Extending Pine Bark Supplies with *Wholetree* and Clean Chip Residual Substrates[1]

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Abstract

A limited supply of pine bark (PB) over the past several years has caused concern among many nursery producers. In continuing the search for alternative substrates and working to quantify the extent to which substrates can be amended with high wood content alternatives, this study was developed to evaluate substrate treatments comprised of PB with 25, 50, and 75% clean chip residual (CCR) or *WholeTree* substrate (WT), as well as 100% substrates of each high wood fiber substrate. By 180 and 365 DAT, pH and electrical conductivity (EC) values for all treatments were similar to those of the 100% PB control. Growth data at 365 days after planting (DAT) showed that with all nursery crops tested, nursery producers could use 75% CCR or 75% WT in their standard PB substrate with limited impact on crop growth. The purpose of this study was to allow nursery producers the opportunity to become comfortable using CCR or WT as amendments before switching completely to 100% alternative substrates.

Index words: media, alternative, amendment, nursery, container-grown.

Species used in this study: 'New Gold' lantana (*Lantana camara* L. 'New Gold'); 'Gold Mound' spirea (*Spiraea japonica* L.f. 'Gold Mound'); 'Amaghasa' azalea (*Rhododendron* ×'Amaghasa' L.); tea olive (*Osmanthus fragrans* Lour.); 'Rotundifolia' ligustrum (*Ligustrum japonicum* Thunb. 'Rotundifolia'); 'Soft Touch' holly (*Ilex crenata* Thunb. 'Soft Touch').

Significance to the Nursery Industry

With the recent decline of pine bark (PB) supplies, and the threat of continued decline, nursery growers need alternative components or amendments for their standard growing substrate. Clean chip residual (CCR) and *WholeTree* substrate (WT) are two possible alternative substrates with commercialization possibilities. This study demonstrated that woody nursery crops grown in varying ratios of PB:CCR and PB:WT had similar growth to plants grown in a current nursery standard of 100% PB. This information will allow growers to develop plans for extending existing PB supplies with CCR or WT.

Introduction

Due to a number of factors, PB supplies have significantly decreased over the past few years (13). While alternative substrates have been evaluated (3, 4, 5, 6, 7, 8, 9, 11, 18), many growers are asking if these alternative substrates can be used to stretch existing PB supplies. In this study, two alternative substrates, CCR and WT were evaluated as amendments to PB to determine their effect on the growth of six common nursery crops. Both CCR and WT contain higher wood content than PB alone. CCR is composed of approximately 50% wood, 40% bark, and 10% needles (4), and is created when transportable in-field harvesters are used to process pine trees into 'clean chips' that are used by pulp mills. CCR is a by-product of pulp wood processing that is either sold for boiler fuel or more commonly, spread back across the harvested area. Several studies have been conducted to evaluate CCR as a viable alternative substrate. Three annual species ['Blue Hawaii' ageratum (*Ageratum houstonianum* Mill.), 'Vista Purple' salvia (*Salvia ×superba* Sellow *ex* J.A. Schultes), and 'Coral' or 'White' impatiens (*Impatiens wallerana* Hook.f.)] were evaluated in a greenhouse setting (5) in nine substrate treatments comprised of PB, peat moss, and CCR blends. At study termination, growth for two of the

[1]Received for publication April 30, 2010; in revised form July 9, 2010. This research was supported by **The Horticultural Research Institute, 1000 Vermont Avenue, NW, Suite 300, Washington, DC 20005**.

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three species was similar to standard PB substrates. Boyer et al. (4) evaluated eight perennial species in Auburn, AL, for growth in CCR; species evaluated included 'Pink Delight' buddleia (*Buddleia davidii* 'Pink Delight' Franch.), 'Siskiyou Pink' gaura (*Gaura lindheimeri* 'Siskiyou Pink' Engelm. & A. Gray), 'Sweet Dreams' coreopsis (*Coreopsis rosea* 'Sweet Dreams' Nutt.), 'Homestead Purple' verbena (*Verbena canadensis* 'Homestead Purple' (L.) Britt.), 'Butterfly Blue' scabiosa (*Scabiosa columbaria* 'Butterfly Blue' L.), 'Firewitch' dianthus (*Dianthus gratianopolitanus* 'Firewitch' Vill.), 'Irene' rosemary (*Rosemarinus officinalis* 'Irene' L.), and 'Black and Blue' salvia (*Salvia guaranitica* 'Black and Blue' St.-Hil. *ex* Benth.). The study was duplicated in Poplarville, MS, with few differences in growth at the conclusion of the study for most species. Growth indices were similar at Poplarville for 6 of 8 species and for 3 of 7 species at Auburn. In 2009, Boyer et al. (6) also reported on the use of CCR as a nursery crop substrate for container-grown ornamentals at several screen sizes (3.18, 1.91, 1.27, and 0.95 cm) (1.25, 0.75, 0.50, and 0.375 in, respectively). Five species were tested, including *Loropetalum chinensis* var. *rubrum* R. Br., *Buddleia davidii* 'Black Knight' Franch., *Lagerstroemia indica* L. 'Hopi', *Lagerstroemia ×fauriei* 'Natchez' Wallich ex Paxt., and *Rhododendron indicum* 'Mrs. G.G. Gerbing'. The study was conducted in two locations; Auburn, AL, and Poplarville, MS. Few differences were reported among loropetalum, buddleia, lagerstroemia, and rhododendron plants grown in CCR, compared to PB treatments. However, data indicated that treatments with larger particle sizes tended to have higher air space percentages, as well as lower water holding capacity percentages. Their data also indicated that root growth was greater in treatments with smaller particle sizes. Consistency among pH and EC levels suggested that CCR would be a dependable substrate comparable to PB.

The WT substrate (80% wood, 15% bark, 5% needles) is different from CCR in that it consists of the entire pine tree harvested from pine plantations at the thinning stage, therefore having a higher wood content than CCR (9). Just as with CCR, several studies have been conducted to assess the value of WT as a comparable substrate to traditional PB. In 2006, Fain and Gilliam reported that annual vinca (Catharanthus roseus (L.) G.Don 'Little Blanche')grown in WT had similar growth to plants grown in PB (7). While shoot dry mass was 15% higher for plants grown in 100% PB 60 days after planting, there were no differences in plant growth indices. Another study evaluating WT in production of five herbaceous greenhouse crops indicated that growth varied with the crop produced, but also showed that WT could have potential for becoming an acceptable, and highly economical, alternative to traditional peat moss based substrates (8). Plants were grown in treatments containing 100% WT ground to three different screen sizes (0.375, 0.25, or 0.187 in), as well as in treatments containing 1:1 and 4:1 WT:peatmoss ratios. At 34 DAP, there were no differences in flower number for marigold; however, lantana grown in 100% WT substrates had the fewest flowers. Petunias grown in an industry standard peat blend substrate had over twice the number of flowers than was observed on plants grown in other substrates. In general, plants grown in WT substrates were smaller than plants in other blends, but plants increased in size with increasing percentages of peat moss.

A recent study by Jackson et al. (2010) reported on the results of substrate physical properties and plant growth in treatments with combined amounts of wood particle sizes. Results from that study indicated that by combining no less than 50% small-particle-sized pine tree substrate (produced from whole pine trees that are chipped and ground, or with CCR) with that of coarse particles of pine tree substrate, an adequate container capacity of between 45–65% could be obtained (11). Their study also evaluated plant growth in pine tree substrate amended with either 10% sand, 25% peatmoss, 25% aged pine bark, or a sand/pine bark mix. The authors noted that while some differences occurred with respect to shoot dry weight, growth index, and root ratings, all plants performed well and exhibited no nutritional-related disorders.

While previous studies have indicated the possibilities of using CCR or WT as an alternative to PB in container production, many growers are uncomfortable with making such a drastic switch in substrate material. They are interested in the possibilities of adding CCR or WT to their existing PB, and want to know how much they could amend their PB in order to stretch their supplies, as well as any differences in performance between CCR and WT. Therefore, the objective of this study was to determine the extent to which PB could be amended with either CCR or WT without reducing plant growth of six woody ornamental species.

Materials and Methods

Nine substrate treatments utilizing varying levels of PB, CCR, and WT were evaluated. CCR and WT used in the study were each processed to pass through a 0.95 cm (3/8 in) screen. Treatments consisted of 100% PB, WT, and CCR, 75:25 PB:CCR, 50:50 PB:CCR, or 25:75 PB:CCR (v:v). PB:WT substrates had the same ratios as PB:CCR. All substrates were pre-incorporated with a 6:1 (v:v) ratio of sand, and amended 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., Lakeland, FL) 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).

Six species were used in the experiment, which was initiated on July 22, 2008. Species included 'New Gold' lantana (*Lantana camara* L. 'New Gold'), 'Gold Mound' spirea (*Spiraea japonica* L.f. 'Gold Mound'), 'Amaghasa' azalea (*Rhododendron* × 'Amaghasa'), tea olive (*Osmanthus fragrans* Lour.), 'Rotundifolia' ligustrum (*Ligustrum japonicum* Thunb. 'Rotundifolia'), and 'Soft Touch' holly (*Ilex crenata* 'Soft Touch'). Liners were transplanted from standard 32-cell packs into #1 containers and watered using overhead irrigation (1.27 $cm \cdot day^{-1}$) (0.5 $in \cdot day^{-1}$). Average pH of the irrigation water was between 6.7 and 7.0 for the duration of the study. Irrigation water electrical conductivity (EC) was 0.2 $mS \cdot cm^{-1}$, while alkalinity (HCO_3– $mg \cdot liter^{-1}$) was 80. All species were placed in full sun, except for 'Amaghasa' azaleas, which were placed under a 30% shade structure.

The experimental design was a randomized complete block design with 7 single pot replications per treatment. Each species was treated as its own separate experiment. Physical properties and particle-size distribution (PSD) were evaluated at the USDA-ARS Southern Horticultural Laboratory in Poplarville, MS (n = 3). Physical properties [substrate air space (AS), water holding capacity (WHC), total porosity (TP)] were determined using the North Carolina State University porometer method (10). Bulk density (BD) was determined from 347.5 cm^3 samples dried in a 105C (221F) forced air oven for 48 hours. The PSD was determined by passing a 100 g air-dried sample through a series of sieves. Sieves were shaken for three minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker. Shrinkage of substrates was evaluated at 15, 120 and 365 DAT by measuring distance (in cm) from the top of the pot to the top of the substrate. Leachates were collected from 'Amaghasa' azalea plants using the Virginia Tech PourThru technique (17). pH and EC ($mS \cdot cm^{-1}$) were measured at 7, 15, 30, 60, 90, 120, 180 and 365 days after transplanting (DAT). Growth indices [(height + width1 + width2) / 3] (cm) were measured at 90 and 365 DAT. Leaf chlorophyll content was quantified using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) at 30, 120 and 365 DAT. Root growth and general health was assessed at study termination (365 DAT) on a scale from 1–5, where 1 was assigned to plants with less than 20% root ball coverage, and 5 was assigned to plants with between 80–100% root ball coverage. Tissue nutrient content was determined using 25–30 recently matured leaves of lantana (n = 4). The concentration of nitrogen (N) in the leaves was determined by conducting combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining macronutrients, as well as micronutrients [phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu) and boron (B)] were quantified by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Data were analyzed using Tukey's Studentized Range Test ($p \leq 0.05$) in a statistical software package (SAS® Institute version 9.1.3, Cary, NC) (2). Studies were conducted at the AU Paterson Greenhouses at Auburn University, AL.

Results and Discussion

Physical properties. With only one exception at 36.4% (by vol) (75:25 PB:CCR), all container substrate AS percentages were within recommended ranges (10–30%) (16) (Table 1). Values were between 25 and 36.4%, with the lowest percentage at 25.1% (75:25 PB:WT). Subsequently, percent WHC for substrate treatments tended to be toward the low end of the recommended range of 45–65%. Treatments with WHC percentages below the recommended range included 100% PB (40.7%) and 100% WT (40.7%), as well as most treatments containing CCR. The only treatments within the WHC recommended range (45–65%) were 75:25 PB:WT (46.9%), 50:50 PB:WT (46.3%), 25:75 PB:WT (46.9%), and 25:75 PB:CCR (45.0%). The recommended range for TP in a container substrate is 50–85%. All treatment percentages of TP were similar to the 100% PB industry standard except for 75:25 PB:CCR (75.9%). Also with respect to TP, all v:v ratios of PB:WT were similar to their PB:CCR counterparts. Total porosity values for all treatments were within the recommended range. Bulk density for all substrates was also within BMP recommended range (0.19–0.70 $g \cdot cm^{-3}$) (16), although there were several differences across treatments. With two exceptions (50:50 PB:WT and 50:50 PB:CCR), treatments containing WT had higher BD values than their corresponding treatments containing CCR.

Particle size distribution analysis was broken down into three texture sizes, coarse (3.35–9.50 mm), medium (1.00–2.36 mm), and fine (0.00–0.50 mm). Particles greater than 3.35 mm afford aeration to container substrates (15). There were no differences in the amount of coarse particles of any substrate treatment (Table 2). Medium particles were greatest in substrates with increased levels of CCR (25:75 PB:CCR and 100% CCR, 41.4 mm and 44.9 mm, respectively). Medium particles were least in 100% PB (32.9 mm) and 75:25 PB:WT (34.1 mm). Only two treatments (75:25 PB:WT and 25:75 PB:WT, 34.1 and 36.3 mm, respectively) had similar amounts of medium particles compared to that of the 100% PB industry standard (39.2 mm). Fine particles in a container substrate greatly influence substrate water holding capacity (1). Container substrates with increased fine particles will often become water-soaked, while container substrates with too few fine particles will often dry out more

Table 1. Physical properties of nine substrates containing pine bark, clean chip residual, and *WholeTree* substrate[z].

Substrate[y]	Air space[x] (% vol)	Substrate water holding capacity[w] (% vol)	Total porosity[v] (% vol)	Bulk density[u] ($g \cdot cm^{-3}$)
100% PB	26.0b[t]	40.7cd	66.7b	0.37e
75:25 PB:CCR	36.4a	39.5d	75.9a	0.20f
50:50 PB:CCR	26.2b	41.3bcd	67.5b	0.39de
25:75 PB:CCR	26.3b	45.0abc	71.3ab	0.40cd
100% CCR	28.6b	43.3a–d	71.9ab	0.39de
75:25 PB:WT	25.1b	46.9a	72.1ab	0.45a
50:50 PB:WT	27.2b	46.3ab	73.4ab	0.39de
25:75 PB:WT	26.6b	46.9a	73.5ab	0.42b
100% WT	25.9b	40.7cd	66.6b	0.41bc
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, WT = *WholeTree*.

[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 substrate water holding capacity + air space.

[u]Bulk density after forced-air drying at 105C (221.0F) for 48 hrs; 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 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.

Table 2. Particle size distribution analysis of nine substrates containing pine bark, clean chip residual and *WholeTree* substrate.

U.S. standard sieve no.	Sieve opening (mm)[y]	Substrates[z]								
		100%PB	75:25 PB:CCR	50:50 PB:CCR	25:75 PB:CCR	100% CCR	75:25 PB:WT	50:50 PB:WT	25:75 PB:WT	100% WT
3/8	9.50	0.1a[x]	0.1a	0.0a	0.0a	0.0a	0.1a	0.3a	0.1a	0.0a
1/4	6.35	4.4a	3.7a	1.5b	0.6b	0.6b	1.2b	1.1b	0.8b	0.1b
6	3.35	15.8a	17.8a	15.9a	15.7a	17.5a	13.9a	19.2a	16.9a	18.3a
8	2.36	9.7d	13.5ab	12.5bc	13.6ab	14.9a	10.5cd	13.7ab	11.8bcd	12.9ab
10	2.00	4.0d	5.6ab	5.0bc	5.6ab	6.1a	4.0d	4.9bc	4.6cd	4.9bc
14	1.40	10.4d	12.1bc	11.7bcd	12.5ab	13.8a	10.4d	12.3abc	10.7cd	11.8bcd
18	1.00	8.8a	9.2a	9.4a	9.5a	10.0a	9.3a	9.5a	9.2a	9.6a
35	0.50	21.0a	16.2b	20.8a	20.9a	20.4a	23.2a	19.8a	21.9a	22.0a
60	0.25	14.8abc	9.3d	13.9abc	13.6abc	11.1cd	17.0a	12.0cbd	15.0ab	13.9abc
140	0.11	7.7abc	5.7abc	7.1abc	6.5abc	4.7c	8.4a	5.5bc	7.4ab	5.5bc
270	0.05	1.8b	2.8a	1.5bc	1.1cd	0.7d	1.4bc	1.1cd	1.2bcd	0.7d
pan	0.00	1.5b	3.9a	0.7c	0.4cde	0.2e	0.6cd	0.6cd	0.4de	0.3e
Texture[w]										
Coarse		20.4a	21.5a	17.4a	16.1a	18.1a	15.2a	20.6a	17.8a	18.4a
Medium		32.9d	40.5b	38.5bc	41.4ab	44.9a	34.1d	40.4b	36.3cd	39.2bc
Fine		46.7ab	38.0b	44.1ab	42.5ab	37.0b	50.7a	39.0b	45.9ab	42.4ab

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

[y]1 mm = 0.0394 in.

[x]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Tukey's Studentized Range Test at α = 0.05 (n = 3).

[w]Coarse = 3.35–9.50 mm; Medium = 1.00–2.36 mm; Fine = 0.00–0.50 mm.

quickly than desired (1). All substrate treatments had similar fine particle weights to that of the nursery standard, 100% PB (46.7 mm).

Shrinkage. No differences occurred for shrinkage between any container substrate treatment at any of the three testing dates (15, 180 and 365 DAT) (data not shown). Throughout the study, shrinkage for all substrates increased steadily for an overall average of 1.53 cm. This is most likely due to the natural settling of the substrate in the container. Settling may be increased due to the large amount of air space in each substrate. Some shrinkage may also be due to microbial activity (12).

pH and EC. With few exceptions, substrate pH remained within BMP recommended levels of 4.5–6.5 (16) for the duration of the study (Table 3). Increasing levels of CCR and WT tended to raise substrate pH compared to PB alone. While pH of 100% WT substrate was slightly out of the desired range at 30 and 60 DAT (6.6 and 6.9), PB:WT blends were well within range. Only at three times were pH levels of substrates with CCR out of the recommended range [25:75 PB:CCR at 15 DAT (6.7), 100% CCR at 60 DAT (6.6) and 100% CCR at 120 DAT (6.6)]. At both 180 and 365 DAT, no treatment had dissimilar pH values than that of the 100% PB industry standard. Data indicates that CCR and WT additives may raise pH levels to the top of the desired range, but in general, levels will still be sufficient for plant culture.

Best management practice suggests a recommended range of 0.5–1.0 $mS \cdot cm^{-1}$ for EC values (16). At 7 DAT, EC levels were slightly elevated for all treatments, except for 25:75 PB:WT (0.86 $mS \cdot cm^{-1}$) (Table 3). At 15 DAT, EC levels began to decrease as a whole, however treatments with greater amounts of PB still tended to stay slightly out of range [100% PB (1.12 $mS \cdot cm^{-1}$), 75:25 PB:WT (1.10 $mS \cdot cm^{-1}$), 75:25 PB:CCR (1.28 $mS \cdot cm^{-1}$)]. This data concurs with a study by Wright and Browder (18) in an evaluation of chipped pine logs as a container substrate. Data from that study indicated that EC readings of treatments with pine chips were lower than that of treatments with pine bark, possibly due to the increased porosity (greater leaching) and greater nutrient retention by the pine chips. By 30 DAT, EC levels were similar across all treatments. Some treatment differences occurred at 60, 90, and 120 DAT, but there was no obvious trend to those differences. After 180 DAT, there were no differences among any substrate EC levels.

Growth indices (GI). At 90 DAT, growth indices for all species, in all substrates, were similar to, or larger than, plants grown in 100% PB (Table 4). By 365 DAT in the current study, there were no differences in GI of 'Amaghasa' azalea, 'Rotundifolia' ligustrum, 'Gold Mound' spirea, and tea olive in any substrate. For 'New Gold' lantana, GI of plants in all substrates were similar to GI of plants in 100% PB (71.8). For 'Soft Touch' holly at 365 DAT, 75:25 PB:WT (20.6), 50:50 PB:CCR (18.9) and 100% CCR (19.6) were the only substrate treatments to be similar to plant GI in 100% PB (22.9). 'Soft Touch' holly was slightly smaller when grown in the following substrates compared to 100% PB (22.9); 50:50 PB:WT (18.2), 25:75 PB:WT (17.7), 100% WT (16.4), 75:25 PB:CCR (18.0), and 25:75 PB:CCR (17.2).

SPAD. At 30 DAT, SPAD values were similar among all substrate treatments for all species except tea olive (data not shown). However, all substrate treatments were similar to 100% PB with respect to tea olive. At 120 DAT, SPAD values were similar for all substrate treatments for 'Amaghasa' azalea, 'Soft Touch' holly, 'New Gold' lantana, and 'Gold Mound' spirea. The only treatment that was different from the 100% PB standard (66.0) in 'Rotundifolia' ligustrum was

100% WT (55.1). SPAD values in all substrates for tea olive (at 120 DAT) were similar to 100% PB (43.6). By 365 DAT, there were no differences in SPAD values for any species. Comparatively, leaf chlorophyll content data from this study concurs with earlier work with CCR. By the end of a study (371 DAT) evaluating four varying particle sizes [3.2, 1.9, 1.3, and 1.0 cm (1.25, 0.75, 0.50, and 0.38 in, respectively)] of CCR as 100% alternative substrates, no differences were found for SPAD values across treatments compared to a 100% PB industry standard (3).

Root ratings. There were no differences in root ratings across substrates in any species (data not shown). With the exception of 'Soft Touch' holly, root ratings were high (above 4.7 for 'Amaghasa' azalea, 'New Gold' lantana, 'Rotundifolia' ligustrum and 'Gold Mound' spirea). Root growth in all treatments with 'Soft Touch' holly, including the 100% PB industry standard, was low (from 2.1 to 3.3), indicating that the lack of root growth was probably not a result of any specific substrate.

Tissue nutrient content. A search of the literature revealed no published tissue nutrient sufficiency range for 'New Gold' lantana. However, a survey range for macronutrients and micronutrients was located for 'Homestead Purple' verbena (*Verbena* × 'Homestead Purple'), which is in the same family (Verbenaceae) as 'New Gold' lantana (14). Tissue nutrient percentages for N were all within the survey range (2.71–3.99%), and no treatments were different from the 100% PB standard (Table 5). Values for P (0.21–0.28%) were slightly lower than those in the 'Homestead Purple' verbena survey range of 0.44–0.76%. The only treatment differing from the 100% PB treatment (0.28%) was 25:75 PB:CCR (0.21%). For the most part, K content was less than the survey range (2.24–4.75%), as only two treatments [100% PB (2.28%) and 75:25 PB:CCR (2.24%)] fell within the range. However, no differences occurred across treatments with respect to K content. Calcium content (1.47–1.69%) was slightly higher than the survey range (1.18–1.25%), although there were no differences among treatments. All reported values for Mg content were within the survey range (0.55–0.79%), and no differences occurred among treatments. With respect to micronutrients, Mn, Zn, and Cu levels (132–530, 171–294, and 33–51 ppm, respectively) were all higher than those given in the survey range (59–124, 59–141, and 9–23 ppm, respectively). There were only three treatments similar to the 100% PB standard (530 ppm) with respect to Mn [50:50 PB:WT (451 ppm), 100%WT (387 ppm), and 75:25 PB:CCR (445 ppm)]. All other treatments had much lower Mn values. The 100% PB industry standard had the lowest reported Zn value (171 ppm) of all treatments. There were no differences among treatments with respect to Cu. Tissue nutrient content values for B were all within the survey sufficiency range (37–48 ppm), and no differences occurred across treatments.

Table 3. Solution pH and substrate electrical conductivity (EC) for nine substrates containing pine bark, clean chip residual, and *WholeTree* substrate[z].

	7 DAT[x]		15 DAT		30 DAT		60 DAT	
Substrate[y]	pH	EC (mS·cm^{-1})[w]	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})
100% PB	6.0[v,ns]	1.39ab	6.5ab	1.12ab	6.0[ns]	0.77ab	6.3c	0.57ab
75:25 PB:CCR	6.2	1.60a	6.3b	1.28a	6.2	0.95a	6.3c	0.72a
50:50 PB:CCR	6.3	1.28ab	6.3b	0.96ab	6.4	0.54bc	6.4bc	0.58ab
25:75 PB:CCR	6.4	1.20ab	6.7a	0.62b	6.1	0.66abc	6.5bc	0.42ab
100% CCR	6.3	1.03ab	6.5ab	0.75ab	6.5	0.40bc	6.6b	0.37b
75:25 PB:WT	6.2	1.51a	6.3b	1.10ab	6.1	0.74ab	6.3c	0.61ab
50:50 PB:WT	6.3	1.24ab	6.4ab	0.91ab	6.1	0.41bc	6.5bc	0.39b
25:75 PB:WT	6.4	0.86b	6.5ab	0.97ab	6.4	0.13bc	6.5bc	0.39b
100% WT	6.3	1.10ab	6.5ab	0.82ab	6.6	0.35c	6.9a	0.34b
	90 DAT		**120 DAT**		**180 DAT**		**365 DAT**	
Substrate	**pH**	**EC (mS·cm^{-1})**	**pH**	**EC (mS·cm^{-1})**	**pH**	**EC (mS·cm^{-1})**	**pH**	**EC (mS·cm^{-1})**
100% PB	6.0d	0.47ab	6.2[ns]	0.45b	6.3[ns]	0.53[ns]	5.7ab	0.21[ns]
75:25 PB:CCR	5.9d	0.62b	6.3	0.66a	6.2	0.83	5.5b	0.28
50:50 PB:CCR	6.2bcd	0.38a	6.3	0.47b	6.2	0.56	6.0a	0.23
25:75 PB:CCR	6.5ab	0.39b	6.4	0.37b	6.4	0.61	5.9ab	0.25
100% CCR	6.5ab	0.32b	6.6	0.36b	6.5	0.42	5.8ab	0.27
75:25 PB:WT	6.1cd	0.43b	6.3	0.43b	6.2	0.82	5.8ab	0.20
50:50 PB:WT	6.4abc	0.37b	6.3	0.42b	6.4	0.58	5.8ab	0.22
25:75 PB:WT	6.6a	0.39b	6.3	0.42b	6.5	0.58	5.8ab	0.23
100% WT	6.5a	0.35b	6.3	0.36b	6.4	0.46	5.9ab	0.26

[z]pH and EC of solution determined using pour-through method on 'Amaghasa' azalea.

[y]PB = pine bark, CCR = clean chip residual, WT = *WholeTree*.

[x]DAT = days after transplanting.

[w]1 mS·cm^{-1} = 1 mmho·cm^{-1}.

[v]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range (HSD) Test at α = 0.05 (n = 4).

[ns]Means not significantly different.

Table 4. **Effect of nine substrates containing pine bark, clean chip residual, and *WholeTree* substrate on growth indices[z] of six ornamental species.**

Substrate[y]	'Amaghasa' azalea 90 DAT[x]	'Amaghasa' azalea 365 DAT	'Soft Touch' holly 90 DAT	'Soft Touch' holly 365 DAT	'New Gold' lantana 90 DAT	'New Gold' lantana 365 DAT
100% PB	15.1[w,ns]	39.4[ns]	10.7[ns]	22.9a	58.9ab	71.8ab
75:25 PB:CCR	14.5	40.4	10.3	18.0b	64.1ab	81.9a
50:50 PB:CCR	14.7	41.5	10.4	18.9ab	66.4a	75.6ab
25:75 PB:CCR	13.5	35.4	9.0	17.2b	62.3ab	68.8ab
100% CCR	13.9	39.6	10.3	19.6ab	56.0ab	63.0b
75:25 PB:WT	14.6	41.1	10.9	20.6ab	67.4a	76.8ab
50:50 PB:WT	14.9	39.7	9.0	18.2b	61.8ab	75.6ab
25:75 PB:WT	14.2	37.8	10.3	17.7b	58.3ab	76.3ab
100% WT	13.9	37.3	9.3	16.4b	52.6b	78.6ab

Substrate[y]	'Rotundifolia' ligustrum 90 DAT	'Rotundifolia' ligustrum 365 DAT	'Gold Mound' spirea 90 DAT	'Gold Mound' spirea 365 DAT	tea olive 90 DAT	tea olive 365 DAT
100% PB	21.6[ns]	64.6[ns]	30.6[ns]	56.7[ns]	24.9[ns]	46.2[ns]
75:25 PB:CCR	23.4	67.1	38.8	62.7	23.0	47.0
50:50 PB:CCR	22.0	60.7	34.4	61.5	24.5	47.8
25:75 PB:CCR	21.4	61.5	29.5	56.8	19.8	49.7
100% CCR	22.8	66.7	35.5	61.1	23.2	47.4
75:25 PB:WT	22.0	63.0	32.3	58.2	26.3	48.7
50:50 PB:WT	25.5	55.9	35.3	61.7	23.0	50.0
25:75 PB:WT	22.2	60.0	31.6	59.6	22.1	49.7
100% WT	21.9	61.2	33.9	59.6	21.3	47.7

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

[y]PB = pine bark, CCR = clean chip residual, WT = *WholeTree*.

[x]DAT = days after transplanting.

[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 = 7).

[ns]Means not significantly different.

Plant growth in substrates amended with up to 75% alternative substrate (either CCR or WT) was acceptable and comparable to those grown in 100% PB industry standard for all species tested. Nursery producers are interested in the finished product, and whether or not that finished product is any different from ones they have been growing for years. These data indicate that growers could amend their standard PB substrate with up to 75% CCR or WT with little difference in plant growth and overall root health compared to plants grown in a PB substrate.

Table 5. **Tissue nutrient content of *Lantana camara* L. 'New Gold' grown in nine substrates containing pine bark, clean chip residual and *WholeTree* substrate.**

Substrate[z]	Tissue nutrient content[y] N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm[x])	Zn (ppm)	Cu (ppm)	B (ppm)
100% PB	3.53ab[w]	0.28a	2.28[ns]	1.69[ns]	0.67[ns]	530a	171c	44[ns]	42[ns]
75:25 PB:CCR	3.63ab	0.26ab	2.24	1.62	0.65	445ab	211bc	47	46
50:50 PB:CCR	3.66a	0.22ab	2.03	1.51	0.64	191cd	218bc	43	40
25:75 PB:CCR	3.46ab	0.21b	1.94	1.47	0.62	132d	194bc	41	38
100% CCR	3.43ab	0.22ab	2.02	1.50	0.66	199cd	236b	33	40
75:25 PB:WT	3.58ab	0.24ab	2.11	1.64	0.64	336bc	195ab	37	47
50:50 PB:WT	3.47ab	0.24ab	2.16	1.56	0.63	451ab	234b	51	41
25:75 PB:WT	3.34b	0.22ab	2.05	1.53	0.63	159d	202bc	34	39
100% WT	3.49ab	0.24ab	2.12	1.66	0.63	387ab	294a	50	39
Sufficiency range[v]	2.71–3.99	0.44–0.76	2.24–4.75	1.18–1.25	0.55–0.79	59–124	59–141	9–23	37–48

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

[y]Tissue analysis performed on 15 most recently matured leaves per plant on October 21, 2008 (appx. 90 DAT); N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Mn = manganese, Zn = zinc, Cu = copper, B = boron.

[x]1 ppm = 1 $mg \cdot kg^{-1}$.

[v]Sufficiency range of 'Homestead Purple' Verbena (family Verbenaceae) published by Mills and Jones (1996).

[w]Means within column followed by the same latter are not significantly different based on Tukey's Studentized Range Test at $\alpha = 0.05$ (n = 7).

[ns]Means not significantly different.

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