 6.5 with an EC of 0.2 (mmhos·cm) and alkalinity (HCO_3^- mg·L) of 80. Azalea plants at Auburn were grown under 30% shade cloth. Plants were arranged by species in a randomized complete block with eight single plant replications. Containers were top-dressed with 4.2 kg·m^{-3} (7 lb·yd^{-3}) 19–6–12 Polyon® control release fertilizer (6 month) on February 23, 2007. The study was terminated on June 18, 2007, at Auburn, and on June 22, 2007, at Poplarville.

Substrates were analyzed for particle size distribution (PSD) by passing a 100 g air-dried sample through a series of sieves (Table 2). Sieves were shaken for 3 min with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations·min, 159 taps·min). Substrate air space (AS), water holding capacity (WHC), and total porosity (TP) were determined following procedures described by Bilderback et al. (1). Substrate bulk density (gm·cm^{-3}) was determined from 347.5 cm^3 samples dried in a 105C (221F) forced air oven for 48 hr.

Substrate pH and electrical conductivity (EC) were determined at 16, 30, 60, 90, 120, 240 and 365 days after planting (DAP) using the pour-through technique (12). Media shrinkage (cm below the top of the container) was measured at 7 and 365 DAP. Leaf chlorophyll content was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) at 60, 90, 120 and 365 DAP. Growth indices (GI) [(height + width + perpendicular width) / three (cm)] were recorded at 60, 90, 120 and 365 DAP. Flower counts were conducted at 60 and 90 DAP for buddleja. Root ratings (percent coverage of the rootball) were conducted at 365 DAP. Shoot dry weights (SDW) were recorded at the conclusion of the study (365 DAP) by drying in a forced air oven at 70C (158F) for 48 hr.

Recently matured, current season terminal shoots [5.1 to 7.6 cm (2–3 in)] (11) were sampled from loropetalum at both locations. Foliar (shoot) samples (four replications per treatment) were analyzed for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn). Tissue N content was determined by combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using Waller-Duncan k ratio t tests ($P \leq 0.05$) using a statistical software package (SAS® Institute version 9.1, Cary, NC). Data were analyzed separately for each location.

Results and Discussion

Physical properties were analyzed and are described as in Boyer et al. (2). Air space in all substrates was high (47–65%; recommended 10–30%) (Table 1). Air space tended to increase with increasing particle size. Water holding capacity (WHC) was low for all substrates (27–38%; recommended 45–65% (15)); however, 1.27 cm (0.50 in) and 0.95 cm (0.38 in) CCR had similar CC to PB. Total porosity was slightly above (90–92%) recommended ranges (50–85%) except for PB (84%). This is similar to results reported by Wright and Browder (13) in that substrates composed of 100% PB had the lowest TP (70%) and substrates composed of 100% pine chips or a 75:25 (by vol) pine chip:PB blend had greater TP (82–86%). Bulk density was low for all substrates (0.11–0.15 g·cm^{-3}; recommended 0.19–0.70 g·cm^{-3}).

As expected, 3.18 cm (1.25 in) CCR and 1.91 cm (0.75 in) CCR had a higher component of large particles and fewer medium and small particles (Table 2). Substrates composed

Table 2. Particle size analysis of pine bark and clean chip residual substrates.

U.S. standard sieve no.	Sieve opening (mm)^z	Substrate^y 3.18 cm (1.25 in) CCR	1.91 cm (0.75 in) CCR	1.27 cm (0.50 in) CCR	0.95 cm (0.38 in) CCR	PB
1/2	12.50	3.2a^x	0.4b	0.1b	0.0b	0.0b
3/8	9.50	8.5a	2.2b	0.1b	0.0b	0.1b
1/4	6.35	17.9a	10.3b	3.4d	1.3d	6.5c
6	3.35	25.5a	33.4a	29.9a	25.5a	26.2a
8	2.36	17.9b	19.6b	23.4a	23.1a	14.7c
10	2.00	6.2c	7.5b	9.6a	9.7a	5.6c
14	1.40	9.2d	11.5c	14.1ab	15.4a	12.9bc
18	1.00	4.7d	6.4c	8.1b	9.3ab	9.6a
35	0.50	4.1d	5.5cd	7.2c	9.1b	14.2a
60	0.25	1.6d	1.7cd	2.6c	4.1b	6.1a
140	0.11	0.8c	0.8c	1.1c	1.9b	2.6a
270	0.05	0.3c	0.3c	0.3c	0.5b	0.9a
pan	0.00	0.1a	0.4a	0.1a	0.1a	0.6a
Texture^w						
Coarse		55.1a	46.3b	33.6c	26.8d	32.7cd
Medium		37.9c	45.0b	55.1a	57.5a	42.9b
Fine		7.0d	8.7cd	11.3c	15.7b	24.4a

^{z}1 mm = 0.0394 in.

^{y}PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 in.

^{x}Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests at α = 0.05 (n = 3).

^{w}Coarse = > 3.35 mm; Medium = > 1.00– < 3.35 mm; Fine = < 1.0 mm.

of 1.27 cm (0.50 in) CCR or 0.95 cm (0.38 in) CCR were similar to PB with the exception of more extra fine particles in the PB.

Substrate pH and EC remained relatively constant over the course of the year (Table 3). At Auburn, pH of PB was consistently lower than that of CCR substrates by about 0.5 units. In general, the pH was around 6.5 at both sites, which is acceptable for plant growth. The trend of lower pH for PB at Auburn did not occur at Poplarville. All pH levels were similar at all rating dates at Poplarville except 238 DAP where the larger sizes of CCR had a slightly higher pH level. Electrical conductivity (EC) also remained relatively constant over the course of the year, though a small, but steady EC decline from 0.36 mS·cm at 16 DAP to a low of about 0.13 mS·cm at 258 DAP existed at Auburn possibly due to depletion of the fertilizer. Electrical conductivity levels at 377 DAP were similar to those at 92 DAP after topdressing in February of 2007. A similar trend occurred at Poplarville except that

Table 3. Substrate electrical conductivity (EC) and pH for pine bark and clean chip residual substrates in a container-grown woody ornamental study at two locations.

Substrate^z	EC (mS·cm^{-1})^x	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH
Auburn, AL	**16 DAP^y**		**31 DAP**		**59 DAP**		**92 DAP**		**141 DAP**		**258 DAP**		**377 DAP**	
3.18 cm (1.25 in) CCR	0.31^{ns}	6.4a^w	0.42^{ns}	6.3a	0.47^{ns}	6.0a	0.41^{ns}	6.3b	0.23^{ns}	6.4ab	0.15a	6.4a	0.34^{ns}	6.3a
1.91 cm (0.75 in) CCR	0.39	6.4a	0.38	6.4a	0.48	5.8a	0.31	6.5a	0.22	6.4a	0.14a	6.4a	0.31	6.3a
1.27 cm (0.50 in) CCR	0.44	6.4a	0.52	6.3a	0.44	5.9a	0.33	6.4a	0.21	6.3b	0.11b	6.3a	0.34	6.1a
0.95 cm (0.38 in) CCR	0.36	6.4a	0.45	6.4a	0.43	5.3b	0.32	6.4a	0.20	6.3ab	0.11b	6.3a	0.46	6.0ab
PB	0.38	5.9b	0.52	5.0b	0.55	4.8c	0.34	6.0c	0.18	5.9c	0.11b	5.8b	0.28	5.7b
Poplarville, MS	**16 DAP**		**30 DAP**		**61 DAP**		**98 DAP**		**128 DAP**		**238 DAP**		**374 DAP**	
3.18 cm (1.25 in) CCR	0.35^{ns}	6.9^{ns}	0.38^{ns}	6.9^{ns}	0.41^{ns}	6.5^{ns}	0.13^{ns}	6.6^{ns}	0.10^{ns}	6.5^{ns}	0.10^{ns}	6.5ab	0.11^{ns}	5.7^{ns}
1.91 cm (0.75 in) CCR	0.39	6.9	0.35	6.8	0.67	6.3	0.14	6.7	0.36	6.5	0.08	6.7a	0.14	5.0
1.27 cm (0.50 in) CCR	0.34	6.9	0.42	6.9	0.55	6.3	0.14	6.6	0.12	6.5	0.10	6.4bc	0.20	5.2
0.95 cm (0.38 in) CCR	0.50	6.9	0.43	7.0	0.83	6.3	0.14	6.6	0.17	6.4	0.10	6.2c	0.23	4.1
PB	0.42	6.9	0.47	6.9	0.68	6.2	0.16	6.4	0.13	6.1	0.08	6.2c	0.18	4.5

^{z}PB = pine bark, CCR = clean chip residual, 1 cm = 0.394 in.

^{y}DAP = days after planting. Auburn plants were planted on June 6, 2006; Poplarville plants were planted on June 14, 2006. All plants were topdressed with 4.2 kg·m^{-3} (7 lb·yd^{-3}) 19–6–12 Polyon control release fertilizer on February 23, 2007.

^{x}1 mS·cm^{-1} = 1 mmho–cm.

^{w}Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests at α = 0.05 (n = 4).

^{ns}Means not significantly different.

Table 4. **Effects of pine bark and clean chip residual substrates on growth of *Loropetalum chinensis* var. *rubrum* and *Buddleja davidii* 'Black Knight' at two locations.**

Substrate[z]	Growth index[x]				Percent rootball coverage[w]		Shoot dry weight (g)[v]	
	Loropetalum		Buddleja		Loropetalum	Buddleja	Loropetalum	Buddleja
Auburn, AL	**141 DAP[y]**	**373 DAP**	**141 DAP**	**373 DAP**	**373 DAP**	**373 DAP**	**377 DAP**	**377 DAP**
3.18 cm (1.25 in) CCR	33.2c[u]	58.0bc	83.6[ns]	101.8[ns]	57.5c	72.5c[v]	60.3c	145.4[ns]
1.91 cm (0.75 in) CCR	41.2a	66.6a	79.8	96.5	71.9b	75.0bc	81.7abc	136.6
1.27 cm (0.50 in) CCR	40.3ab	62.4abc	78.7	85.9	77.5ab	85.0ab	88.5ab	128.2
0.95 cm (0.38 in) CCR	42.1a	63.3ab	88.0	97.6	83.1ab	90.0a	99.7a	152.4
PB	35.8bc	57.1c	87.2	98.4	85.0a	93.1a	76.4bc	162.4
Poplarville, MS	**128 DAP**	**373 DAP**	**128 DAP**	**372 DAP**	**373 DAP**	**372 DAP**	**373 DAP**	**372 DAP**
3.18 cm (1.25 in) CCR	41.6[ns]	60.2[ns]	66.6a	94.0[ns]	55.0[ns]	18.3[ns]	124.1b	138.1[ns]
1.91 cm (0.75 in) CCR	37.2	59.8	56.6b	96.3	46.7	20.0	130.1b	140.4
1.27 cm (0.50 in) CCR	38.2	62.8	61.4ab	99.8	46.7	23.3	131.0b	148.7
0.95 cm (0.38 in) CCR	40.8	65.6	62.1ab	98.1	60.0	25.0	134.1b	155.0
PB	40.6	64.1	62.3ab	96.5	48.3	35.0	160.8a	153.6

[z]PB = pine bark, CCR = clean chip residual, 1 cm = 0.0394 in.

[y]DAP = days after planting.

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

[w]Percent rootball coverage was rated on a scale of 0–100% coverage of the rootball by roots.

[v]1 g = 0.0353 oz.

[u]Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio *t* tests at α = 0.05 (n = 8).

[ns]Means not significantly different.

the spike in EC levels occurred at 238 DAP instead of 374 DAP. Previous studies (2, 3) with CCR have generally been short-term and these data demonstrate relative stability in pH with crops grown in CCR.

There were no differences in GI of loropetalum at Auburn at 55 DAP; however, by 92 DAP slight differences were measured (data not shown). At 141 DAP plants grown in 3.18 cm (1.25 in) CCR were the smallest (33.2) along with PB (35.8) (Table 4). At the conclusion of the study (373 DAP), plants grown in PB were the smallest (57.1), but were similar to plants grown in 3.18 cm (1.25 in) CCR (58.0) and 1.27 cm (0.50 in) CCR (62.4). There were no differences in GI of loropetalum at Poplarville at any rating date during the study. While plants grown in PB at Auburn may have exhibited less shoot growth than plants grown in CCR, root growth was excellent (85.0% rootball coverage) as was the root growth of plants grown in 1.27 cm (0.50 in) CCR (77.5%) and 0.95 cm (0.38 in) CCR (83.1%). Plants grown in 3.18 cm (1.25 in) CCR had the least rootball coverage (57.5%). Loropetalum plants grown at Poplarville had no differences in percent rootball coverage at study termination. Shoot dry weight of loropetalum at Auburn at 377 DAP indicated that plants grown in 0.95 cm (0.38 in) CCR had the greatest shoot growth (99.7 g) while plants grown in 1.91 cm (0.75 in) CCR and 1.27 cm (0.50 in) CCR were similar (81.7 g, 88.5 g). Plants grown in PB had the least SDW (76.4 g), but were similar to all other treatments except 0.95 cm (0.38 in) CCR. However, SDW of loropetalum at Poplarville revealed that plants grown in PB had significantly more shoot growth than plants grown in any CCR treatment. There was a trend for SDW to increase at Poplarville with decreasing screen size.

Tissue nutrient content of loropetalum was similar among treatments for N, P, Mg, S, B, Fe, Mn, Cu, and Zn (Table 5). Foliar K content (0.70–0.86%) among all treatments was higher than the sufficiency range (0.40–0.52%) (11), but all CCR treatments were similar to PB. Calcium content was less in the tissue from plants grown in larger CCR particle sizes, however, overall calcium content was similar (though low overall) for 0.95 cm (0.38 in) CCR and PB.

Recommended ranges (11) for tissue nutrient content showed that N was acceptable for CCR treatments (1.4%), but was low for PB (1.1%) (Table 5). Phosphorus content was slightly high overall (0.16%; range is 0.10–0.13), but PB was lower than CCR treatments (0.13%). There were no differences among treatments for K, but the values (0.67–0.75%) were above the sufficiency range (0.40–0.52%). Calcium values were similar among treatments (1.0–1.2%), but below the sufficiency range (2.0–2.9%). Magnesium was slightly high among all treatments (0.17–0.19%, range is 0.13–0.15%), however 3.18 cm (1.25 in) CCR had less Mg (0.17%) than other treatments, though 1.27 cm (0.50 in) CCR and PB were similar. Sulfur was similar among treatments (0.15%), though slightly high (sufficiency range 0.12–0.14%). Boron (15–18 ppm) was similar among treatments, but lower than sufficiency ranges (55–126 ppm). Iron (41–53 ppm) was lower than sufficiency ranges (58–69 ppm) however, 3.18 cm (1.25 in) CCR (41 ppm) was lower than other treatments except PB (44 ppm). There were no differences for Mn, though values were slightly high (29–39 ppm; range is 15–35 ppm). Copper was low in PB (3 ppm), but 1.27 cm (0.50 in) CCR and 0.95 cm (0.38 in) CCR (5 ppm) were similar. Zinc was highest in 1.91 cm (0.75 in) CCR (23 ppm) and all treatments were above the sufficiency range (7–10 ppm).

Growth indices of buddleja at Auburn were similar among treatments at both 141 and 373 DAP (Table 4). At Poplarville at 128 DAP the greatest GI occurred with 3.18 cm (1.25 in) CCR (66.6) and the least with 1.91 cm (0.75 in) CCR (56.6). All other treatments were similar to both 3.18 cm and 1.91 cm (0.75 in) CCR. At the conclusion of the study (372 DAP) there were no differences in GI. Leaf chlorophyll content and

Table 5. Tissue nutrient content of *Loropetalum chinensis* var. *rubrum* grown in pine bark and clean chip residual substrates at two locations.

Substrate[z]	Tissue nutrient content[y] N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)
Auburn, AL											
3.18 cm (1.25 in) CCR	1.4[ns]	0.13[ns]	0.86a[x]	1.4b	0.20[ns]	0.16[ns]	18[ns]	50[ns]	45[ns]	7[ns]	27[ns]
1.91 cm (0.75 in) CCR	1.4	0.13	0.82ab	1.4b	0.20	0.15	19	49	40	10	33
1.27 cm (0.50 in) CCR	1.3	0.12	0.70c	1.4b	0.19	0.14	19	48	35	10	33
0.95 cm (0.38 in) CCR	1.3	0.13	0.74bc	1.6ab	0.21	0.14	20	59	33	10	31
PB	1.3	0.12	0.75abc	1.7a	0.20	0.15	17	48	38	7	31
Poplarville, MS											
3.18 cm (1.25 in) CCR	1.4a	0.17a	0.74[ns]	1.0[ns]	0.17b	0.15[ns]	15[ns]	41c	37[ns]	6a	13b
1.91 cm (0.75 in) CCR	1.4a	0.16a	0.74	1.1	0.19a	0.15	18	53a	38	6a	23a
1.27 cm (0.50 in) CCR	1.4a	0.15a	0.71	1.0	0.18ab	0.15	16	48ab	37	5ab	15b
0.95 cm (0.38 in) CCR	1.4a	0.15a	0.75	1.1	0.19a	0.15	18	47b	39	5ab	17ab
PB	1.1b	0.13b	0.67	1.2	0.18ab	0.13	17	44bc	29	3b	14b
Sufficiency range[w]	1.43–1.90	0.10–0.13	0.40–0.52	2.0–2.9	0.13–0.15	0.12–0.14	55–126	58–69	15–35	4–6	7–10

[z]PB = pine bark, CCR = clean chip residual, 2.54 cm = 1 in.

[y]Tissue analysis performed on 20 terminal shoots (5.1 cm–7.6 cm (2–3 in) of most recently mature leaves) per plant on June 15, 2007; N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S = sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, 1 ppm = 1 mg·kg^{-1}.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, n = 4).

[w]Sufficiency range published by Mills and Jones (1996).

[ns]Means not significantly different.

number of inflorescences was similar among all treatments at both locations (data not shown). Percent rootball coverage at Auburn was greatest in PB (93.1%) and 0.95 cm (0.38 in) CCR (90.0%), though 1.27 cm (0.50 in) CCR was similar (85.0%). Percent rootball coverage was similar among plants in all treatments at Poplarville. There were no differences in SDW at either location.

These data concur with previous work (2) with 'Pink Delight' buddleja grown in 100% PB, 100% 1.91 cm (0.75 in) CCR, 100% 1.27 cm (0.50 in) CCR or these mixed 4:1 (by vol) with peat. Initial growth differences occurred; however, all buddleja had similar in growth indices, flower counts and leaf color in the 100% substrates at the conclusion of the study.

Crapemyrtle at both locations had no differences for GI, leaf chlorophyll content, percent rootball coverage at any rating date (data not shown). There were no differences for crapemyrtle SDW at Auburn. Shoot dry weight for was greatest

Table 6. Effects of pine bark and clean chip residual substrates on substrate shrinkage in container.

Substrate[z]	Substrate shrinkage (cm)[y]	Loropetalum	Buddleja	Crapemyrtle	Azalea
Auburn, AL	**7 DAP[x]**	**373 DAP**	**373 DAP**	**373 DAP**	**373 DAP**
3.18 cm (1.25 in) CCR	0.5[ns]	2.9a[w]	1.4a	2.3a	4.3a
1.91 cm (0.75 in) CCR	0.3	2.1b	1.1ab	1.8ab	3.8a
1.27 cm (0.50 in) CCR	0.3	1.9b	1.1ab	1.4bc	3.9a
0.95 cm (0.38 in) CCR	0.2	2.1b	0.9b	1.9ab	4.1a
PB	0.3	1.9b	0.8b	1.3c	2.3b
Poplarville, MS	**15 DAP**	**372 DAP**	**373 DAP**	**371 DAP**	**373 DAP**
3.18 cm (1.25 in) CCR	2.4ab	3.7[ns]	2.1ab	1.8a	4.6[ns]
1.91 cm (0.75 in) CCR	2.7a	3.4	2.3a	1.7a	4.2
1.27 cm (0.50 in) CCR	2.6ab	3.6	2.0b	1.7a	4.4
0.95 cm (0.38 in) CCR	2.2bc	3.4	2.1ab	1.8a	4.3
PB	1.9c	2.8	1.4c	0.9b	4.5

[z]PB = pine bark, CCR = clean chip residual.

[y]Measured from the top of the container to the surface of the substrate.

[x]DAP = days after planting. Auburn plants were potted on June 6, 2006; Poplarville plants were potted on June 14, 2006.

[w]Means within column followed by the same letter are not significantly different based onWaller-Duncan k ratio t tests at $\alpha = 0.05$ (n = 8).

[ns]Means not significantly different.

for plants grown in PB (247.4 g) at Poplarville with all other treatments being similar to each other (185.7–204.3 g).

Azalea plants at Auburn had similar GI at all rating dates (data not shown). At Poplarville GI were similar at 62 DAP, however, by 97 and 128 DAP 3.18 cm (1.25 in) CCR had the greatest GI (23.6 and 23.8) though 1.27 cm (0.50 in) CCR was similar (21.7 and 21.8). There were no differences in GI of azalea at Poplarville by 373 DAP. Leaf chlorophyll content was similar among all treatments at all rating dates at both locations. At the conclusion of the study (373 DAP) plants grown in PB at Auburn had greater percent rootball coverage (93.8%) than all other treatments (66.3–71.3%). There were no differences in percent rootball coverage of azalea at Poplarville. There were no differences in azalea SDW at either location.

Substrate shrinkage can be an important indicator of substrate degradation due to microbial activity. A study by Kenna and Whitcomb (8) reported large differences in drainable pore space for newly prepared media (composed of freshly chipped hardwood trees), compared to those after one growing season, suggesting that substantial decomposition of elm and oak chips did occur; however volume shrinkage of the media in the container was minimal and plant growth over the course of the study was acceptable. In the current study, there were no differences in substrate shrinkage at 7 DAP for Auburn (Table 6). At the conclusion of the study (365 days) substrate shrinkage was greatest for plants grown in 3.18 cm (1.25 in) CCR. This was most likely due to settling of the substrate with such a large initial amount of air space due to the large particle sizes. At 15 DAP in Poplarville there were slight differences in substrate shrinkage. Pine bark had the least shrinkage (1.9 cm) though 0.95 cm (0.38 in) CCR was similar (2.2 cm). There were no differences in substrate shrinkage at the conclusion of the study for loropetalum or azalea. Buddleja and crapemyrtle plants had the least substrate shrinkage in PB. All containers were hand-weeded throughout the study. Substrate shrinkage measurements varied by species and location; however none of the shrinkage values at one year after potting appeared to negatively affect crop growth or salability.

In general, plants grown in CCR had comparable growth to plants grown in PB. The 3.18 cm (1.25 in) CCR and 1.91 cm (0.75 in) CCR had much larger amounts of substrate air space, and consequently less ability to hold water than other substrates. These substrates were also slightly lighter (low bulk density) than other substrates which resulted in more frequent blow-over in the small containers during the first summer growing period. Root growth of loropetalum and buddleja at Auburn was less in 3.18 cm (1.25 in) CCR and 1.91 cm (0.75 in) CCR substrates than in other treatments. These two screen sizes may be more appropriate for crops grown in larger containers (#15 to #25) where a more porous substrate is typically desired to encourage root penetration. The smaller screen sized material, 1.27 cm (0.50 in) CCR and 0.95 cm (0.38 in) CCR, works well in #1 containers for outdoor nursery crops.

Loropetalum, buddleja, crapemyrtle, and azalea plants grown in CCR and PB exhibited few differences. Plants grown in larger particle size CCR tended to have more substrate shrinkage and, in some cases, less growth than other treatments indicating they may not be the best option for #1 containers. There was also a tendency for plants in the smaller particle size substrate to have the best root growth. Long-term consistency among pH and EC levels suggest that CCR will be a dependable substrate comparable to PB where water quality is similar to Auburn and Poplarville. Similarly, nutrient analysis revealed that plant response was similar whether plants were grown in PB or CCR. Plant growth among the four woody species was generally similar at both locations with CCR and PB.

Our study had similar results to a study evaluating a high wood-content substrate for production of woody crops (14) in that most of our plants produced in CCR grew similarly to PB. Where differences occurred they appeared to be more related to substrate physical properties from large screen sizes, with larger screen sized material being less suitable for use in production of plants in small containers. Overall, CCR has shown great potential as a substitute for PB in nursery crop production. In the Southeast United States, CCR is locally available, sustainable and an economical substrate option for producers. Use of CCR could significantly impact future nursery production practices as PB supplies decline and PB prices rise.

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