

# Evaluation of Composted Poultry Litter as a Substrate Amendment for WholeTree, Clean Chip Residual, and Pinebark for Container Grown Woody Nursery Crops<sup>1</sup>

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## Abstract

WholeTree (WT) and clean chip residual (CCR) are potential new nursery substrates that are by-products of the forestry industry containing high wood content. Initial immobilization of nitrogen is one concern when using these new substrates; however the addition of composted poultry litter (CPL) to substrates containing high wood content could balance initial nitrogen immobilization and provide an inexpensive fertilizer source for growers. This study evaluated five woody nursery species being grown in WT, CCR, and pinebark (PB) with the addition of CPL or peat as a substrate amendment. Results indicate that these species can be grown successfully in WT and CCR substrates 6:1 (by vol) with CPL. Use of CPL in WT and CCR substrates may provide an alternative to traditional PB plus peat based combinations in container plant production while providing poultry producers an environmentally sound means of waste disposal.

**Index words:** composted poultry litter, alternative substrates, woody ornamentals, nursery production, peat moss.

**Species used in this study:** azalea (*Rhododendron* × 'Iveryana' and *Rhododendron* × 'Amelia Rose'); boxwood (*Buxus sempervirens* L.); holly (*Ilex crenata* Thunb. 'Compacta'); loropetalum (*Loropetalum chinense* Oliv. 'Chang's Ruby'); and ternstroemia (*Ternstroemia gymnanthera* Thunb. and *Ternstroemia gymnanthera* 'Bronze Beauty').

## Significance to the Nursery Industry

This study evaluated composted poultry litter (CPL) as an amendment with pine bark (PB), WholeTree (WT), and clean chip residual (CCR) substrates for use in container production of five woody ornamental species. Results indicate that these species can be grown in WT and CCR substrates 6:1 (by vol) with CPL. Use of CPL in WT and CCR substrates could provide an alternative to traditional PB and peat based combinations in container production while providing poultry producers an environmentally sound means of waste disposal.

## Introduction

Pine bark and PB plus peat combinations are the predominant substrate components for container plant production in the southeastern United States (5). Reduced forestry production in the United States paired with the increased use of PB as a fuel source is reducing the availability of PB (17). The growing concern over future availability of PB, high shipping costs associated with peat and the argument that peat is a non-renewable resource, has led to the exploration for alternatives to these two commonly used substrate components (3, 12).

WholeTree consists of entire pine trees (*Pinus taeda* L.) that are harvested from pine plantations at the thinning stage, chipped whole and later hammermilled through specific screen sizes based upon crop specification (10). WholeTree (~90% wood fiber) is made up of wood, bark, limbs, needles, and cones. Studies suggest WT can be used successfully in production of greenhouse crops (10, 11).

Mobile field equipment is now being used for in-field pine tree harvesting operations that process trees into 'clean chips' for pulp mills, leaving behind a residual material composed of about 50% wood, 40% bark, and 10% needles (3). This material, referred to as clean chip residual (CCR) is either sold as boiler fuel or spread back across the harvested area. Clean chip residual accounts for about 25% of the total biomass harvested. With millions of acres in the southeast United States in forestry production, CCR has the potential to provide an economical and sustainable substrate alternative for the nursery industry (5).

The major concern associated with the use of a wood based substrate is the initial immobilization of nitrogen. Reports indicate that substrates containing high wood content require higher fertilizer applications to achieve similar plant growth as standard bark or peat based substrates (12, 13, 15, 27). In a study by Jackson and Wright (16), plants grew less in pine tree based substrate (approximately 95% wood) due to severe nitrogen immobilization. However, Boyer et al. (4) reported similar microbial respiration in CCR and PB during a 60 day production cycle, indicating that plant production in CCR, a high wood fiber substrate, did not result in nitrogen immobilization. Fain et al. (12) reported that with adequate starter nutrient charge, WT was an acceptable substrate component for production of petunia (*Petunia* × *hybrida* Vilm.) and marigold (*Tagetes patula* L.).

One of the problems in modern agricultural operations is the large amount of waste generated by intense animal production in concentrated areas. Historically, land application was the preferred method of poultry waste disposal with almost 90% of all poultry litter being applied to agricultural

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land (7). The U.S. Environmental Protection Agency (EPA) has passed new regulations which now require larger poultry operations (> 100,000 birds) or operations within close proximity to water sources such as lakes, streams, rivers, and ground-water supplies, to obtain permits for manure disposed according to a nutrient management plan (9). For example, the average livestock operation in the Mid-Atlantic states will have to increase the amount of land used for spreading animal manures from 28 to 161 hectares (69 to 398 acres) in order to meet a nitrogen-based application standard (18). In areas where poultry production is intense and concentrated, such as in the southeastern United States, excess manure exists and limits placed on the amount of litter that can be land applied on an annual basis leaves poultry producers in need of new economical ways to safely dispose of waste.

Poultry litter has higher concentrations of nutrients than other animal wastes, is relatively dry (easily mixed with substrates) and is totally collectable (22). Typical poultry litter has the following nutrient ranges: nitrogen from 2.1 to 6.0%, phosphorus from 1.4 to 9.0%, potassium from 0.8 to 6.2%, calcium from 0.8 to 6.1%, magnesium from 0.2 to 2.1%, and sulfur from 0.1 to 0.8%, on a dry-weight basis (20). Research has shown that composted organic material has the potential to improve the physical and chemical properties of container substrates (14, 23). In studies by Bilderback and Fonteno (2), growth of *Cotoneaster dammeri* C.K. Schneid was improved when grown in a substrate composed of PB, rockwool, and CPL when compared to plants grown in substrates containing only PB. In a study by Tyler et al. (24) *Cotoneaster dammeri* C.K. Schneid. 'Skogholm' and *Hermerocallis* sp. 'Red Magic' grew as well in substrates amended with composted turkey litter as plants grown in a 100% pinebark substrate.

Fertilizer becomes more expensive with the rising cost of natural gas, the primary raw material used to produce ammonium nitrate (25). National composite fertilizer prices increased 113% between 2000 and 2007 due to increases in nitrogen costs. During this seven-year period the price of ammonium nitrate, the main source of nitrogen in fertilizer production, increased 130% and the price of urea, the primary solid nitrogen fertilizer used in the United States, rose 127% (25). The USDA Economic Research Service reported a 20% rise in national fertilizer prices in 2007 and an 18% increase at the end of 2008.

As fertilizer prices continue to rise, searching for alternatives to conventional fertilizers is important. Use of CPL in wood based substrates could potentially negate any possible initial nitrogen immobilization and provide the nursery industry with a valuable substrate component as well as a low cost nutrient supplement. In addition, poultry producers would have a more environmentally friendly means of waste disposal.

The objective of this study was to evaluate WT, CCR and PB with the addition of CPL as a substrate for production of container-grown nursery crops.

## Materials and Methods

**Experiment 1.** Experiment 1 was conducted at the Auburn University Ornamental Horticulture Research Center, located in Mobile, AL. Five species [*Rhododendron* × 'Ivoryana' (azalea), *Buxus sempervirens* L. (boxwood), *Ilex crenata* Thunb. 'Compacta' (holly), *Loropetalum chinense* Oliv. 'Chang's Ruby' (loropetalum), and *Ternstroemia gym-*

*nanthera* Thunb. (ternstroemia)] were transplanted from cell pack liners (72, 48, 38, 50, and 50 cell pack liners, respectively) into 3.8 liter (#1) containers on May 31, 2007, placed in full sun and overhead irrigated as needed. Treatments consisted of nine substrates composed of varying ratios of PB, WT, CCR, CPL, and Peat: WT:CPL (6:1 by vol), CCR:CPL (6:1 by vol), PB:CPL (6:1 by vol), 100% WT, 100% CCR, 100% PB, WT:Peat (6:1 by vol), CCR:Peat (6:1 by vol), and PB:Peat (6:1 by vol). WholeTree and CCR used in this study were processed to pass a 0.64 and 0.95 cm (0.25 and 0.375 in) screen, respectively using a swinging hammer mill (No. 30 C.S. Bell, Tifton, OH). Fresh poultry litter was obtained from Greenville, AL, and was composted in an in-vessel rotating drum digester (BW Organics, Inc. Sulphur Springs, TX) for two weeks until temperature fluctuations leveled, indicating that the material was stable and fully composted (6). Nutrient content of CPL based on analysis by Brookside Laboratories Inc. (New Knoxville, OH) was 2.5% N, 1.4% P, and 2.3% K on a wet weight basis. Each substrate treatment was pre-plant incorporated with 18N-2.6P-9.9K (15-6-12) (Harrell's Fertilizer Inc. Sylacauga, AL) (8 to 9 month formulation) at 10.7 kg·m<sup>-3</sup> (18 lb·yd<sup>-3</sup>), 1.2 kg·m<sup>-3</sup> (2 lb·yd<sup>-3</sup>) gypsum and 0.9 kg·m<sup>-3</sup> (1.5 lb·yd<sup>-3</sup>) Micromax® (The Scotts Co., Maryville, OH). Plants were arranged by species in a randomized complete block design with eight single plant replications.

Pour-through extractions were conducted using hollies at 7, 15, 30, 60, 90, 120 and 180 days after transplanting (DAT) and analyzed for pH and electrical conductivity (EC) (26). Foliar color ratings were taken at 60 and 120 DAT on a scale of 1 to 5 where 1 = severe chlorosis, 2 = moderate chlorosis, 3 = slight chlorosis, 4 = light green, and 5 = dark green. Growth indices [(height + width1 + width2) / 3] were taken at 120 and 340 DAT, and shrinkage measurements (measured in cm from the substrate surface to the top of the container) were taken on boxwood at 120 and 340 DAT. Root ratings estimated root coverage of the outer surface of the root ball at 340 DAT on a scale of 1 to 5 with 1 = no visible roots, 2 = 25% of surface covered with roots, 3 = 50% root coverage, 4 = 75% coverage, and 5 = 100% coverage.

Leaves from recently matured, current season terminal shoots [5.1 to 7.6 cm (2–3 in)] (19) were sampled from ternstroemia at 340 DAT. Foliar 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), sodium (Na), Copper (Cu), and zinc (Zn). Foliar N 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 Duncan's Multiple Range Test ( $P \leq 0.05$ ) using SAS 9.1.

**Experiment 2.** Methodology was similar as Experiment 1 with the following exceptions: five species [*Rhododendron* × 'Amelia rose' (azalea), *Buxus sempervirens* L. (boxwood), *Ilex crenata* Thunb. 'Compacta' (holly), *Loropetalum chinense* Oliv. 'Chang's Ruby' (loropetalum), and *Ternstroemia gymnanthera* 'Bronze Beauty' Thunb. (ternstroemia)] were transplanted into 3.8 liter (#1) containers on April 17, 2008. CPL from the same batch as experiment 1 was used in experiment 2, however CPL was analyzed again to determine

if any changes in nutrient levels had occurred over time. Nutrient content analysis of CPL indicated 2.3% N, 1.5% P, and 2.3% K on a wet weight basis.

Substrate air space (AS), container capacity (CC), and total porosity (TP) were determined following procedures described by Bilderback et al. (1). Substrate bulk density (BD) (measured in grams·cm<sup>-3</sup>) was determined from 374.5 cm<sup>-3</sup> samples dried in a 105C forced air oven for 48 h. 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 sieve shaker (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) (278 oscillations·min<sup>-1</sup>, 159 taps·min<sup>-1</sup>).

Pour-through extractions were conducted at 7, 30, 60, 90, 120, 285, and 390 DAT. Foliar color ratings were taken at 60 and 120, and 390 DAT. Growth indices were taken at 60 and 390 DAT, and shrinkage measurements were taken on boxwood at 7, 30, 60, and 390 DAT. Root ratings were taken by rating root coverage of the outer surface of the root ball at 390 DAT on a scale of 0 to 10, 0 = 0% of rootball covered with roots, 10 = 100% of the rootball surface covered with roots.

## Results and Discussion

**Experiment 1. pH and EC.** Addition of CPL generally increased pH while peat lowered pH (Table 1). Leachate pH levels at 7 DAT for PB, CCR, and WT (3.8, 4.7, and 5.2, respectively) increased (5.8, 6.7, and 6.9 respectively) when CPL was added. Conversely, addition of peat tended to lower pH for PB (3.8 to 3.7), CCR (4.7 to 4.2) and WT (5.2 to 4.3). pH levels for all substrates amended with CPL declined over time; however pH levels at the end of the study were within the desired range (4.5 to 6.5) (25). However, substrates with peat added or 100% WT, CCR, or PB had unacceptable pH levels at 180 DAT ( $\leq 4.5$ ).

Electrical conductivity levels were initially high (7 DAT) in WT, CCR, and PB substrates amended with CPL (1.3, 1.2, and 1.6 dS·m<sup>-1</sup> respectively) (Table 1). However by

30 DAT substrates of all CPL treatments were within the recommended range (0.5 to 1.0 dS·m<sup>-1</sup>) with the exception of PB:CPL which remained slightly higher (28). At 60 DAT all CPL treatments had acceptable EC levels and remained within an acceptable range for the duration of the study. In general, CPL treatments had the highest pH throughout the study and the highest EC at 7 DAT, however few differences were seen in EC at later dates. Substrates amended with CPL had pH levels closer to the BMP recommended range than 100% WT, CCR, and PB or substrates containing peat which remained very acidic throughout the study. While high initial EC levels may be a concern for more sensitive crops, the majority of woody nursery crops would not be affected by the EC levels exhibited in CPL treatments which peaked at 1.6 dS·m<sup>-1</sup> and declined quickly.

**Growth indices (GI).** Growth indices at 120 DAT indicated that hollies tended to be larger when grown in CCR:CPL, PB:CPL, 100% WT, 100% CCR, 100% PB, or CCR:Peat (Table 2). At 340 DAT hollies grown in 100% WT, 100% CCR, and CCR:Peat were larger than hollies grown in WT:CPL and PB:Peat (Table 2). At 120 DAT boxwood grown in CCR:CPL were larger than plants in all other substrates, a trend that continued at 340 DAT. The least growth in boxwood occurred in substrates containing 100% CCR, 100% PB, CCR:Peat, and PB:Peat which may be attributed to low pH levels (8). Loropetalum were larger in substrates containing 100% CCR or CCR:Peat at 120 and 340 DAT. At 120 DAT, loropetalums were smaller when grown in WT:CPL than in any other treatment with the exception of PB:CPL which was similar. Loropetalums prefer acidic soils and the high leachate pH of WT:CPL could have attributed to the low GI observed in this treatment (8). At 340 DAT these treatments were again smaller than other treatments with the exception of 100% PB, WT:Peat, and PB:Peat which had comparable GI. Azaleas grown in substrates containing 100% CCR were similar to azaleas grown in 100% PB and were larger than all other treatments at 120 DAT; however, by 340 DAT growth indices of plants grown in 100% CCR were similar to WT:Peat

**Table 1. Solution pH and electrical conductivity (EC) of substrates<sup>a</sup> in holly, Experiment 1.**

| Treatment               | 7 DAT             |                          | 30 DAT |                          | 60 DAT |                          | 120 DAT |                          | 180 DAT |                          |
|-------------------------|-------------------|--------------------------|--------|--------------------------|--------|--------------------------|---------|--------------------------|---------|--------------------------|
|                         | pH                | EC (dS·m <sup>-1</sup> ) | pH     | EC (dS·m <sup>-1</sup> ) | pH     | EC (dS·m <sup>-1</sup> ) | pH      | EC (dS·m <sup>-1</sup> ) | pH      | EC (dS·m <sup>-1</sup> ) |
| 6:1 WT:CPL <sup>w</sup> | 6.9a <sup>v</sup> | 1.3a                     | 6.6a   | 0.3e                     | 6.3a   | 0.4b                     | 5.9a    | 0.3a                     | 5.3b    | 0.24a                    |
| 6:1 CCR:CPL             | 6.7b              | 1.2a                     | 6.4b   | 0.5cde                   | 5.9a   | 0.8a                     | 6.0a    | 0.2a                     | 5.8a    | 0.15bc                   |
| 6:1 PB:CPL              | 5.8c              | 1.6a                     | 5.6c   | 1.2a                     | 5.5b   | 0.5ab                    | 5.2ab   | 0.2a                     | 4.9b    | 0.13c                    |
| 100% WT                 | 5.2d              | 0.4b                     | 4.9d   | 0.4de                    | 5.1c   | 0.4b                     | 3.8c    | 0.3a                     | 3.4c    | 0.2ab                    |
| 100% CCR                | 4.7e              | 0.4b                     | 4.6e   | 0.8b                     | 4.6de  | 0.6ab                    | 4.5bc   | 0.3a                     | 3.4c    | 0.18abc                  |
| 100% PB                 | 3.8g              | 0.4b                     | 3.8g   | 0.7bc                    | 4.3e   | 0.5ab                    | 3.5c    | 0.2a                     | 3.3c    | 0.21ab                   |
| 6:1 WT:Peat             | 4.3f              | 0.6b                     | 4.4f   | 0.4de                    | 4.7d   | 0.4b                     | 4.6bc   | 0.2a                     | 3.5c    | 0.2abc                   |
| 6:1 CCR:Peat            | 4.2f              | 0.6b                     | 4.3f   | 0.6bcd                   | 4.4de  | 0.4b                     | 3.7c    | 0.2a                     | 3.7c    | 0.18abc                  |
| 6:1 PB:Peat             | 3.7g              | 0.6b                     | 3.7g   | 0.8b                     | 4.3e   | 0.4b                     | 3.8c    | 0.3a                     | 3.5c    | 0.19abc                  |

<sup>a</sup>pH and EC of solution obtained by the pour through method.

<sup>v</sup>DAT = days after transplanting.

<sup>w</sup>WT = WholeTree.

<sup>w</sup>CPL = composted poultry litter.

<sup>v</sup>Means separated within column by Duncan's Multiple Range Test ( $P = 0.05$ ).

<sup>w</sup>CCR = clean chip residual.

<sup>w</sup>PB = pinebark.

**Table 2.** Influence of substrate composition on growth indices<sup>a</sup> at 120 and 340 days after transplanting, Experiment 1.

| Substrate                             | Holly                |         | Boxwood |         | Loropetalum |         | Azalea  |         | Ternstroemia |         |
|---------------------------------------|----------------------|---------|---------|---------|-------------|---------|---------|---------|--------------|---------|
|                                       | 120 DAT <sup>b</sup> | 340 DAT | 120 DAT | 340 DAT | 120 DAT     | 340 DAT | 120 DAT | 340 DAT | 120 DAT      | 340 DAT |
| 6:1 WT <sup>c</sup> :CPL <sup>w</sup> | 27.0bcd <sup>y</sup> | 32.8b   | 15.3b   | 25.2b   | 34.4e       | 39.5c   | 20.5d   | 29.1c   | 20.0a        | 31.3a   |
| 6:1 CCR <sup>u</sup> :CPL             | 32.3a                | 35.8ab  | 20.6a   | 30.2a   | 45.8bc      | 46.4b   | 19.8d   | 31.6bc  | 24.7a        | 35.6a   |
| 6:1 PB <sup>v</sup> :CPL              | 31.1ab               | 36.2ab  | 17.4b   | 23.7bc  | 37.3de      | 40.7c   | 21.1cd  | 29.6c   | 25.3a        | 32.3a   |
| 100% WT                               | 28.8abcd             | 36.7a   | 14.7bc  | 21.7cd  | 45.1c       | 46.4b   | 23.0bcd | 33.7b   | 25.6a        | 35.1a   |
| 100% CCR                              | 29.4abc              | 37.4a   | 14.8bc  | 19.2de  | 53.3a       | 53.2a   | 27.3a   | 39.4a   | 25.6a        | 35.9a   |
| 100% PB                               | 28.1bcd              | 36.2ab  | 12.4c   | 16.5e   | 41.8cd      | 43.2bc  | 24.8ab  | 33.4b   | 24.8a        | 33.5a   |
| 6:1 WT:Peat                           | 26.0cd               | 34.5ab  | 15.1bc  | 20.4d   | 41.9cd      | 42.6bc  | 20.7d   | 38.9a   | 20.7a        | 32.3a   |
| 6:1 CCR:Peat                          | 28.3abcd             | 36.7a   | 14.8bc  | 19.5de  | 51.2ab      | 51.6a   | 24.0bc  | 37.9a   | 24.6a        | 32.4a   |
| 6:1 PB:Peat                           | 24.7d                | 32.8b   | 12.5c   | 17.0e   | 42.6cd      | 44.1bc  | 20.4d   | 31.9bc  | 24.2a        | 41.0a   |

<sup>a</sup>Growth indices = [(height + width1 + width2) / 3]<sup>b</sup>DAT = days after transplanting.<sup>c</sup>WT = WholeTree.<sup>w</sup>CPL = composted poultry litter.<sup>y</sup>Means separated within column using Duncan's Multiple Range Test ( $P = 0.05$ ).<sup>u</sup>CCR = clean chip residual.<sup>v</sup>PB = pinebark.

and CCR:Peat and were larger than all other treatments. No differences were observed in the growth of ternstroemia in any substrate throughout the study.

**Foliar color ratings (FCR).** Foliar color ratings were similar among all treatments in holly at 60 and 120 DAT (Table 3). At 60 DAT, boxwood grown in WT:CPL, CCR:CPL, PB:CPL, 100% WT, 100% CCR, WT:Peat, and CCR:Peat had slightly higher FCR than other treatments; However, at 120 DAT, no significant differences existed. Loropetalum FCR were highest in 100% CCR and CCR:Peat at 60 DAT; however by 120 DAT, 100% WT, CCR:CPL and PB:CPL had the highest FCR. No differences were seen in azalea FCR at 60 DAT, with the exception of azaleas grown in WT:CPL and CCR:CPL, which had lower FCR than all other treatments. In general, azaleas had the lowest FCR in treatments containing

CPL at 120 DAT, however azaleas grown in 100% PB and PB:Peat had similar FCR. Ternstroemia FCR at 60 DAT was similar for plants grown in 100% WT, CCR, PB, PB:Peat, and CCR:Peat and this trend continued at 120 DAT.

**Root ratings (RR).** Hollies grown in substrates containing CPL had the lowest RR while RR for all other treatments were similar (Table 4). Boxwood RR were highest in CCR:CPL and lowest in substrates containing 100% PB, CCR:Peat, and PB:Peat. Root ratings in loropetalum were lowest in WT:CPL followed by CCR:CPL and PB:Peat, and highest in 100% CCR, 100% WT, 100% PB, CCR:Peat, and WT:Peat. Loropetalums grown in PB:CPL were similar to loropetalums grown in 100% WT, 100%PB, WT:Peat and CCR:Peat. Azaleas had the highest RR in CCR:Peat and lowest RR in WT:CPL. Ternstroemia RR were higher in 100%

**Table 3.** Influence of substrate composition on foliar color ratings<sup>a</sup> at 60 and 120 DAT<sup>b</sup>, Experiment 1.

| Treatment                             | Holly             |         | Boxwood |         | Loropetalum |         | Azalea |         | Ternstroemia |         |
|---------------------------------------|-------------------|---------|---------|---------|-------------|---------|--------|---------|--------------|---------|
|                                       | 60 DAT            | 120 DAT | 60 DAT  | 120 DAT | 60 DAT      | 120 DAT | 60 DAT | 120 DAT | 60 DAT       | 120 DAT |
| 6:1 WT <sup>c</sup> :CPL <sup>w</sup> | 4.0a <sup>y</sup> | 4.0a    | 3.9ab   | 4.0a    | 3.1d        | 3.8d    | 3.4c   | 3.6d    | 3.7c         | 3.6c    |
| 6:1 CCR <sup>u</sup> :CPL             | 4.0a              | 4.0a    | 4.0a    | 4.0a    | 3.8bc       | 4.3ab   | 3.5c   | 3.8d    | 3.8bc        | 3.1d    |
| 6:1 PB <sup>v</sup> :CPL              | 4.0a              | 4.0a    | 3.8ab   | 4.0a    | 3.9b        | 4.3ab   | 3.9ab  | 3.8d    | 3.8bc        | 3.8bc   |
| 100% WT                               | 4.0a              | 4.0a    | 3.9ab   | 4.0a    | 3.8bc       | 4.5a    | 3.9ab  | 4.2bc   | 4.1ab        | 4.4a    |
| 100% CCR                              | 4.0a              | 4.0a    | 3.9ab   | 4.0a    | 4.4a        | 4.1bc   | 4.2a   | 4.5ab   | 4.0abc       | 4.0abc  |
| 100% PB                               | 4.0a              | 4.0a    | 3.4c    | 4.0a    | 3.6c        | 3.9cd   | 3.9ab  | 3.9cd   | 4.1ab        | 4.1ab   |
| 6:1 WT:Peat                           | 4.0a              | 4.0a    | 3.9a    | 4.0a    | 3.6c        | 4.1bcd  | 4.1a   | 4.8a    | 3.8bc        | 3.9bc   |
| 6:1 CCR:Peat                          | 4.0a              | 4.0a    | 3.9ab   | 4.0a    | 4.3a        | 4.1bcd  | 3.9ab  | 4.2bc   | 3.9abc       | 3.9bc   |
| 6:1 PB:Peat                           | 4.0a              | 4.0a    | 3.6bc   | 4.0a    | 3.8bc       | 3.4e    | 3.9ab  | 3.9cd   | 4.2a         | 4.0abc  |

<sup>a</sup>Foliar color rated on a scale of 1 to 5, 1 = severe chlorosis, 2 = yellow, 3 = light green, 4 = green, 5 = dark green.<sup>b</sup>DAT = days after transplanting.<sup>c</sup>WT = WholeTree.<sup>w</sup>CPL = composted poultry litter.<sup>y</sup>Means separated within column using Duncan's Multiple Range Test ( $P = 0.05$ ).<sup>u</sup>CCR = clean chip residual.<sup>v</sup>PB = pinebark.



**Table 4.** Influence of substrate composition on root rating and shrinkage, Experiment 1.

| Treatment                             | Root ratings <sup>z</sup> |         |             |        |              | Shrinkage <sup>y</sup> (cm) |         |
|---------------------------------------|---------------------------|---------|-------------|--------|--------------|-----------------------------|---------|
|                                       | Holly                     | Boxwood | Loropetalum | Azalea | Ternstroemia | 120 DAT <sup>x</sup>        | 340 DAT |
| 6:1 WT <sup>w</sup> :CPL <sup>v</sup> | 3.1b <sup>u</sup>         | 2.8bc   | 2.2d        | 1.3e   | 2.3c         | 5.7a                        | 7.35a   |
| 6:1 CCR <sup>t</sup> :CPL             | 3.7b                      | 3.8a    | 2.6c        | 2.2d   | 3.1bc        | 4.9b                        | 6.5b    |
| 6:1 PB <sup>b</sup> :CPL              | 3.6b                      | 3.1b    | 3.3b        | 2.3d   | 3.2bc        | 3.1e                        | 3.6e    |
| 100% WT                               | 4.6 a                     | 2.4c    | 3.6ab       | 3.4c   | 4.2a         | 3.7cd                       | 4.5cd   |
| 100% CCR                              | 4.8a                      | 2.7bc   | 3.9a        | 4.3ab  | 4.0ab        | 4.0c                        | 4.5cd   |
| 100% PB                               | 4.6 a                     | 1.6d    | 3.6ab       | 4.1b   | 3.3b         | 3.4de                       | 4.1de   |
| 6:1 WT:Peat                           | 4.3a                      | 2.3c    | 3.4ab       | 4.1b   | 3.2bc        | 4.1c                        | 4.8c    |
| 6:1 CCR:Peat                          | 4.7a                      | 1.8d    | 3.6ab       | 4.6a   | 3.6ab        | 3.7cd                       | 4.3cd   |
| 6:1 PB:Peat                           | 4.3a                      | 1.4d    | 2.9c        | 3.8b   | 4.0ab        | 3.7cd                       | 4.3cd   |

<sup>z</sup>Root rating scale of 1 to 5, based on percentage of root ball covered with visible roots: 1 = 0%, 2 = 25%, 3 = 50%, 4 = 75%, 5 = 100%.

<sup>y</sup>Shrinkage = measure (cm) from medium surface to the top of pot.

<sup>x</sup>DAT = days after transplanting.

<sup>w</sup>WT = WholeTree.

<sup>v</sup>CPL = composted poultry litter.

<sup>u</sup>Means separated within column using Duncan's Multiple Range Test ( $P = 0.05$ ).

<sup>t</sup>CCR = clean chip residual.

<sup>b</sup>PB = pinebark.

WT, 100% CCR, CCR:Peat, and PB:Peat than in WT:CPL. Ternstroemia had similar RR in all other treatments. Results indicate that plants which prefer an acidic soil (azalea and loropetalum) generally had higher RR in 100% substrates or in substrates containing peat which had lower leachate pH levels. Plants that prefer a higher pH (boxwood) had higher RR in treatments containing CPL, which also had higher leachate pH levels. Holly and ternstroemia are considered pH adaptable plants and while few differences were seen in ternstroemia, it is unclear why hollies had lower RR in substrates containing CPL.

**Substrate shrinkage.** Shrinkage measurements were all similar with the exception of WT:CPL and CCR:CPL which had more shrinkage than any other treatment at 340 DAT (Table 4) possibly due to further decomposition of the substrate components. Interestingly, PB:CPL substrates had the least shrinkage of any treatment except 100% PB, and had even less shrinkage than PB:Peat combination (3.6 to 4.3). High wood substrates (WT and CCR) had more shrinkage in general than treatments containing PB. However, similarities between 100% WT, CCR, and PB indicate that the use of high wood substrates alone does not increase substrate settling due to wood decomposition.

**Tissue nutrient content.** Tissue nutrient content of ternstroemia was similar among treatments for K, Fe, Cu, and Zn (Table 5). In general, all treatments contained nutrient contents higher than or equal to the sufficiency range (19) for each nutrient level tested. Foliar N tended to be highest in 100% WT, 100% CCR, and 100% PB, as well as in WT:Peat and CCR:Peat. Treatments containing CPL also tended to have the lowest foliar N. Foliar P levels in PB:CPL were higher than in any other treatment with the exception of CCR:Peat, which was similar.

**Experiment 2. Physical properties.** All substrates had acceptable air space except substrates containing PB, which had a higher than recommended AS (10–30%) (28) (Table

6). Air space tended to increase with increasing particle size as substrates containing PB had a higher component of large particles and fewer medium and fine particles than any of the other substrates (Table 7). Container capacity of all substrates were in the acceptable ranges (45–65%) (25) except for PB:CPL and 100% PB which were slightly lower. Total porosity results were within acceptable ranges for all substrates tested. Bulk density results indicated that all substrates had acceptable bulk density with the exception of CCR:Peat, which was slightly lower than the recommended range (0.19 to 0.70 g·cm<sup>-3</sup>) (28).

**pH and EC.** Similar to experiment 1, addition of CPL tended to increase pH while the addition of peat to substrates tended to decrease pH (Table 8). At 7 DAT the addition of CPL increased pH levels of WT (5.5 to 7.4), CCR (4.8 to 7.4) and PB (4.2 to 6.9). Conversely, peat decreased pH in WT, CCR, and PB substrates to levels of 4.6, 4.1, and 4.0, respectively. pH levels generally decreased in all substrates over time, and by 60 DAT, most substrates were within the desired range for container-grown nursery crops (4.5 to 6.5) (28). Substrates were within acceptable ranges until 285 DAT when all substrates without CPL dropped below desired levels, a trend that remained at 390 DAT.

At 7 DAT EC levels were initially very high in substrates containing CPL (Table 8). It is unclear why EC levels were higher at 7 DAT in experiment 2 than in experiment 1. However, by 30 DAT, all EC levels were within desired ranges (0.5 to 1.0) (28) with the exception of PB:CPL which remained slightly higher. After 60 DAT, EC began to gradually decline in all substrates with the exception of PB:CPL, possibly due to gradual depletion of fertilizer. While all EC levels declined over time, substrates containing CPL generally had the highest EC levels all of substrates until 285 DAT when almost all substrate EC levels leveled off.

**Growth indices (GI).** At 60 DAT, GI indicated that hollies grown in PB:CPL were larger than hollies grown in all other treatments, while hollies grown in WT:CPL had the

**Table 5. Tissue nutrient content of *Ternstroemia gymnanthera* (ternstroemia), Experiment 1.**

| Treatment                      | Tissue nutrient content <sup>z</sup> |           |           |         |           |          |         |          |          |          |          |          |
|--------------------------------|--------------------------------------|-----------|-----------|---------|-----------|----------|---------|----------|----------|----------|----------|----------|
|                                | N (%)                                | P (%)     | K (%)     | Ca (%)  | Mg (%)    | Al (ppm) | B (ppm) | Fe (ppm) | Mn (ppm) | Na (ppm) | Cu (ppm) | Zn (ppm) |
| 6:1 WT:CPL <sup>x</sup>        | 1.5bcde <sup>w</sup>                 | 0.18bc    | 1.1a      | 1.3ab   | 0.34ab    | 52.5e    | 30.2ab  | 36.2a    | 27.6c    | 438.8abc | 9.5a     | 17.6a    |
| 6:1 CCR:CPL                    | 1.3de                                | 0.17bc    | 0.9a      | 1.5ab   | 0.34ab    | 74.1de   | 26.4ab  | 54.8a    | 29.2c    | 448.4abc | 6.6a     | 12.7a    |
| 6:1 PB:CPL                     | 1.4cde                               | 0.23a     | 1.0a      | 1.7ab   | 0.38a     | 113.4cd  | 37.5a   | 54.8a    | 55.3ab   | 506.1ab  | 11.7a    | 22.9a    |
| 100% WT                        | 1.6a                                 | 0.14bc    | 1.0a      | 1.2b    | 0.33ab    | 102.7cd  | 20.7b   | 41.3a    | 37.0bc   | 394.7c   | 3.8a     | 11.7a    |
| 100% CCR                       | 1.5abc                               | 0.12bc    | 1.1a      | 1.4ab   | 0.34ab    | 129.5bc  | 22.2b   | 34.9a    | 54.0ab   | 390.3c   | 0.1a     | 10.1a    |
| 100% PB                        | 1.4abcd                              | 0.17bc    | 1.1a      | 2.0a    | 0.32b     | 198.7a   | 30.4ab  | 49.9a    | 54.6ab   | 523.3a   | 11.4a    | 20.4a    |
| 6:1 WT:Peat                    | 1.6ab                                | 0.13bc    | 1.0a      | 1.6ab   | 0.32b     | 124.0bc  | 23.4b   | 38.9a    | 34.9c    | 459.5abc | 3.6a     | 12.3a    |
| 6:1 CCR:P                      | 1.6ab                                | 0.20ab    | 1.2a      | 1.9ab   | 0.30b     | 166.1ab  | 30.6ab  | 44.9a    | 59.8a    | 514.7ab  | 8.5a     | 15.8a    |
| 6:1 PB:P                       | 1.3e                                 | 0.11c     | 0.9a      | 1.6ab   | 0.30b     | 158.5ab  | 21.0b   | 44.4a    | 36.3bc   | 426.3bc  | 22.5a    | 12.4a    |
| Sufficiency range <sup>t</sup> | 1.43–1.90                            | 0.10–0.13 | 0.40–0.52 | 2.0–2.9 | 0.13–0.15 | ****     | 55–126  | 58–69    | 15–35    | ***      | 4–6      | 7–10     |

<sup>z</sup>Tissue analysis performed on 10 terminal shoots [5.1–7.6 cm (2–3 in) of most recently matured leaves] per plant; N = nitrogen, P = phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Al = aluminum, B = boron, Fe = iron, Mn = manganese, Zn = zinc.

<sup>y</sup>WT = WholeTree.

<sup>x</sup>CPL = composted poultry litter.

<sup>w</sup>Means separated within column using Duncan's Multiple Range Test ( $P = 0.05$ ).

<sup>v</sup>CCR = clean chip residual.

<sup>u</sup>PB = pinebark.

<sup>t</sup>Sufficiency range published by Mills and Jones (1996).

\*\*\*\* = Sufficiency ranges not applicable.

lowest GI (Table 9). By 390 DAT, hollies grown in PB:CPL substrate continued to be larger than hollies grown in all other substrates. Growth indices of boxwood at 60 DAT were generally similar among all substrates. By 390 DAT, boxwood grown in WT:CPL and CCR:CPL had a higher GI than boxwood grown in all other substrates, possibly due to the higher pH levels of these substrates (8). Loropetalum showed little difference in growth at 60 DAT, however by 390 DAT, substrates containing CPL along with 100% PB and PB:Peat substrate had higher GI than most other substrates.

Azalea GIs at 60 DAT indicated that azaleas grown in 100% PB, WT:Peat, and PB:Peat were larger than azaleas grown 100% CCR or in any substrate containing CPL. By 390 DAT, azaleas grown in 100% WT, WT:Peat, 100% PB, CCR:Peat, PB:Peat, were largest, while azaleas grown in WT:CPL, and CCR:CPL were smaller than azaleas grown in all other treatments. Few statistical differences were observed in ternstroemia at 60 DAT, however at 390 DAT ternstroemia were largest in 100% WT and all substrates containing peat. Ternstroemia in substrates containing CPL tended to have the

**Table 6. Physical properties of WholeTree, pinebark, and clean chip residual based substrates<sup>z</sup>, Experiment 2.**

| Treatments <sup>u</sup>        | Air space <sup>y</sup> | Container capacity <sup>x</sup><br>(% vol) | Total porosity <sup>w</sup> | Bulk density <sup>v</sup><br>(g·cm <sup>-3</sup> ) |
|--------------------------------|------------------------|--|-----------------------------|--|
| 6:1 WT:CPL                     | 21f                    | 56a  | 77e                         | 0.23b  |
| 6:1 CCR:CPL                    | 28de                   | 51b  | 80c                         | 0.24ab   |
| 6:1 PB:CPL                     | 37b                    | 38e  | 75f                         | 0.25a  |
| 100% WT                        | 26e                    | 55a  | 80bc                        | 0.20d  |
| 100% CCR                       | 35bc                   | 47c  | 82b                         | 0.20d  |
| 100% PB                        | 42a                    | 41d  | 83a                         | 0.22c  |
| 6:1 WT:Peat                    | 27de                   | 57a  | 83a                         | 0.20d  |
| 6:1 CCR:Peat                   | 29d                    | 45c  | 74f                         | 0.17e  |
| 6:1 PB:Peat                    | 33c                    | 45c  | 78d                         | 0.23bc   |
| Recommended range <sup>s</sup> | 10–30                  | 45–65                                      | 50–85                       | 0.19–0.70  |

<sup>z</sup>Analysis performed using the North Carolina State University porometer.

<sup>y</sup>Air space is volume of water drained from the sample divided by volume of the sample.

<sup>x</sup>Container capacity is (wet weight – oven dry weight) divided by volume of the sample.

<sup>w</sup>Total porosity is container capacity + air space.

<sup>v</sup>Bulk density after forced-air drying at 105C (221.0F) for 48 h; 1 g·cm<sup>-3</sup> = 62.4274 lb·ft<sup>-3</sup>

<sup>u</sup>WT = WholeTree, CCR = clean chip residual, PB = pinebark, CPL = composted poultry litter.

<sup>t</sup>Means separated within columns using Duncan's Multiple Range Test ( $P = 0.05$ ).

<sup>s</sup>Recommended ranges as reported by Yeager et al., 2007. Best Management Practices Guide for Producing Container-Grown Plants.

**Table 7. Particle size analysis of substrates, Experiment 2.**

| U.S. standard sieve no. | Sieve opening (mm) <sup>z</sup> | Substrates <sup>y</sup> |             |            |         |          |         |             |              |             |
|-------------------------|---------------------------------|-------------------------|-------------|------------|---------|----------|---------|-------------|--------------|-------------|
|                         |                                 | 6:1 WT:CPL              | 6:1 CCR:CPL | 6:1 PB:CPL | 100% WT | 100% CCR | 100% PB | 6:1 WT:Peat | 6:1 CCR:Peat | 6:1 PB:Peat |
| 1/2                     | 12.5                            | 0.0c <sup>a</sup>       | 0.0c        | 2.8b       | 0.0c    | 0.0c     | 5.0a    | 0.0c        | 0.0c         | 5.6a        |
| 3/8                     | 9.5                             | 0.0c                    | 0.0c        | 3.8b       | 0.0c    | 0.0c     | 3.8b    | 0.0c        | 0.1c         | 6.1a        |
| 1/4                     | 6.35                            | 1.6c                    | 1.9c        | 9.2b       | 0.4c    | 0.3c     | 11.3a   | 0.8c        | 1.1c         | 10.2ab      |
| 6                       | 3.35                            | 15.0c                   | 17.8bc      | 20.2ab     | 10.8d   | 16.5c    | 21.6a   | 20.4ab      | 16.7c        | 21.0ab      |
| 8                       | 2.36                            | 18.8b                   | 19.5b       | 12.5c      | 19.5b   | 20.7b    | 12.7c   | 25.4a       | 18.4b        | 10.6c       |
| 10                      | 2                               | 6.9c                    | 7.7bc       | 4.5d       | 10.1a   | 9.0ab    | 4.4d    | 75bc        | 7.2c         | 3.6d        |
| 14                      | 1.4                             | 17.0bc                  | 19.7a       | 11.5d      | 18.8ab  | 18.4ab   | 11.0d   | 16.7bc      | 15.5c        | 8.9e        |
| 18                      | 1                               | 12.8a                   | 12.0ab      | 9.5c       | 12.3ab  | 13.1a    | 8.3c    | 11.1b       | 11.9ab       | 6.9d        |
| 35                      | 0.5                             | 15.0ab                  | 12.0bc      | 14.8ab     | 13.5abc | 13.0abc  | 12.6abc | 10.7c       | 15.6a        | 11.9bc      |
| 60                      | 0.25                            | 7.0ab                   | 5.2ab       | 6.7ab      | 5.6ab   | 5.2ab    | 6.4ab   | 4.6b        | 8.1ab        | 8.8a        |
| 140                     | 0.11                            | 3.1ab                   | 2.3b        | 2.1b       | 3.3ab   | 1.9b     | 2.1b    | 1.6b        | 3.7ab        | 5.1a        |
| 270                     | 0.05                            | 1.0ab                   | 0.87ab      | 0.50b      | 0.70ab  | 0.40b    | 0.50b   | 0.43b       | 0.80ab       | 1.3a        |
| pan                     | 0                               | 0.43ab                  | 0.50a       | 0.37ab     | 0.23ab  | 0.13b    | 0.37ab  | 0.47a       | 0.33ab       | 0.43ab      |
| Texture <sup>w</sup>    |                                 |                         |             |            |         |          |         |             |              |             |
| Coarse                  |                                 | 16.6c                   | 19.7c       | 36.0b      | 11.2d   | 16.9c    | 41.6a   | 21.2c       | 17.9c        | 42.6a       |
| Medium                  |                                 | 55.6bc                  | 58.8ab      | 38.0d      | 60.8ab  | 61.2a    | 36.4d   | 60.7ab      | 53.0c        | 30.0e       |
| Fine                    |                                 | 58.6c                   | 62.8bc      | 43.0d      | 66.8ab  | 68.2ab   | 44.4d   | 69.7a       | 63.0bc       | 41.0d       |

<sup>z</sup>1 mm = 0.0394 in.<sup>y</sup>WT= WholeTree, CPL = composted poultry litter, CCR = clean chip residual, PB = pinebark.<sup>a</sup>Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Duncan's Multiple Range Test at ( $P = 0.05$ ).<sup>w</sup>Coarse = 3.35–12.5 mm; Medium = 1.00–2.36 mm; Fine = 0.00–0.50 mm.

lowest GI, with the exception of PB:CPL which was similar to the PB:Peat nursery standard.

**Foliar color ratings (FCR).** No differences were observed in FCR of holly at 60 or 120 DAT (Table 10). Only slight differences occurred at 390 DAT, with WT:CPL, WT:Peat, and PB:Peat having slightly lower FCR than other treatments, however all substrates generally performed similarly. Small differences were observed in boxwood FCR at 60 DAT, and

no there were no differences in FCR among boxwoods in any substrate at 120. However, by 390 DAT boxwoods grown in CCR:CPL and PB:CPL had higher FCR than boxwoods grown in CCR:Peat and PB:Peat. At 60 and 120 DAT loropetalum tended to have higher FCR in substrates containing peat, however by 390 DAT there were no differences in FCR among any substrate. Azaleas had high FCR in 100% PB and WT:Peat substrates at 60 DAT, but PB:CPL, 100% WT, CCR:Peat, and PB:Peat were similar. In general, at 120

**Table 8. Solution pH and electrical conductivity (EC) of substrates<sup>z</sup> in holly, Experiment 2.**

| Treatment                             | 7 DAT <sup>y</sup> |                          | 30 DAT |                          | 60 DAT |                          | 90 DAT |                          | 120 DAT |                          | 285 DAT |                          | 390 DAT |                          |
|---------------------------------------|--------------------|--------------------------|--------|--------------------------|--------|--------------------------|--------|--------------------------|---------|--------------------------|---------|--------------------------|---------|--------------------------|
|                                       | pH                 | EC (dS·m <sup>-1</sup> ) | pH     | EC (dS·m <sup>-1</sup> ) | pH     | EC (dS·m <sup>-1</sup> ) | pH     | EC (dS·m <sup>-1</sup> ) | pH      | EC (dS·m <sup>-1</sup> ) | pH      | EC (dS·m <sup>-1</sup> ) | pH      | EC (dS·m <sup>-1</sup> ) |
| 6:1 WT <sup>x</sup> :CPL <sup>w</sup> | 7.4a <sup>v</sup>  | 3.9a                     | 7.3a   | 0.8b                     | 6.6a   | 0.7cd                    | 6.8a   | 0.46bc                   | 6.5a    | 0.28a                    | 5.7a    | 0.16b                    | 5.5a    | 0.14c                    |
| 6:1 CCR <sup>x</sup> :CPL             | 7.4a               | 2.9b                     | 7.1a   | 0.7b                     | 6.5a   | 0.9bc                    | 6.3b   | 0.73a                    | 6.3a    | 0.24ab                   | 6.0a    | 0.12cd                   | 5.2b    | 0.14c                    |
| 6:1 PB <sup>x</sup> :CPL              | 6.9b               | 2.8b                     | 6.5b   | 1.3a                     | 5.8bc  | 1.3a                     | 5.7c   | 0.48b                    | 5.3b    | 0.21abc                  | 5.0b    | 0.16b                    | 4.1c    | 0.21ab                   |
| 100% WT                               | 5.5c               | 1.0cd                    | 6.3c   | 0.5cd                    | 6.0b   | 0.6cd                    | 5.1de  | 0.37bcd                  | 4.5bc   | 0.18bcd                  | 3.3d    | 0.16bc                   | 3.1e    | 0.23ab                   |
| 100% CCR                              | 4.8d               | 0.7cd                    | 5.8d   | 0.3d                     | 5.9b   | 0.4d                     | 5.2d   | 0.27d                    | 4.3c    | 0.17bcd                  | 3.4d    | 0.16bc                   | 3.0e    | 0.26a                    |
| 100% PB                               | 4.2f               | 0.5d                     | 4.8f   | 0.5cd                    | 5.3cd  | 0.7bcd                   | 4.8e   | 0.28d                    | 4.3c    | 0.14cd                   | 3.5cd   | 0.17b                    | 3.3de   | 0.22ab                   |
| 6:1 WT:Peat                           | 4.6e               | 0.9cd                    | 5.8d   | 0.3d                     | 5.7bc  | 0.4d                     | 5.6c   | 0.22d                    | 5.2b    | 0.11d                    | 3.8c    | 0.12d                    | 3.5d    | 0.18bc                   |
| 6:1 CCR:Peat                          | 4.1fg              | 1.2c                     | 5.5e   | 0.5c                     | 5.5bcd | 0.9bc                    | 4.8e   | 0.31cd                   | 4.5c    | 0.17bcd                  | 3.3d    | 0.22a                    | 3.2de   | 0.23ab                   |
| 6:1 PB:Peat                           | 4.0g               | 0.9cd                    | 4.6f   | 0.5c                     | 5.1d   | 1.0ab                    | 5.0de  | 0.37bcd                  | 4.4c    | 0.13cd                   | 3.7cd   | 0.15bcd                  | 3.3de   | 0.23ab                   |

<sup>z</sup>pH and EC of solution obtained by the pour through method.<sup>y</sup>DAT = days after transplanting.<sup>x</sup>WT = WholeTree.<sup>w</sup>CPL = composted poultry litter.<sup>v</sup>Means separated within columns using Duncan's Multiple Range Test ( $P = 0.05$ ).<sup>w</sup>CCR = clean chip residual.<sup>x</sup>PB = pinebark.

**Table 9.** Influence of substrate composition on growth indices<sup>a</sup> at 60 and 390 days after transplanting, Experiment 2.

| Substrate                             | Holly               |         | Boxwood |         | Loropetalum |         | Azalea  |         | Ternstroemia |         |
|---------------------------------------|---------------------|---------|---------|---------|-------------|---------|---------|---------|--------------|---------|
|                                       | 60 DAT <sup>b</sup> | 390 DAT | 60 DAT  | 390 DAT | 60 DAT      | 390 DAT | 60 DAT  | 390 DAT | 60 DAT       | 390 DAT |
| 6:1 WT <sup>c</sup> :CPL <sup>w</sup> | 26.0c <sup>v</sup>  | 40.3c   | 18.5ab  | 31.1a   | 42.4ab      | 50.0a   | 24.8bc  | 33.3d   | 30.4abc      | 39.2dc  |
| 6:1 CCR <sup>u</sup> :CPL             | 30.4b               | 43.5bc  | 17.2ab  | 30.4a   | 38.1b       | 54.4a   | 25.5bc  | 34.2d   | 26.5c        | 37.6d   |
| 6:1 PB <sup>b</sup> :CPL              | 35.8a               | 48.6a   | 18.8ab  | 27.5b   | 37.9b       | 52.7a   | 26.7bc  | 37.8c   | 30.5abc      | 45.3bc  |
| 100% WT                               | 32.3b               | 45.1b   | 18.5ab  | 26.5b   | 43.5ab      | 37.7bc  | 29.2ab  | 45.9a   | 29.5bc       | 47.2ab  |
| 100% CCR                              | 32.2b               | 43.4bc  | 16.9b   | 23.6cd  | 37.8b       | 36.2bc  | 23.5c   | 42.0b   | 27.7c        | 44.1bc  |
| 100% PB                               | 31.1b               | 41.7bc  | 18.0ab  | 23.0d   | 47.6a       | 50.4a   | 31.0a   | 45.5ab  | 30.6abc      | 45.5bc  |
| 6:1 WT:Peat                           | 29.3b               | 41.1c   | 18.6ab  | 26.0bc  | 43.7ab      | 41.4b   | 31.0a   | 46.6a   | 34.3a        | 52.3a   |
| 6:1 CCR:Peat                          | 29.2b               | 44.2bc  | 25.7a   | 24.0cd  | 41.6ab      | 34.9c   | 27.5abc | 43.7ab  | 31.1abc      | 47.6ab  |
| 6:1 PB:Peat                           | 31.8b               | 40.3c   | 17.9ab  | 23.4cd  | 48.0a       | 49.2a   | 31.1a   | 44.1ab  | 33.2ab       | 50.1ab  |

<sup>a</sup>Growth indices = [(height + width1 + width2) / 3]<sup>b</sup>DAT = days after transplanting.<sup>c</sup>WT = WholeTree.<sup>w</sup>CPL = composted poultry litter.<sup>v</sup>Means separated within columns using Duncan's Multiple Range Test ( $P = 0.05$ ).<sup>u</sup>CCR = clean chip residual.<sup>b</sup>PB = pinebark.

DAT azaleas tended to have the highest FCR when grown in substrates containing peat and lowest FCR in CPL, but at 390 DAT there were no differences in FCR among azaleas in any substrate. Ternstroemia had the lowest FCR when grown in CPL at 60 DAT, a trend that continued at 120 DAT. By 390 DAT, 100% WT and 100% CCR had the highest FCR, but FCR was similar to other treatments.

**Root ratings (RR).** Root ratings were higher in hollies grown in 100% WT, 100% CCR, 100% PB, and PB:Peat than when grown in WT:CPL, or CCR:CPL (Table 11). Holly had significantly lower RR in WT:CPL than in any other treatment. In contrast, boxwood RR were highest in WT:CPL, and similar root growth in CCR:CPL. Loropetalum grown

in 100% PB had highest RR, however PB:CPL, 100% CCR, and PB:Peat were similar. As in experiment 1, azaleas had lowest RR in WT:CPL. While ternstroemia in experiment 1 had significantly higher RR in WT:CPL, in experiment 2 WT:CPL along with CCR:CPL had the significantly lower RR than all other treatments.

**Substrate shrinkage.** At 7 DAT substrate shrinkage was greatest in treatments containing WT, specifically WT:CPL, 100% WT, and WT:P. PB:CPL and CCR:Peat had less shrinkage than any other treatment (Table 11). This trend continued at 30 DAT. By 60 DAT, WT:CPL and CCR:CPL treatments had significantly more shrinkage than any other treatment, possibly due to further decomposition of WT and CCR. At

**Table 10.** Influence of substrate composition on foliar color ratings<sup>a</sup> at 60, 120, and 390 days after transplanting, Experiment 2.

| Treatment                             | Holly             |      |        | Boxwood |      |       | Loropetalum |        |      | Azalea |        |      | Ternstroemia |      |        |
|---------------------------------------|-------------------|------|--------|---------|------|-------|-------------|--------|------|--------|--------|------|--------------|------|--------|
|                                       | DAT <sup>b</sup>  |      |        | DAT     |      |       | DAT         |        |      | DAT    |        |      | DAT          |      |        |
|                                       | 60                | 120  | 390    | 60      | 120  | 390   | 60          | 120    | 390  | 60     | 120    | 390  | 60           | 120  | 390    |
| 6:1 WT <sup>c</sup> :CPL <sup>w</sup> | 4.0a <sup>v</sup> | 4.0a | 4.1bc  | 3.3abc  | 3.9a | 3.9ab | 3.3cd       | 4.1c   | 3.9a | 3.3bc  | 3.3cd  | 4.0a | 3.6b         | 3.1c | 3.8c   |
| 6:1 CCR <sup>u</sup> :CPL             | 4.0a              | 4.0a | 4.4a   | 3.0c    | 4.0a | 4.0a  | 3.1d        | 4.2c   | 2.9a | 3.1c   | 3.1d   | 4.0a | 3.6b         | 3.0c | 4.1abc |
| 6:1 PB <sup>b</sup> :CPL              | 4.0a              | 4.0a | 4.3ab  | 3.6a    | 4.0a | 3.7a  | 3.9bc       | 4.6abc | 3.1a | 4.0ab  | 3.8bcd | 4.0a | 3.6b         | 3.8b | 3.9bc  |
| 100% WT                               | 4.0a              | 4.0a | 4.4a   | 3.5ab   | 4.0a | 3.8ab | 4.4ab       | 5.0a   | 2.8a | 3.6abc | 4.4ab  | 4.0a | 3.9a         | 4.0a | 4.4a   |
| 100% CCR                              | 4.0a              | 4.0a | 4.4a   | 3.2bc   | 3.9a | 3.7ab | 3.7cd       | 4.9ab  | 3.4a | 3.2c   | 3.8abc | 3.5a | 3.9a         | 4.1a | 4.4a   |
| 100% PB                               | 4.0a              | 4.0a | 4.4a   | 3.7a    | 4.0a | 3.8ab | 4.6a        | 4.3bc  | 2.8a | 4.3a   | 4.5a   | 4.0a | 4.2a         | 4.0a | 3.9bc  |
| 6:1 WT:Peat                           | 4.0a              | 4.0a | 4.3abc | 3.4abc  | 3.9a | 3.7ab | 4.6a        | 5.0a   | 3.0a | 4.3a   | 4.6a   | 4.0a | 4.2a         | 4.1a | 4.2ab  |
| 6:1 CCR:Peat                          | 4.0a              | 4.0a | 4.5a   | 3.5ab   | 4.0a | 3.6b  | 4.6a        | 5.0a   | 2.6a | 3.8abc | 4.6a   | 4.0a | 4.1a         | 4.0a | 4.0bc  |
| 6:1 PB:Peat                           | 4.0a              | 4.0a | 4.1c   | 3.2bc   | 4.0a | 3.6b  | 4.6a        | 5.0a   | 3.3a | 3.8abc | 4.6a   | 4.0a | 4.1a         | 4.0a | 4.1abc |

<sup>a</sup>Foliar color rated on a scale of 1 to 5, 1 = severe chlorosis, 2 = yellow, 3 = light green, 4 = green, 5 = dark green.<sup>b</sup>DAT = days after transplanting.<sup>c</sup>WT = WholeTree.<sup>w</sup>CPL = composted poultry litter.<sup>v</sup>Means within columns separated using Duncan's Multiple Range Test ( $P = 0.05$ ).<sup>u</sup>CCR = clean chip residual.<sup>b</sup>PB = pinebark.



**Table 11. Influence of substrate composition on root ratings and shrinkage, Experiment 2.**

| Treatment                             | Root rating <sup>a</sup> |         |             |        |         | Shrinkage <sup>b</sup> (cm) |        |        |         |
|---------------------------------------|--------------------------|---------|-------------|--------|---------|-----------------------------|--------|--------|---------|
|                                       | Holly                    | Boxwood | Loropetalum | Azalea | Cleyera | 7 DAT <sup>c</sup>          | 30 DAT | 60 DAT | 390 DAT |
| 6:1 WT <sup>u</sup> :CPL <sup>v</sup> | 3.8c <sup>u</sup>        | 7.1a    | 2.5e        | 1.0d   | 2.4e    | 2.5ab                       | 3.3a   | 4.9a   | 6.4a    |
| 6:1 CCR <sup>u</sup> :CPL             | 6.3b                     | 6.1ab   | 3.3de       | 0.9d   | 2.0e    | 2.1cd                       | 3.0ab  | 4.6a   | 5.7b    |
| 6:1 PB <sup>u</sup> :CPL              | 7.6ab                    | 5.5bc   | 5.1ab       | 3.4c   | 4.5d    | 1.9e                        | 2.2c   | 2.9d   | 2.9f    |
| 100% WT                               | 9.1a                     | 5.0c    | 4.3bcd      | 7.9a   | 7.3abc  | 2.6a                        | 3.0ab  | 3.7b   | 4.6c    |
| 100% CCR                              | 8.8a                     | 3.6de   | 4.8abc      | 5.9b   | 7.5ab   | 2.3cd                       | 2.5cd  | 3.3bcd | 3.5de   |
| 100% PB                               | 8.1a                     | 2.9ef   | 6.0a        | 7.4a   | 6.0c    | 2.3bc                       | 2.5bc  | 3.1cd  | 3.0ef   |
| 6:1 WT:Peat                           | 7.8ab                    | 4.6cd   | 3.8cde      | 6.6ab  | 8.1a    | 2.5ab                       | 3.2a   | 3.6bc  | 3.8d    |
| 6:1 CCR:Peat                          | 7.6ab                    | 3.8de   | 3.3de       | 7.5a   | 7.9ab   | 1.8e                        | 2.3c   | 3.0d   | 3.3def  |
| 6:1 PB:Peat                           | 8.1a                     | 2.3f    | 4.9abc      | 7.9a   | 6.6bc   | 2.0de                       | 2.4bc  | 3.0d   | 2.8f    |

<sup>a</sup>Root rating on a scale of 0 to 10, based on percentage of root ball covered with visible roots: 0 = 0%, 1 = 10%, 2 = 20%, 3 = 30%, 4 = 40%, 5 = 50%, 6 = 60%, 7 = 70%, 8 = 80%, 9 = 90%, and 10 = 100%.

<sup>b</sup>Shrinkage = measured in cm from medium surface to top of the pot.

<sup>c</sup>DAT = days after transplanting.

<sup>u</sup>WT = WholeTree.

<sup>v</sup>CPL = composted poultry litter.

<sup>u</sup>Means within columns separated using Duncan's Multiple Range Test ( $P = 0.05$ ).

<sup>u</sup>CCR = clean chip residual.

<sup>u</sup>PB = pinebark.

the conclusion of the study WT:CPL had more shrinkage than any other treatment followed by CCR:CPL (6.4 and 5.7 cm). PB:CPL, 100% PB, and PB:Peat all had less shrinkage than WT:CPL, CCR:CPL, 100% WT, 100% CCR, or WT:Peat.

In summary, similarities among substrates in these studies amended with peat or CPL indicate that CPL could be an economically viable and sustainable substrate amendment for container plant production. In both experiments, CPL tended to raise pH and peat tended to lower pH, particularly in the first 2 months. At the conclusion of each experiment, treatments containing CPL were closer to the suggested BMP pH levels than any other treatments.

CPL increased substrate EC levels, more dramatically in experiment 2 than in experiment 1. However, in each study, EC levels quickly declined and were within recommended levels by 30 DAT.

While growth differences did occur with individual species throughout these studies, at the end of both studies all five species grown in high wood substrates had growth similar to plants grown in the PB:Peat commercial standard substrate. Foliar color ratings were similar among most treatments for holly and boxwood in experiment 1, and holly, boxwood, loropetalum, and azalea in experiment 2. Root rating results were again species specific concerning the use of CPL. Similarly, in a study by Tyler et al. (24) high EC levels resulting from incorporation of composted turkey litter inhibited root growth of cotoneaster (*Cotoneaster dammeri* 'Skogholm') and daylily (*Hemerocallis* sp. 'Red Magic'). The initial high EC levels of the substrates containing CPL could have caused lower RR in some species (holly, loropetalum, and azalea in experiment 1; loropetalum, azalea, ternstroemia in experiment 2), however in both studies all species grown in alternative wood based substrates had RR comparable to the grower standard PB:P at final evaluations.

One concern with using CPL in substrates containing high wood content is a possible increase in shrinkage. In addition to increased nitrogen in CPL, use of CPL is likely introducing higher microbial populations which could increase the rate of

cellulose break down in these substrates (21). WT:CPL had the most shrinkage in both studies, possibly due to further decomposition of the high percentage of cellulose (wood) in WT. The smaller particle size of the WT used in comparison with CCR and PB also contributed to the high shrinkage of this substrate, especially when CPL was added to WT. While WT:CPL had high shrinkage in both studies, when WT was used at 100%, or in combination with peat, shrinkage was similar to 100% PB and PB:Peat in experiment 1. However, in experiment 2 100% WT and WT:Peat had more shrinkage than 100% PB or PB:Peat.

Use of CPL in container production could possibly reduce initial nitrogen immobilization which is often a concern when using substrates with high wood content. CPL could also be used as a peat substitute while growing species that are tolerant to initially high EC levels and are pH adaptable. As PB supplies decline and fertilizer prices continue to increase, growers must look to the future for economically sustainable substrates. These results show high wood substrates with or without CPL (depending on crop) have potential to address future industry needs.

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