Clean Chip Residual as a Substrate for Perennial Nursery Crop Production[1]

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Abstract

Pine bark (PB) for horticultural uses is becoming less available and as a result, there is a need to develop alternative substrates for continued profitability of the nursery industry. This study, conducted at Poplarville, MS, and Auburn, AL, evaluated the growth of nine perennial species in a substrate composed of a pulpwood harvesting by-product called clean chip residual (CCR) which contains approximately 50% wood fiber. Two CCR particle sizes were used alone or amended with peat moss (PM) (4:1 by vol) and compared with control treatments PB and PB:PM. Substrates composed of 100% PB or 100% CCR had high air space (AS) and low water holding capacity (WHC) which resulted in less available water to plants. Addition of PM lowered AS and increased WHC. There were no significant differences among growth indices at Poplarville for 6 of 8 species and for 3 of 7 species at Auburn, though the remaining 4 species were only slightly smaller when grown in 100% CCR. Shoot dry weight was greatest in substrates amended with PM. 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 PM.

Index words: media, forest residuals, pine, Loblolly, peat moss, pine bark, sustainable.

Species used in this study: loblolly (*Pinus taeda* L.); butterfly bush (*Buddleia davidii* 'Pink Delight' Franch.); gaura (*Gaura lindheimeri* 'Siskiyou Pink' Engelm. & A. Gray); coreopsis (*Coreopsis grandiflora* 'Early Sunrise' Hogg *ex* Sweet); coreopsis (*Coreopsis rosea* 'Sweet Dreams' Nutt.); verbena (*Verbena canadensis* 'Homestead Purple' (L.) Britt.); scabiosa (*Scabiosa columbaria* 'Butterfly Blue' L.); dianthus (*Dianthus gratianopolitanus* 'Firewitch' Vill.); rosemary (*Rosemarinus officinalis* 'Irene' L.); salvia (*Salvia guaranitica* 'Black and Blue' St.-Hil. *ex* Benth.).

Significance to the Nursery Industry

In recent years, pine bark (PB) supplies have begun to decline (10) and the cost of shipping peat moss (PM) from Canada has increased rapidly. Pursuit of local/regional, sustainable substrate resources have become paramount. One substrate option is clean chip residual (CCR), a forest by-product of the pulp industry. This study demonstrated that perennial plants grown in substrates composed of CCR amended 4:1 (by vol) with PM had similar growth responses to plants grown in 100% PB and PB:PM (4:1 by vol). In general, there were few differences in growth indices for most species. However, SDW tended to be greatest in substrates containing PM.

Introduction

Aged PB used alone or amended with sand or PM has been the primary substrate used in container nurseries since the 1960s. Unfortunately, availability of PB is declining due to reduced domestic forestry production, an increase in in-field harvesting, increased importation of logs (no bark), and use of PB as a fuel source (10). It is important to explore alternatives to the rapidly declining resource of PB as a substrate. Potential options must be readily available, sustainable, economical, pest-free, and easily processed.

A new trend in harvesting pine trees is mobile in-field chipping operations. In-field harvesting operations are increasing and are located across the Southeast United States where several million acres are currently in pine production. Whole tree in-field harvesting equipment is used to process trees into 'clean chips' to be sent to pulp mills. This process occurs in the pine plantation being harvested. A by-product of this process is a residual material (about 25% of the site biomass) composed of about 50% wood, 40% bark and 10% needles. This by-product, 'clean chip residual' (CCR), is either sold for boiler fuel, or more commonly, spread back across the harvested area. If the processed product is sold for boiler fuel the approximate cost was $3–4 per cubic yard in Alabama in 2005. Additional costs will be incurred to process CCR for use as a substrate. Clean chip residual can be used in a fresh state and is a regionally available resource in the Southeastern United States. This material is not currently being marketed to the horticultural industries, but instead is generally left in the woods due to lack of a market.

One concern among nursery producers about CCR is the increased wood content compared to the traditionally used PB substrate. A recent study by Wright and Browder (14) showed that a predominantly wood-fiber substrate could be used successfully for nursery crop production with proper nutrition and irrigation. A later study by Wright et al. (15) evaluated 23 species of woody nursery crops for production in a pine chip or PB substrate. Results suggested that with adjustments to fertility, pine chips could be a suitable substrate for container production of woody ornamental plants. Studies by Fain and Gilliam (7), Fain et al. (5) and Boyer et al. (3) successfully used substrates composed of whole pine trees (*WholeTree*) to produce container-grown

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nursery crops. Wood percentage in *WholeTree* substrates ranges from 75–85%. Clean chip residual was previously tested as a growth substrate for greenhouse-grown annuals (4). Annuals produced in CCR were similar in size to those grown in PB alone. In addition, several 100% wood-fiber products have been used in Europe for use in vegetable production (8). The 2001 study by Gruda and Schnitzler (8) evaluated the physical properties of wood fiber substrates and demonstrated that the material had high amounts of air space, necessitating more frequent watering. A subsequent study by Gruda and Schnitzler (9) showed that wood fiber substrates had a similar volume weight and total pore space as PM substitutes, but lower water retention. Wood fiber substrates used in the Gruda and Schnitzler studies (8, 9) evaluated a substrate composed of pure, untreated spruce wood chips with little bark which was a by-product of the woodworking industry. Chips were shredded under frictional pressure, and a nitrogen (N)-source was added in an attempt to avoid N-immobilization. These studies show that having a larger portion of wood in the substrate may be acceptable for producing horticultural crops.

If CCR can be established as a container-grown plant substrate, it could reduce substrate costs for growers and provide an alternative market for forestry loggers and landowners. It has potential to provide a locally available, sustainable and economical substrate to meet the continuing needs of the nursery industry. Currently, CCR has been evaluated for use as a growth substrate for greenhouse-grown annuals, however, no studies have evaluated the potential of CCR for production of container-grown perennials. The objective of this work was to evaluate fresh CCR as a PB replacement substrate for outdoor cultivation of container-grown perennial crops.

Materials and Methods

Clean chip residual used in this study was obtained from a 10-year-old pine plantation near Evergreen, AL, on December 1, 2005. A loblolly pine (*Pinus taeda* L.) 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., Eugene, OR). Clean chip residual material obtained for this study was processed again through a swinging hammer mill (No. 30; C.S. Bell, Tifton, OH) to pass either a 1.9 cm (0.75 in) or 1.3 cm (0.50 in) screen on March 29, 2006. These two CCR particle sizes were used alone or blended 4:1 (by vol) with PM and compared to standard controls of PB or 4:1 PB:PM (Table 1).

These studies were conducted concurrently at two locations: USDA-ARS Southern Horticultural Laboratory, Poplarville, MS (March 30, 2006) and at Paterson Greenhouse, Auburn University, Auburn, AL (June 2, 2006). Each substrate was pre-plant incorporated with 8.3 $kg{\cdot}m^{-3}$ (14 $lb{\cdot}yd^{-3}$) 18N–2.6P–9.9K (18–6–12) Polyon (Harrell's Fertilizer, Inc., Sylacauga, AL) control release fertilizer (9 month); 3.0 $kg{\cdot}m^{-3}$ (5 $lb{\cdot}yd^{-3}$) dolomitic limestone and 0.9 $kg{\cdot}m^{-3}$ (1.5 $lb{\cdot}yd^{-3}$) Micromax (The Scotts Company, Marysville, OH). Plants used in this study were obtained from Yoder Brothers Inc./Greenleaf Perennials (Lancaster, PA). Nine perennial species, *Buddleia davidii* 'Pink Delight', *Gaura lindheimeri* 'Siskiyou Pink', *Coreopsis grandiflora* 'Early Sunrise' (Poplarville only), *Coreopsis rosea* 'Sweet Dreams' (Auburn only) (differences in genus per location (coreopsis) were due to slight inventory differences at the time of order for each location), *Verbena canadensis* 'Homestead Purple', *Scabiosa columbaria* 'Butterfly Blue', *Dianthus gratianopolitanus* 'Firewitch', *Rosemarinus officinalis* 'Irene', and *Salvia guaranitica* 'Black and Blue' (Poplarville only, unavailable when plants were ordered for Auburn), were transplanted from 36-cell flats into #1 containers (NS400C, Nursery Supplies, Inc., Kissimmee, FL), placed outdoors on a gravel container pad and overhead irrigated twice daily (0.5 in total). Water quality between locations was similar. Irrigation water pH at Poplarville was 6.2, electrical conductivity (EC) ($mmhos{\cdot}cm^{-1}$) was 0.1 and alkalinity (HCO_3^- $mg{\cdot}L^{-1}$)

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

Substrate[y]	Air space[x] (% vol)	Substrate water holding capacity[w] (% vol)	Total porosity[v] (% vol)	Bulk density ($g{\cdot}cm^{-3}$)[u]
100% PB	51b[t]	30c	81e	0.15a
100% 1.9 cm (0.75 in) CCR	60a	30c	90c	0.13c
100% 1.3 cm (0.50 in) CCR	60a	32c	92b	0.12cd
4:1 PB:PM	38d	49a	87d	0.14b
4:1 1.9 cm (0.75 in) CCR:PM	48b	44b	92ab	0.11e
4:1 1.3 cm (0.50 in) CCR:PM	44c	49a	93a	0.11de
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, PM = sphagnum peat moss, 1 cm = 0.394 in.

[x]Air space is volume of water drained from the sample ÷ volume of the sample.

[w]Substrate 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 $g{\cdot}cm^{-3}$ = 62.4274 $lb{\cdot}ft^{-3}$.

[t]Means within column followed 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.

was 41. Irrigation water pH at Auburn was 6.5 with an EC of 0.2 ($mmhos·cm^{-1}$) and alkalinity (HCO_3^- $mg·L^{-1}$) of 80. Plants were arranged by species in a randomized complete block with eight single plant replications.

Substrates were analyzed for particle size distribution (PSD) by passing a 100-g air-dried sample through 12.5, 9.5, 6.35, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, and 0.11 mm sieves with particles passing the 0.11-mm sieve collected in a pan. 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 (measured in $g·cm^{-3}$) was determined from 347.5 cm^3 samples dried in a 105C (221F) forced air oven for 48 hr. Substrate pH and EC were determined at 15, 30, and 60 days after planting (DAP) using the pour-through technique (13). Media shrinkage (cm below the top of the container) was measured at 7 and 90 DAP (no differences, data not presented). An indirect measurement of leaf chlorophyll content (as expressed by the level of greenness in the leaves) was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) at 30, 60 and 97–109 DAP, however, due to lack of differences, data is not presented. Growth indices (GI) [(height + width + perpendicular width) / three (cm)] were recorded at 30, 60 and 90 DAP (30 DAP data not shown). Flower counts were conducted at 64 DAP. Root ratings (percent coverage of the rootball) were conducted at 98 DAP in Auburn, though few differences were observed thus data is not presented. Shoot dry weights (SDW) were recorded at the conclusion of the study (110 DAP) by drying in a forced air oven at 70C (158F) for 48 hr. 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, species, and measurement.

Results and Discussion

Physical properties. Recommended range for container substrate AS is 10–30% (12). All substrates in this study were well above this range including the industry standard 4:1 PB:PM control treatment (38%). Treatments composed of 100% substrate had the highest AS in general (Table 1). Substrate water holding capacity were opposite of the AS numbers in that the 100% substrates had the lowest values (30–32%) while blends with PM had the highest (44–49%; recommended range: 45–65%). Total porosity was slightly high (81–93%) in all substrates (recommended range: 50–85%) though it was highest in the 4:1 CCR:PM substrate (92–93%) and lowest in 100% PB (81%). This is similar to results reported by Wright and Browder (14) in that substrates composed of 100% PB had the lowest TP (70%) and substrates composed of 100% pine chips (predominantly wood fiber) 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 range is 0.19–0.70 $g·cm^{-3}$), although no blow-over problems occurred during this test.

Particle size analysis indicated that substrates containing PB or 1.9 cm (0.75 in) CCR had more coarse particles (3.35–12.50 mm) than those substrates composed of 1.3 cm (0.50 in) CCR (Table 2). Coarse particles provide aeration to substrates (11). Medium sized particles (1.00–2.36 mm) were greatest in 100% 1.3 cm (0.50 in) CCR and least in 100% PB, 4:1 PB: PM and 4:1 1.9 cm (0.75 in) CCR:PM. Fine particles (0.00–0.50 mm) were greatest in 4:1 PB:PM, 4:1 1.3 cm (0.50

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

		Substrate[y]					
U.S. standard sieve no.	Sieve opening (mm)[z]	100% PB	100% 1.9 cm (0.75 in) CCR	100% 1.3 cm (0.50 in) CCR	4:1 PB:PM	4:1 1.9 cm (0.75 in) CCR:PM	4:1 1.3 cm (0.50 in) CCR:PM
1/2	12.50	0.7a[x]	0.4a	0.0a	0.0a	0.5a	0.1a
3/8	9.50	0.3b	1.4a	0.2b	0.0b	1.1a	0.4b
1/4	6.35	8.9ab	10.1a	3.3c	8.3b	8.5ab	2.9c
6	3.35	32.4a	32.2a	29.6ab	30.1ab	31.8a	27.0b
8	2.36	16.1d	20.6b	22.1a	15.1d	18.7c	20.2b
10	2.00	5.7e	7.6c	8.8a	5.3e	6.9d	8.1b
14	1.40	11.8bcd	11.3cd	14.4a	12.0bc	10.8d	12.8b
18	1.00	7.9a	6.4b	8.3a	8.7a	6.8b	8.0a
35	0.50	9.8b	5.9c	7.8bc	13.0a	8.7b	10.2b
60	0.25	4.0abc	2.4c	3.2bc	5.1ab	4.0abc	6.1a
140	0.11	1.1b	1.1b	1.4b	1.8b	1.6b	3.4a
270	0.05	0.7a	0.4b	0.4b	0.4b	0.4b	0.6a
pan	0.00	0.6a	0.2a	0.5a	0.2a	0.2a	0.2a
Texture[w]							
Coarse		42.4ab	44.3a	33.3cd	38.3bc	42.0ab	30.4d
Medium		41.5d	45.8c	53.5a	41.1d	43.1d	49.1b
Fine		16.1ab	9.9c	13.2bc	20.6a	14.9b	20.5a

[z]1 mm = 0.0394 in.

[y]PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 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 = 3.35–12.50 mm; Medium = 1.00–2.36 mm; Fine = 0.00–0.50 mm.

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

	Poplarville, MS					
	15 DAP[y]		32 DAP		63 DAP	
Substrate[z]	EC (mS·cm⁻¹)[x]	pH	EC (mS·cm⁻¹)	pH	EC (mS·cm⁻¹)	pH
100% PB	1.01[w,ns]	6.2b	0.13b	6.4[ns]	0.15[ns]	6.2b
100% 1.9 cm (0.75 in) CCR	0.88	6.5a	0.18b	6.6	0.15	6.6a
100% 1.3 cm (0.50 in) CCR	1.03	6.5a	0.19b	6.7	0.12	6.6a
4:1 PB:PM	1.07	5.9c	0.32a	6.2	0.09	5.7c
4:1 1.9 cm (0.75 in) CCR:PM	1.20	6.3b	0.17b	6.5	0.13	6.1b
4:1 1.3 cm (0.50 in) CCR:PM	1.04	6.4a	0.19b	6.6	0.09	6.3ab
	Auburn, AL					
	14 DAP		28 DAP		60 DAP	
	EC (mS·cm⁻¹)	pH	EC (mS·cm⁻¹)	pH	EC (mS·cm⁻¹)	pH
100% PB	0.54[ns]	5.9b	0.25c	5.9c	0.71[ns]	5.2c
100% 1.9 cm (0.75 in) CCR	0.54	6.5a	0.43b	6.5ab	0.67	5.8ab
100% 1.3 cm (0.50 in) CCR	0.55	6.3a	0.53ab	6.6a	0.81	6.1a
4:1 PB:PM	0.55	5.6 c	0.66 a	6.2bc	0.54	5.0c
4:1 1.9 cm (0.75 in) CCR:PM	0.52	6.3a	0.53ab	6.3abc	0.48	5.2bc
4:1 1.3 cm (0.50 in) CCR:PM	0.58	6.2a	0.50ab	6.3abc	0.63	4.9c

[z]PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 in.

[y]DAP = days after planting.

[x]1 mS·cm⁻¹ = 1 mmho·cm⁻¹.

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

[ns]Means not significantly different.

in) CCR:PM and 100% PB, though 100% PB was not different from 100% 1.3 cm (0.50 in) CCR or 4:1 1.9 cm (0.75 in) CCR:PM. Substrates composed of 100% 1.9 cm (0.75 in) CCR had the least amount of fine particles. Small particles in the substrate contribute to water-holding capacity (2). Too many small particles will render the substrate water-logged and too few will result in the substrate needing frequent irrigation. Potential exists with CCR to manipulate these parameters for the needs of each crop by processing CCR at different screen sizes, mixing to enhance physical properties, and creating prescription substrates. For example, a substrate with a large percentage of fine particles may hold more water than a coarser substrate, but a small amount of large particles would need to be added in for aeration, depending on cultural requirements for the crop.

pH and EC. Substrate pH at both locations remained within recommended levels of 4.5–6.5 (12) for the duration of the study (Table 3). Substrates composed of 4:1 PB:PM tended to have the lowest pH at both locations across most sample dates. Substrates with 100% CCR tended to have highest pH at both locations and most sample dates, though they were acceptable for plant culture. EC levels at Poplarville were slightly high at 15 DAP (0.88–1.20 mS·cm⁻¹; recommended range: 0.5–1.0 mS·cm⁻¹). By 32 DAP and for the duration of the study EC levels were below recommended levels (0.09–0.32 mS·cm⁻¹). At Auburn EC levels were within acceptable levels from 14 DAP through 60 DAP. Wright and Browder (14) reported that EC of a pine chip (predominantly wood fiber) substrate solution was generally lower than that of PB, possibly due to greater leaching with the more porous pine chip. Data presented in the current study differ in that EC readings were generally similar among treatments at both sites. This is most likely due to the presence of approximately 40% PB in CCR material.

Growth indices (GI). There were no differences among treatments for GI of buddleia at Poplarville at either 64 or 102 DAP (Table 4). At 61 DAP buddleia grown at Auburn were largest in 4:1 CCR:PM. However, at 97 DAP only plants grown in 100% 1.9 cm (0.75 in) CCR were smaller than other treatments though plants grown in 100% PB and 1.3 cm (0.50 in) CCR were similar in GI. For gaura at Poplarville, GI at 64 DAP was greatest in 4:1 PB: PM, though 100% PB and 4:1 1.9 cm (0.75 in) CCR:PM were similar. By 106 DAP gaura plants grown in 4:1 PB:PM had the most growth. Gaura at Auburn showed that at 61 and 97 DAP GI of plants grown in 100% 1.9 cm (0.75 in) CCR were smaller than all other treatments. Gaura plants grown in substrates containing combinations of CCR:PM or PB had similar plant GI and SDW. Coreopsis plants at Poplarville had similar GI at both 64 and 103 DAP. Growth indices of coroepsis at Auburn were smallest in 100% CCR treatments at 61 DAP. By 97 DAP there were no differences in GI among treatments. Verbena at Poplarville had minor differences in growth indices at 64 DAP (4:1 1.3 cm (0.50 in) CCR:PM being the largest), but at 103 DAP verbena in all treatments had similar GI. At 61 DAP in Auburn greatest GI for verbena occurred with 4:1 PB:PM though the CCR:PM blends were similar to PB:PM. At 97 DAP all verbena had similar GI. There were no differences

Table 4. Effects of pine bark-based and clean chip residual-based substrates on growth indices[z] of *Buddleia davidii* 'Pink Delight', *Gaura lindheimeri* 'Siskiyou Pink', *Coreopsis grandiflora* 'Early Sunrise' (Poplarville), *Coreopsis rosea* 'Sweet Dreams' (Auburn), *Verbena canadensis* 'Homestead Purple', *Scabiosa columbaria* 'Butterfly Blue', *Dianthus gratianopolitanus* 'Firewitch', *Rosmarinus officinalis* 'Irene', and *Salvia guaranitica* 'Black and Blue' (Poplarville only) grown concurrently at two locations.

	Poplarville, MS															
	Buddleia		*Gaura*		*Coreopsis*		*Verbena*		*Scabiosa*		*Dianthus*		*Rosmarinus*		*Salvia*	
Substrate[y]	**64 DAP[x]**	**102 DAP**	**64 DAP**	**106 DAP**	**64 DAP**	**103 DAP**	**64 DAP**	**103 DAP**	**64 DAP**	**109 DAP**	**64 DAP**	**109 DAP**	**64 DAP**	**109 DAP**	**64 DAP**	**106 DAP**
100% PB	55.7[w,ns]	66.4[ns]	28.2ab	24.8b	32.3[ns]	37.4[ns]	45.7ab	82.3[ns]	16.9[ns]	21.8[ns]	14.4a	18.2a	34.5[ns]	53.7[ns]	36.4ab	43.4[ns]
100% 1.9 cm (0.75 in) CCR	57.4	65.1	23.8c	22.8b	31.3	34.9	45.8ab	85.3	16.0	22.0	13.4b	16.6cd	32.1	51.1	31.4c	42.2
100% 1.3 cm (0.50 in) CCR	60.0	68.3	25.4bc	22.8b	31.3	34.9	42.1b	86.8	15.8	20.8	13.4b	16.1d	31.8	52.8	34.3abc	41.2
4:1 PB:PM	55.2	68.9	32.4a	28.6a	33.8	37.0	46.3ab	84.8	18.5	21.5	14.8a	18.0ab	34.3	49.6	37.1a	45.6
4:1 1.9 cm (0.75 in) CCR:PM	56.7	69.5	28.2ab	24.1b	31.6	34.8	46.6ab	84.1	16.4	23.2	13.6b	17.2bc	33.6	54.1	34.0abc	41.7
4:1 1.3 cm (0.50 in) CCR:PM	63.0	67.4	27.3bc	24.6b	32.2	37.8	49.1a	86.8	17.6	21.7	13.6b	16.7cd	33.7	50.3	33.7bc	41.7
	Auburn, AL															
	Buddleia		*Gaura*		*Coreopsis*		*Verbena*		*Scabiosa*		*Dianthus*		*Rosmarinus*		*Salvia*	
	61 DAP	**97 DAP**	**61 DAP**	**97 DAP**	**61 DAP**	**97 DAP**	**61 DAP**	**97 DAP**	**61 DAP**	**97 DAP**	**61 DAP**	**97 DAP**	**61 DAP**	**97 DAP**	—	—
100% PB	17.8b	49.6ab	27.9a	25.6a	32.7abc	38.4[ns]	51.8b	58.6[ns]	22.3ab	22.5abc	12.5a	14.9a	28.9b	36.7[ns]	—	—
100% 1.9 cm (0.75 in) CCR	13.3c	45.6b	21.1b	20.1b	27.7c	38.9	52.3b	60.1	20.2bc	21.1bc	10.5c	13.3bc	26.1b	37.7	—	—
100% 1.3 cm (0.50 in) CCR	15.0c	49.6ab	25.4ab	24.6ab	29.5bc	40.3	52.6b	59.6	17.8c	20.4c	10.4c	13.2c	33.8a	40.3	—	—
4:1 PB:PM	19.1b	53.2a	28.2a	26.8a	35.1a	41.1	59.3a	64.6	23.5a	23.9a	12.4a	14.3ab	32.9a	41.3	—	—
4:1 1.9 cm (0.75 in) CCR:PM	24.4a	53.1a	27.6a	26.4a	32.0abc	40.0	56.0ab	60.4	23.6a	23.4ab	11.5b	14.1abc	34.0a	39.7	—	—
4:1 1.3 cm (0.50 in) CCR:PM	23.8a	55.0a	28.6a	27.8a	32.9ab	39.3	56.1ab	64.0	21.9ab	22.6abc	11.7ab	14.5a	32.1a	37.7	—	—

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

[y]PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 in.

[x]DAP = days after planting.

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

[ns]Means not significantly different.

Table 5. Effects of pine bark-based and clean chip residual-based substrates on flower number of *Buddleia davidii* 'Pink Delight', *Gaura lindheimeri* 'Siskiyou Pink', *Coreopsis grandiflora* 'Early Sunrise' (Poplarville), *Coreopsis rosea* 'Sweet Dreams' (Auburn), *Verbena canadensis* 'Homestead Purple', *Scabiosa columbaria* 'Butterfly Blue', *Dianthus gratianopolitanus* 'Firewitch', and *Salvia guaranitica* 'Black and Blue' (Poplarville only) grown concurrently at two locations 64 days after planting.

Substrate[z]	*Buddleia*	*Gaura*	*Coreopsis*	*Verbena*	*Scabiosa*	*Dianthus*	*Salvia*
	Poplarville, MS						
100% PB	7.1[y,ns]	13.1ab	10.6ab	20.8a	11.3a	18.4a	11.5[ns]
100% 1.9 cm (0.75 in) CCR	7.5	6.1c	2.9c	15.0b	5.5c	9.3b	9.1
100% 1.3 cm (0.50 in) CCR	9.1	8.4bc	3.0c	12.9b	6.4bc	9.5b	8.5
4:1 PB:PM	6.1	15.9a	12.0a	22.1a	11.6a	18.0a	11.0
4:1 1.9 cm (0.75 in) CCR:PM	7.0	9.9bc	8.1b	13.4b	8.4b	14.5a	10.6
4:1 1.3 cm (0.50 in) CCR:PM	7.4	8.9bc	8.8ab	12.5b	6.1bc	8.9b	7.9
	Auburn, AL						
	Buddleia	*Gaura*	*Coreopsis*	*Verbena*	*Scabiosa*	*Dianthus*	*Salvia*
100% PB	2.9bc	9.6bc	37.5b	8.4c	4.1ab	7.4[ns]	—
100% 1.9 cm (0.75 in) CCR	3.3bc	5.6c	39.4b	12.4bc	3.0b	4.9	—
100% 1.3 cm (0.50 in) CCR	1.9c	5.9c	47.0b	10.8bc	1.8b	4.0	—
4:1 PB:PM	4.5b	11.1ab	69.5a	13.1bc	7.4a	8.9	—
4:1 1.9 cm (0.75 in) CCR:PM	9.4a	14.9a	48.1b	14.5ab	4.5ab	5.9	—
4:1 1.3 cm (0.50 in) CCR:PM	8.9a	15.4a	51.6b	19.8a	3.3b	7.3	—

[z]PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 in.

[y]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$.

[ns]Means not significantly different.

in GI for scabiosa at Poplarville at 64 or 109 DAP; however, with scabiosa at Auburn (61 DAP), 100% CCR treatments had less GI than plants in the remaining treatments. At 97 DAP the 100% CCR treatments still had smaller GI than plants in other treatments, but the growth gap was less than at 61 DAP. Dianthus at Poplarville had the greatest GI when grown in substrates containing PB at 64 DAP (4:1 1.9 cm (0.75 in) CCR:PM was similar to 4:1 PB:PM at 109 DAP). For dianthus at Auburn treatments containing CCR (except 4:1 1.3 cm (0.50 in) CCR:PM) had less growth at 61 DAP. By 97 DAP dianthus at Auburn had similar growth in PB substrates and substrates amended with PM. There were no differences in GI for rosmarinus at Poplarville at 64 or 109 DAP. Growth indices for rosmarinus at Auburn were least in 100% PB and 100% 1.9 cm (0.75 in) CCR at 61 DAP, but by 97 DAP there were no differences. There were minor differences among treatments for GI of Salvia at 64 DAP, but at 106 DAP all plants were similar.

Flower number. At 64 DAP there were no differences in flower number for buddleia grown at Poplarville (Table 5). At Auburn buddleia grown in substrates containing 4:1 CCR:PM had the most flowers at 63 DAP (average of 9.2). The least flowering occurred in the 100% CCR and 4:1 PB:PM treatments. For gaura at Poplarville flower numbers were greatest on plants grown 4:1 PB:PM though 100% PB was similar. Flower number data for gaura at Auburn showed the greatest number of flowers were in treatments containing PM. Coreopsis flowers at Poplarville were fewest for 100% CCR treatments (2.9–3.0) and greatest for plants grown in 4:1 PB:PM though 100% PB and 4:1 1.3 cm (0.50 in) CCR:PM were similar. Coreopsis at Auburn grown in 4:1 PB:PM had more flowers than all other treatments at 63 DAP which were similar. Verbena flower numbers at Poplarville were greatest in PB treatments while verbena at Auburn had the greatest number of flowers with CCR:PM. Flower numbers for scabiosa at Poplarville were greatest in PB treatments. Scabiosa plants at Auburn had the greatest flower numbers in treatments containing PB and 4:1 1.9 cm (0.75 in) CCR:PM, though 4:1 1.9 cm (0.75 in) CCR:PM and 100% PB were similar to all other treatments. Flower numbers of dianthus at Poplarville were greater with PB treatments and 4:1 1.9 cm (0.75 in) CCR:PM. There were no differences in flower number for dianthus plants grown at Auburn. There were no differences among treatments for flower number of salvia at Poplarville.

Shoot dry weight. Buddliea Shoot dry weights (SDW) at Poplarville were greatest with 4:1 PB:PM (58.1 g) (Table 6). Plants with the lowest SDW were in treatments containing CCR. Our data concur with results from a study by Fain et al. (5) which reported no differences in flower number of buddleia when grown in either a 100% PB or 0.95 cm (0.375 in) *WholeTree* (approximately 80% wood fiber) substrate at 90 DAP, however SDW was greater in buddleia plants grown in pine bark than those grown in *WholeTree* substrate. Shoot dry weight of buddleia at Auburn was greatest with 4:1 1.3 cm (0.50 in) CCR:PM. Plants with the lowest SDW were in 100% CCR treatments. Gaura SDW at Poplarville were greater in 4:1 PB:PM than all other treatments, which were similar. Guara plants at Auburn had the greatest SDW (29.0–31.8 g) in treatments with PM or 100% PB while 100% CCR treatments had the lowest SDW (13.3–18.5 g). Shoot dry weights of coreopsis at Poplarville were greatest for treatments containing PB and 4:1 1.3 cm (0.50 in) CCR:PM. Coreopsis at Auburn had the greatest SDW in 4:1 PB:PM while all other treatments were similar. Verbena plants grown at Poplarville had the greatest SDW with 4:1 PB:PM (74.2 g); however, 100% PB was similar. Shoot dry weight of verbena at Auburn was greatest in treatments containing

Table 6. **Effects of pine bark-based and clean chip residual-based substrates on shoot dry weight (g)[z] of *Buddleia davidii* 'Pink Delight', *Gaura lindheimeri* 'Siskiyou Pink', *Coreopsis grandiflora* 'Early Sunrise' (Poplarville), *Coreopsis rosea* 'Sweet Dreams' (Auburn), *Verbena canadensis* 'Homestead Purple', *Scabiosa columbaria* 'Butterfly Blue', *Dianthus gratianopolitanus* 'Firewitch', *Rosmarinus officinalis* 'Irene', and *Salvia guaranitica* 'Black and Blue' (Poplarville only) grown concurrently at two locations 110 days after planting.**

Substrate[y]	*Buddleia*	*Gaura*	*Coreopsis*	*Verbena*	*Scabiosa*	*Dianthus*	*Rosmarinus*	*Salvia*
	Poplarville, MS							
100% PB	49.6b[x]	32.6b	52.2a	70.8ab	19.4a	24.8a	56.9ab	35.1a
100% 1.9 cm (0.75 in) CCR	42.7c	28.5b	40.4b	63.3b	15.2ab	20.0b	45.3c	24.4b
100% 1.3 cm (0.50 in) CCR	42.6c	30.0b	38.4b	63.7b	13.2b	19.7b	48.7bc	26.4b
4:1 PB:PM	58.1a	44.1a	54.8a	74.2a	16.4ab	25.1a	61.7a	34.6a
4:1 1.9 cm (0.75 in) CCR:PM	47.7bc	33.9b	42.8b	64.7b	16.7ab	22.1ab	53.0abc	23.7b
4:1 1.3 cm (0.50 in) CCR:PM	45.0bc	31.6b	46.6ab	64.8b	13.4b	20.3b	55.6abc	26.6b
	Auburn, AL							
	Buddleia	*Gaura*	*Coreopsis*	*Verbena*	*Scabiosa*	*Dianthus*	*Rosmarinus*	*Salvia*
100% PB	45.7c	31.8a	24.6b	55.1d	12.5[ns]	11.2a	24.3bc	—
100% 1.9 cm (0.75 in) CCR	28.3d	13.3b	23.5b	61.4cd	12.0	9.2b	21.7c	—
100% 1.3 cm (0.50 in) CCR	31.2d	18.5b	25.4b	69.4bc	10.3	9.1b	32.3ab	—
4:1 PB:PM	48.5bc	30.1a	34.9a	81.8a	14.4	10.9a	33.7a	—
4:1 1.9 cm (0.75 in) CCR:PM	53.0b	29.7a	28.3b	74.7ab	14.6	10.5a	35.7a	—
4:1 1.3 cm (0.50 in) CCR:PM	59.6a	29.0a	26.6b	75.8ab	12.7	10.8a	28.0abc	—

[z]1 g = 0.0353 oz.

[y]PB = pine bark, CCR = clean chip residual, PM = sphagnum peat moss, 1 cm = 0.394 inch.

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$ (n = 6 for Poplarville, n = 8 for Auburn).

[w]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio *t* tests at $\alpha = 0.05$.

[ns]Means not significantly different.

PM. Scabiosa SDW at Poplarville indicated slight differences among treatments, with those containing 1.3 cm (0.50 in) CCR having less SDW; however, there were no differences in SDW for scabiosa plants grown at Auburn. Dianthus SDW was greatest in treatments containing PB or 4:1 1.9 cm (0.75 in) CCR:PM at Poplarville while SDW of dianthus grown at Auburn was the least in 100% CCR treatments; all other treatments were similar. Shoot dry weight of rosmarinus at Poplarville was greatest in 4:1 PB:PM (61.7 g) while 4:1 1.9 cm (0.75 in) CCR:PM (53.0 g), 4:1 1.3 cm (0.50 in) CCR:PM (55.6 g) and 100% PB (56.9 g) were similar. Rosmarinus plants grown at Auburn had the least SDW in 100% 1.9 cm (0.75 in) CCR (21.7 g), however 100% PB (24.3 g) and 4:1 1.3 cm (0.50 in) CCR:PM (28.0 g) were similar. Shoot dry weight of salvia at Poplarvile was greater for treatments containing PB.

In most cases, plants grown in CCR lagged slightly behind other treatments at early rating dates (30 and 60 DAP) for GI. This could potentially be due to early N tie-up in the wood fiber substrates (CCR). Fain et al. (6) suggested that an initial N sink in *WholeTree* substrates early in the crop cycle could explain differences in final growth of greenhouse-grown petunia (*Petunia* × *hybrida* Hort. Vilm.-Andr. 'Dreams Pink'). A study by Wright et al. (16) evaluated the growth of chrysanthemum (*Chrysanthemum* × *grandiflora* Tzvelv. 'Baton Rouge') under four N rates in order to overcome initial N-immobilization in a pine chip substrate (100% wood fiber). Results indicated that the pine tree substrate required 100 $mg \cdot L^{-1}$ N more fertilizer than a commercial peat-lite substrate to obtain comparable growth. Future studies will need to evaluate supplemental fertilizer rates in substrates composed of CCR in order to determine whether or not they are required. The current study suggests that the rate of control release fertilizer evaluated in this test is adequate to provide nutrients for plants grown in PB/PM blends, but plants grown in 100% CCR may require supplemental fertilizer to increase SDW (though GI for most plants were similar).

For Poplarville, 4:1 PB:PM produced the highest plant SDW in 4 of 8 species tested (buddleia, gaura, dianthus and salvia). At Auburn, 4:1 PB:PM produced the most SDW in 2 of 7 species (gaura and coreopsis). At Auburn, PM amended treatments produced similar growth in 5 of 7 species indicating that CCR is an adequate replacement for PB (when combined with PM) for several species of perennial ornamental crops. While minor differences in plant growth were measured, most were not detectable to the human eye when the treatments were de-randomized.

Concerns about high wood content substrates being detrimental to plant growth continue to be addressed by results of this study which concur with several other studies. Fain et al. (7) postulated that N immobilization was not a limiting factor in production of annual vinca (*Catharanthus roseus* (L.) G.Don) in *WholeTree* substrates when using slow release fertilizer. Instead, the differences in annual vinca growth between *WholeTree* and PB was more likely due to differences in substrate physical properties. Substrates composed of 100% PB or CCR had high AS and low WHC which results in less available water to plants. Addition of PM lowered AS and increased WHC. While the addition of PM may not be practical for outdoor container production of perennial crops due to high cost, it is promising that many species performed adequately in substrates composed of 100% PB or CCR. In this study, perennial crops produced in a traditional outdoor, overhead irrigated system performed sufficiently well whether grown in PB or CCR-based substrates when mixed with PM. However, each grower should conduct their own trial with CCR to determine performance at their nursery. While the results of the perennial species tested are positive, more species must be evaluated for growth in alternative substrates in order to continue substantiation of plant growth in wood-based substrates.

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