Evaluation of Sustainable Alternative Substrate Components for Container Plant Production

by

Anna-Marie Murphy

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Approved by

Charles H. Gilliam, Chair, Professor of Horticulture
Glenn B. Fain, Assistant Professor of Horticulture
Jeff L. Sibley, Professor of Horticulture
Tom V.Gallagher, Associate Professor of Forestry and Wildlife Sciences
H. Allen Torbert, III, Research Leader/Soil Scientist
USDA-ARS National Soil Dynamics Laboratory

Abstract

Pine bark, peat, and perlite have served as the standard substrate components of container-grown plants for over 50 years. Due to a number of factors, including increased transportation costs, a shift to in-field harvesting of pine, and proposed federal programming, the future availability of pine bark is widely unknown. The future availability of peat for horticultural use is also unknown due to increased regulations and restrictions on the harvesting of peat. These restrictions, paralleled with constantly fluctuating fuel and shipping prices of peat from Canada, have caused growers to seek alternative greenhouse substrates with equivalent physical characteristics. Additionally, growers are becoming increasingly concerned about amending their container substrates with perlite. Up until now, perlite has simply been considered a general nuisance due to its dusty nature, but increasing concerns related to health issues have caused growers to seek alternative greenhouse substrate amendments with equivalent characteristics to perlite. The main objective of this work is to identify and evaluate possible substrate alternatives or amendments to pine bark, peat and perlite. First, clean chip residual (CCR) and WholeTree (WT) were evaluated in order to observe how far existing bark-based substrates could be amended without negative effects on the growth of woody ornamentals. This study was developed to evaluate substrate treatments comprised of PB with 25%, 50%, and 75% CCR or 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. While there were a few differences in pH and electrical conductivity between CCR and WT early in the study, treatments were not significantly different by study termination (365 days after planting). There were little to no differences in plant growth across all treatments for all species tested (azalea, lantana, spirea, osmanthus, ligustrum, and holly) at the study termination. Next, we evaluated three low-value forest trees (sweetgum, hickory, and redcedar) as possible amendments to standard greenhouse substrates. These studies evaluated three possible substrate alternatives for use in greenhouse products, including fresh sweetgum (SG), hickory (H), and eastern redcedar (RC), in addition to WholeTree (WT) substrate. Three greenhouse annual crops (petunia, impatiens, and vinca) were planted in varying ratios of these species mixed with peat. Plants grown with SG and H as amendments did not perform as well as a traditional peat:perlite mix with respect to flower number, growth indices, and plant dry weight. However, plants grown in RC tended to be equivalent to those grown in a traditional mix. Data showed that greenhouse producers could amend their standard greenhouse substrate with up to 50% eastern redcedar with little to no differences in plant growth.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

The history of nursery and greenhouse container substrates has been filled with numerous discoveries leading to change in best management practices through the years. Shortly after World War II, when nursery and greenhouse operations began to expand, and increase production, field soil and peat were the major components in container media (18, 41). Research on the effects of varying physical properties showed that field soil held too much water, as well as failed to allow adequate air space needed for root respiration (49). In the mid- to late-seventies, pine bark (PB) was identified and evaluated as an ‘inexpensive, readily available, largely inert, and generally pathogen-free’ container media (12, 17, 44, 47).

PB and peat have served as industry standards for substrates in the nursery and greenhouse industries because of several inherit qualities. Not only have they been readily available for the past 40 to 50 years, but they also embody several crucial physical characteristics of an ideal container substrate. Recommended physical characteristic values for *nursery* container substrates after irrigation and drainage are given as follows in percent volume of the pot: total porosity 50 to 85%; air space 10 to 30%; and container capacity 45 to 65% (61). The bulk density of an ideal nursery container substrate should fall somewhere between 0.19 and 0.70 g/cm^3 (61). Values for ideal *greenhouse* container substrates differ slightly to account for the fact that substrates need to be able to hold water more readily. Air space should be between 10 and 20%, while container capacity should fall between 50 and 65% (33). Given these values, it follows that total porosity should be between 60 and 75% for container-grown greenhouse crops. In addition to PB and peat, perlite has also served as a standard container substrate component for a number of years (18). Growers began using perlite in an effort to increase air space in container substrates without increasing bulk density or affecting substrate pH or electrical conductivity.

Due to a number of factors, including a shift to in-field harvesting of timber, an outsourcing of timber processing to international sources, as well as an overall downturn in the economy, a decrease in the availability of PB for nursery container production has occurred (40). In 2010, nursery producers across the southeastern United States were notified that PB supplies are unstable, and current and future needs may not be able to be met (16, 43, 51, 52). In addition to the limiting factors reported by Lu et al. (40), a new Biomass Crop Assistance subsidy program has been implemented in 2010, causing many eligible biomass materials (including PB) to be redirected to facilities that will convert the material into steam, electricity or biofuels (2). The subsidy program is set up to pay up to $45/dry ton for such materials, which is almost a two-fold increase in price for what nursery producers are paying for PB now (42). For these reasons, growers are reaching out to researchers across the country for help in identifying and evaluating alternative nursery container substrates.

Quantities of peat for horticultural uses are also limited due to increased regulations and restrictions on the harvesting of peat from peat bogs (45). These amplified restrictions, paralleled with constant fluctuations in the prices of fuel necessary for the shipping of materials from Canada, have caused growers to seek alternative greenhouse substrates with equivalent physical characteristics (62).

Growers have used expanded perlite for a number of years, and consumer demand now holds the expectation for perlite in market plants (62). Up until now, growers have only expressed complaints about the general lung and eye irritation associated with exposure to perlite. Recent literature has suggested that heavy exposure to perlite may have more serious health risks than originally thought (19, 48). Relatively heavy exposure to perlite dust has been proven to decrease the lung transfer factor, or carbon monoxide (CO) diffusing capacity in the lungs (48). Another study conducted after an accidental perlite spill at a factory in Taiwan followed 24 exposed workers for more than six months to evaluate any potential respiratory problems (19). Of the 24 workers exposed, three developed persistent respiratory symptoms that were confirmed as reactive airway dysfunction syndrome. The authors warned that though exposure to expanded perlite below the permission level given on the MSDS (Material Safety Data Sheet) may be generally safe, precautionary protection during short term heavy exposure is necessary.

Given these problems with obtaining PB and peat, along with the possible health risks associated with using perlite, growers have begun looking for alternatives to their standard substrates. An ideal container substrate alternative or amendment would be locally available, easily adaptable to a number of crops, sustainable, and economical. In addition, an ideal alternative substrate component would require few changes in current production management practices.

A number of alternative substrates have been tested with varying results. Some of these include ground tea leaves (53), cotton gin compost (15, 28, 29, 46), rockwool (56), peanut hulls (4), pecan shells (57), monolithic slag (6), vermicompost (3), wulpak (5), scrubber waste (54), coir pith (38), mushroom compost (37), dairy waste (13), paper production waste (14, 55), crumb rubber (34), bioconverted swine biosolids (24) and switchgrass (1).

Research evaluating the possibility of using cedar, as well as low-value hardwoods as substrate alternatives or amendments began in the 1970's, and has continued to present (11, 25, 26, 27, 35, 36, 50). In 1972, researchers at the University of Illinois tested hardwood bark, in combination with 'other materials' as media for forsythia and juniper plants in containers with various 'growing procedures, bark sources, and fertility practices' (36). Forsythia tended to perform best in a media mixture containing large hardwood bark particles and fine sand (2:1 v:v), although dry weight for plants in that treatment were similar to dry weights in all but two other treatments. However, juniper tended to perform better in a mixture containing large hardwood bark particles, soil and peat (1:1:1 v:v:v). Dry weights of juniper in other treatments were less than that in the previously mentioned treatment, except in the case of one treatment (small hardwood bark particles, soil and peat in a 1:1:1 v:v ratio). In 1975, results were obtained showing that the best growth of two azalea species was from pine shavings followed by cedar shavings (50). Hardwood bark was also explored as a possible alternative in the 1990s (11). Results from the study concluded that substrates amended with as much as 25% hardwood bark could be used successfully as a media for the production of a wide range of woody ornamentals. With relatively few exceptions (35, 49), research involving hardwoods as amendments or alternatives up to this point has only evaluated the use of hardwood bark, not the entire processed tree.

In addition to these possible alternatives, higher wood content substrates are being evaluated, including products such as clean chip residual (CCR) (7, 8, 9, 10), WholeTree (WT) (20, 21, 22, 23) and pine tree substrate (PTS) (30, 31, 32, 58, 59, 60).

Before the most recent work evaluating a number of pine-based, high wood content alternative substrates began, earlier research suggested the use of pine wood as an amendment in standard substrate mixes (39). This study evaluated the growth of azalea (*Rhododendron indica* ‘President Clay’), ligustrum (*Ligustrum sinense* ‘Variegata’) and holly (*Ilex crenata* ‘Compacta’) in treatments containing fresh pine bark ‘with a considerable amount of wood,’ pine tree chips alone, or milled pine bark alone. Plant height was similar across treatments for azalea and ligustrum. For holly, plants in pine tree chips alone were smaller than those in pine bark alone, or pine bark with wood. The authors suggested that the reason for this decreased growth may have been due to the larger particle sizes of the pine tree chips compared to the pine bark. This greater air space may have caused greater leaching, and lower nutrient retention and water holding capacity. These findings were not explored further until the mid 2000’s.

In 2006, Fain and Gilliam (20) reported on the physical properties of media composed of ground whole pine trees (WT) and their effects on the growth of vinca (*Catharanthus roseus* 'Little Blanche' and *Catharanthus roseus* 'Raspberry Red Cooler'). Results from the study indicated annual vinca grown in WT had similar growth to plants grown in PB. While shoot dry weights were 15% greater for plants grown in 100% pine bark 60 days after planting, there were no differences in plant growth indices. The authors also reported that the 100% pine bark substrate had on average 50% less air space and 25% greater water holding capacity than the other substrates, although none were statistically different.

WT is defined as 80% wood, 15% bark, and 5% needles, and is a product that consists of the entire pine tree harvested from pine plantations at the thinning stage (22). Several studies have been conducted to assess the value of WT as a comparable substrate to traditional PB in addition to the one mentioned in the preceding paragraph. An evaluation of WT in the production of herbaceous greenhouse crops [begonia (*Begonia ×semporflorens-cultorum* 'Prelude Scarlet'), marigold (*Tagetes patula* 'Little Hero Yellow'), petunia (*Petunia ×hybrida* 'Dreams Pink'), vinca (*Catharanthus roseus* 'Peppermint Cooler'), and lantana (*Lantana camara* 'Lucky Red Hot Improved')] indicated mixed results (21). Plants were grown in 100% WT ground to three different screen sizes (0.952-cm, 0.635-cm, or 0.476-cm) and mixed on an increasing volume:volume basis with peat moss. 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 peat moss percentage.

Later, Fain et al. (23) reported on the interaction between WT substrate and starter fertilizer rate in the production of greenhouse grown petunia (*Petunia ×hybrida* 'Dreams Purple') and marigold (*Tagetes patula* 'Hero Spry'). WT was either used alone (100%) or blended with either 20 or 50% peat (by volume). Three starter fertilizer rates were evaluated, including 1.19, 2.37, and 3.56 kg/m^3 of a 7-3-10 starter fertilizer. With only one exception (100% WT at 3.56 kg/m^3), petunia dry weights were greatest for any substrate containing at least 20% peatmoss and having a starter fertilizer rate of 2.37 kg/m^3 or greater. Marigold plant dry weights were similar for all substrate where at least the 2.37 kg/m^3 starter fertilizer rate was used. The authors suggested that lower EC values in high volume WT substrates may be due to lower water holding capacity, combined with low cation exchange capacity and possible nitrogen immobilization. However, the authors believed these values could be overcome by processing the WT to a finer particle size, paying close attention to water practices, and even adding a wetting agent to the media. Fain et al. (23) also reported that forest operators may be interested in commercializing WT because it could allow them to decrease the amount of residual left on the ground after harvesting, since WT substrate consists of the entire above-ground shoot portion of the tree. Another way forest operators may be able to capitalize on the residual left behind after a total harvesting would be to sell the material as CCR.

CCR is a product composed of approximately 50% wood, 40% bark, and 10% needles (8). It is created when transportable in-field harvesters are used to process pines into ‘clean chips’ that can be used by pulp mills. This by-product is either sold for boiler fuel or more commonly spread back across the harvested area in an effort to increase the biomass left on the forest floor.

Several studies have been conducted evaluating CCR in the production of annuals, perennials and woody crops. First, three annual species [ageratum (*Ageratum houstonianum* ‘Blue Hawaii’), salvia (*Salvia ×superba* ‘Vista purple’) and impatiens (*Impatiens walleriana* ‘Coral’ or *Impatiens walleriana* ‘White’)] were evaluated in a greenhouse setting (9). CCR in the study was evaluated at two screen sizes (3/4 and 1/2 inch), and the study was duplicated at two separate locations (Auburn, AL, and Poplarville, MS). At the study termination, two out of the three species tested at both locations had similar growth in CCR when compared to standard PB substrates. There were more differences between treatments for impatiens, and the authors noted that additional tests with more species would be needed before recommending CCR as a complete substrate alternative.

Boyer et al. (8) also evaluated nine perennial species including butterfly bush (*Buddleia davidii* ‘Pink Delight’), gaura (*Gaura lindheimeri* ‘Siskiyou Pink’), coreopsis (*Coreopsis rosea* ‘Sweet Dreams’ and *Coreopsis grandiflora* ‘Early Sunrise’), verbena (*Verbena canadensis* ‘Homestead Purple’), scabiosa (*Scabisosa columbaria* ‘Butterfly Blue’), dianthus (*Dianthus gratianopolitanus* ‘Firewitch’), rosemary (*Rosmarinus officinalis* ‘Irene’), and salvia (*Salvia guaranitica* ‘Black and Blue’) for growth in CCR on an outdoor container pad. Treatments consisted of 100% pine bark (control), 100% CCR (0.75 inch screen), and 100% CCR (0.50 inch screen). Additionally, the authors evaluated a 4:1 (v:v) ratio of each of the preceding susbtrates with peat moss. The study was duplicated in Poplarville, MS. Substrates composed of 100% PB or 100% CCR were reported to have higher air space percentages and lower water holding capacity percentages which may have resulted in inadequate amounts of available water to the plants. Even so, there were 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, AL. The four species that did show differences across treatments were only slightly smaller when grown in 100% CCR.

In 2009, Boyer et al. (10) reported that the use of CCR as a nursery crop substrate for container-grown ornamentals was acceptable for use at several screen sizes (1.25, 0.75, 0.5, or 0.38 inches). Five species were tested, including loropetalum (*Loropetalum chinensis* var. rubrum), butterfly bush (*Buddleia davidii* ‘Black Knight’), crapemyrtle (*Lagerstroemia indica* ‘Hopi’, and *Lagerstroemia* x *fauriei* ‘Natchez’), azalea (*Rhododendron indicum* ‘Mrs. G.G. Gerbing’). Loropetalum, buddleia, crapemyrtle, and azalea plants grown in this study reportedly showed few differences in plant growth, leaf chlorophyll content, and inflorescence number over the course of one year for all species. Additionally, percent rootball coverage was generally similar across treatments, although loropetalum, buddleia and azalea had the greatest rootball percentage in PB. In addition to these results, consistency among pH and EC levels suggested that CCR would be a dependable substrate comparable to PB in the production of the five woody ornamentals tested.

Pine tree substrate (PTS) is another possible alternative substrate for horticultural crop production (30). PTS is a wood-based substrate constructed by grinding whole delimbed loblolly pine logs (*Pinus taeda*). An evaluation of pH for PTS-amended substrates showed that PTS was more weakly buffered against a pH change than peatmoss (31). Results from the study also indicated that PTS produced from freshly harvested pine trees has a higher pH than a standard Peat-lite substrate, and that the addition of peatmoss to PTS requires a pH adjustment of the substrate for optimal plant growth. In 2010, Jackson, et al. reported on the methods for preparing a PTS from various wood particle sizes, organic amendments, and sand in order to construct a wood-amended substrate with desired physical characteristics. The studies presented in the article show that amending coarsely ground PTS with a certain amount of finely ground PTS could result in a physically similar substrate (similar air space and water holding capacity) to standard PB and Peat-lite substrates.

Research on these numerous alternative substrates has already proven useful to the nursery industry. Although most growers are uncomfortable with making such a drastic change in their standard production practices, they are asking if some of these alternative substrates can be used to stretch existing PB supplies. Additionally, forest operators across the southeast are looking to capitalize on low-value forest trees. The objectives of this thesis were to determine both how far growers could extend their pine bark supplies with WT or CCR, and to determine the viability of several low-value forest trees as substrate components for annual production.

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CHAPTER II

EXTENDING PINE BARK SUPPLIES WITH *WHOLETREE* AND CLEAN CHIP RESIDUAL SUBSTRATES

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 are being evaluated (3,4,5,6,7,8,9,11), 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 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 cm, 1.91 cm, 1.27 cm, and 0.95 cm) (1 ¼-inch, ¾-inch, ½ -inch, and 3/8-inch, 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 (3/8-inch, 1/4-inch, or 3/16-inch), as well as 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* x '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/day) (0.5 in/day). 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·L) 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). Values for pH and EC ($mS \cdot cm^{-1}$) of the substrates 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, N.C.) (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 2.1). Values were between 25 and 30%, with the lowest percentage at 25.1% (75:25 PB:WT). Subsequently, percent substrate 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 (3.35-9.50mm), medium (1.00-2.36mm), and fine (0.00-0.50mm). Particles greater than 3.35mm afford aeration to container substrates (15). There were no differences in the amount of coarse particles of any substrate treatment (Table 2.2). Medium particles were greatest in substrates with increased levels of CCR (25:75 PB:CCR and 100% CCR, 41.4mm and 44.9mm, respectively). Medium particles were least in 100% PB (32.9mm) and 75:25 PB:WT (34.1mm). Only two treatments (75:25 PB:WT and 25:75 PB:WT, 34.1mm and 36.3mm, respectively) had similar amounts of medium particles compared to that of the 100% PB industry standard (32.9mm). 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 quickly than desired (1). All substrate treatments had similar fine particle weights to that of the nursery standard, 100% PB (46.7mm).

Shrinkage. No differences occurred for shrinkage between any container substrate treatment at any of the three testing dates (15, 180 and 365 DAT) (Table 2.3). Throughout the study, shrinkage for all substrates increased steadily for an overall average of 1.53cm. 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 2.4). 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 the 180 and 365 DAT testing dates, 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 2.4). 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 2.5). 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 (Table 2.6). 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 cm (1.25 in), 1.9 cm (0.75 in), 1.3 cm (0.50 in), and 1.0 cm (0.38 in)] 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 (Table 2.7). 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* x ‘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 2.8). 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 ppm, 171-294 ppm, and 33-51 ppm, respectively) were all higher than those given in the survey range (59-124 ppm, 59-141 ppm, 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.

Conclusion

While some pH and EC differences occurred in substrates amended with CCR and WT early in the study, values leveled out by 180 DAT. 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.

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Table 2.1. 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 ($g\cdot cm^{-3}$)[u]
100% PB	26.0 b[t]	40.7 cd	66.7 b	0.37 e
75:25 PB:CCR	36.4 a	39.5 d	75.9 a	0.20 f
50:50 PB:CCR	26.2 b	41.3 bcd	67.5 b	0.39 de
25:75 PB:CCR	26.3 b	45.0 abc	71.3 ab	0.40 cd
100% CCR	28.6 b	43.3 a-d	71.9 ab	0.39 de
75:25 PB:WT	25.1 b	46.9 a	72.1 ab	0.45 a
50:50 PB:WT	27.2 b	46.3 ab	73.4 ab	0.39 de
25:75 PB:WT	26.6 b	46.9 a	73.5 ab	0.42 b
100% WT	25.9 b	40.7 cd	66.6 b	0.41 bc
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 2.2. Particle size distribution analysis of nine substrates containing pine bark, clean chip residual and *WholeTree* substrate.

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

[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.

Table 2.3. Effect of nine substrates containing pine bark, *WholeTree* substrate, and clean chip residual on media shrinkage[z].

Substrate[y]	15 DAT[x]	120 DAT	365 DAT
100% PB	2.7[w,ns]	4.0[ns]	4.0[ns]
75:25 PB:WT	2.7	3.5	4.1
50:50 PB:WT	2.7	3.6	4.2
25:75 PB:WT	2.5	3.5	4.4
100% WT	3.0	4.1	4.9
75:25 PB:CCR	3.0	3.7	4.0
50:50 PB:CCR	2.6	3.4	4.0
25:75 PB:CCR	2.5	3.6	4.3
100% CCR	2.5	3.7	4.1

[z] Shrinkage reported as cm from top of pot to top of media.

[y] PB = pine bark, WT = Wholetree substrate, CCR = clean chip residual.

[x] DAT = days after transplanting.

[w] Means separated based on Tukey's Studentized Range Test at $\alpha = 0.05$.

[ns] Means not significantly different.

Table 2.4. 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 ($mS \cdot cm^{-1}$)[w]	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)
100% PB	6.0 [v,ns]	1.39 ab	6.5 ab	1.12 ab	6.0 [ns]	0.77 ab	6.3 c	0.57 ab
75:25 PB:CCR	6.2	1.60 a	6.3 b	1.28 a	6.2	0.95 a	6.3 c	0.72 a
50:50 PB:CCR	6.3	1.28 ab	6.3 b	0.96 ab	6.4	0.54 bc	6.4 bc	0.58 ab
25:75 PB:CCR	6.4	1.20 ab	6.7 a	0.62 b	6.1	0.66 abc	6.5 bc	0.42 ab
100% CCR	6.3	1.03 ab	6.5 ab	0.75 ab	6.5	0.40 bc	6.6 b	0.37 b
75:25 PB:WT	6.2	1.51 a	6.3 b	1.10 ab	6.1	0.74 ab	6.3 c	0.61 ab
50:50 PB:WT	6.3	1.24 ab	6.4 ab	0.91 ab	6.1	0.41 bc	6.5 bc	0.39 b
25:75 PB:WT	6.4	0.86 b	6.5 ab	0.97 ab	6.4	0.13 bc	6.5 bc	0.39 b
100% WT	6.3	1.10 ab	6.5 ab	0.82 ab	6.6	0.35 c	6.9 a	0.34 b

	90 DAT		120 DAT		180 DAT		365 DAT	
Substrate[y]	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)
100% PB	6.0 d	0.47 ab	6.2 [ns]	0.45 b	6.3 [ns]	0.53 [ns]	5.7 ab	0.21 [ns]
75:25 PB:CCR	5.9 d	0.62 b	6.3	0.66 a	6.2	0.83	5.5 b	0.28
50:50 PB:CCR	6.2 bcd	0.38 a	6.3	0.47 b	6.2	0.56	6.0 a	0.23
25:75 PB:CCR	6.5 ab	0.39 b	6.4	0.37 b	6.4	0.61	5.9 ab	0.25
100% CCR	6.5 ab	0.32 b	6.6	0.36 b	6.5	0.42	5.8 ab	0.27
75:25 PB:WT	6.1 cd	0.43 b	6.3	0.43 b	6.2	0.82	5.8 ab	0.20
50:50 PB:WT	6.4 abc	0.37 b	6.3	0.42 b	6.4	0.58	5.8 ab	0.22
25:75 PB:WT	6.6 a	0.39 b	6.3	0.42 b	6.5	0.58	5.8 ab	0.23
100% WT	6.5 a	0.35 b	6.3	0.36 b	6.4	0.46	5.9 ab	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 $mS \cdot cm^{-1}$ = 1 $mmho \cdot cm^{-1}$.

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

[ns] Means not significantly different.

Table 2.5. Effect of nine substrates containing pine bark, clean chip residual, and *WholeTree* substrate on growth indices[z] of six ornamental species.

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

	'Rotundifolia' ligustrum		*'Gold Mound' spirea*		*tea olive*	
Substrate[y]	**90 DAT**	**365 DAT**	**90 DAT**	**365 DAT**	**90 DAT**	**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].

[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.

Table 2.6. Influence of nine substrates containing pine bark, clean chip residual, and *WholeTree* substrate on leaf chlorophyll content of six ornamental species.

	'Amaghasa' azalea			*'Soft Touch' holly*			*'New Gold' lantana*		
Substrate^{y}	**30 DAT^{x}**	**120 DAT**	**365 DAT**	**30 DAT**	**120 DAT**	**365 DAT**	**30 DAT**	**120 DAT**	**365 DAT**
100% PB	51.5 ^{w,ns}	60.8 ^{ns}	52.3 ^{ns}	53.2 ^{ns}	66.1 ^{ns}	52.9 ^{ns}	40.1 ^{ns}	36.1 ^{ns}	22.2 ^{ns}
75:25 PB:CCR	52.1	60.9	54.9	45.4	63.0	43.4	40.0	38.8	21.7
50:50 PB:CCR	55.1	60.0	51.8	51.8	71.0	43.4	40.3	38.1	26.5
25:75 PB:CCR	53.4	61.1	53.6	46.8	64.5	44.8	39.7	38.6	23.2
100% CCR	50.1	60.0	54.6	45.9	66.8	50.0	39.1	37.2	25.9
75:25 PB:WT	51.8	61.6	53.1	48.7	66.0	52.1	40.3	38.6	21.3
50:50 PB:WT	54.5	59.7	53.2	49.7	61.3	50.8	39.8	36.5	22.3
25:75 PB:WT	48.1	61.8	52.9	46.6	67.8	47.0	38.9	36.0	26.5
100% WT	50.6	60.8	53.3	49.5	60.1	51.0	38.9	36.3	22.5

	'Rotundifolia' ligustrum			*'Gold Mound' spirea*			*tea olive*		
Substrate^{y}	**30 DAT**	**120 DAT**	**365 DAT**	**30 DAT**	**120 DAT**	**365 DAT**	**30 DAT**	**120 DAT**	**365 DAT**
100% PB	49.3 ^{ns}	66.0 a	52.5 ^{ns}	22.5 ^{ns}	20.8 ^{ns}	19.5 ^{ns}	42.3 ab	43.6 ab	43.7 ^{ns}
75:25 PB:CCR	47.3	61.0 ab	48.2	21.5	24.2	17.1	42.5 ab	49.0 a	45.0
50:50 PB:CCR	41.9	59.0 ab	52.7	23.2	24.8	17.0	47.0 a	46.8 ab	44.4
25:75 PB:CCR	47.6	62.3 ab	54.6	21.7	24.6	18.6	35.7 b	36.8 b	47.3
100% CCR	45.9	62.1 ab	51.1	22.2	25.3	20.4	43.2 ab	40.0 ab	47.0
75:25 PB:WT	46.8	63.1 ab	48.7	23.3	22.5	20.0	42.3 ab	44.3 ab	43.1
50:50 PB:WT	45.2	62.1 ab	47.9	20.2	21.0	18.1	41.4 ab	43.1 ab	47.6
25:75 PB:WT	49.3	56.7 ab	51.4	20.9	22.9	19.1	42.9 ab	48.4 a	47.6
100% WT	44.4	55.1 b	54.7	19.6	21.7	17.8	42.4 ab	40.4 ab	46.5

[z] Leaf chlorophyll content as determined by a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) (n = 3).

[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 α = 0.05 (n=3).

[ns] Means not significantly different.

Table 2.7. Effect of nine substrates containing pine bark, *WholeTree* substrate, and clean chip residual on root growth[z] of six ornamental species.

Substrate[y]	*'Amaghasa' azalea*	*'Soft Touch' holly*	*'New Gold' lantana*	*'Rotundifolia' ligustrum*	*'Gold Mound' spiraea*	*tea olive*
100% PB	$5.0^{x,ns}$	2.6^{ns}	5.0^{ns}	5.0^{ns}	5.0^{ns}	5.0^{ns}
75:25 PB:WT	5.0	2.1	5.0	5.0	4.9	4.7
50:50 PB:WT	5.0	3.1	5.0	5.0	5.0	4.9
25:75 PB:WT	5.0	3.0	4.9	5.0	4.9	4.4
100% WT	4.9	3.0	5.0	5.0	4.9	4.4
75:25 PB:CCR	5.0	2.1	5.0	5.0	5.0	4.3
50:50 PB:CCR	5.0	2.1	5.0	5.0	5.0	3.9
25:75 PB:CCR	5.0	2.6	5.0	5.0	5.0	4.6
100% CCR	4.7	3.3	5.0	5.0	5.0	4.4

[z] Root growth assessed on 1-5 scale (1 - less than 20% root ball coverage, 5 - between 80-100% root ball coverage)

[y] PB = pine bark, WT = Wholetree substrate, CCR = clean chip residual

[x] Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test at $\alpha = 0.05$ ($n = 7$)

[ns] Means not significantly different

Table 2.8. 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**	**Zn**	**Cu**	**B**
	(%)	**(%)**	**(%)**	**(%)**	**(%)**	**(ppm[x])**	**(ppm)**	**(ppm)**	**(ppm)**
100% PB	3.53 ab[w]	0.28 a	2.28[ns]	1.69[ns]	0.67[ns]	530 a	171 c	44[ns]	42[ns]
75:25 PB:CCR	3.63 ab	0.26 ab	2.24	1.62	0.65	445 ab	211 bc	47	46
50:50 PB:CCR	3.66 a	0.22 ab	2.03	1.51	0.64	191 cd	218 bc	43	40
25:75 PB:CCR	3.46 ab	0.21 b	1.94	1.47	0.62	132 d	194 bc	41	38
100% CCR	3.43 ab	0.22 ab	2.02	1.50	0.66	199 cd	236 b	33	40
75:25 PB:WT	3.58 ab	0.24 ab	2.11	1.64	0.64	336 bc	195 ab	37	47
50:50 PB:WT	3.47 ab	0.24 ab	2.16	1.56	0.63	451 ab	234 b	51	41
25:75 PB:WT	3.34 b	0.22 ab	2.05	1.53	0.63	159 d	202 bc	34	39
100% WT	3.49 ab	0.24 ab	2.12	1.66	0.63	387 ab	294 a	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.

CHAPTER III

LOW-VALUE TREES AS ALTERNATIVE SUBSTRATES IN GREENHOUSE PRODUCTION OF THREE ANNUAL SPECIES

Abstract

Peat and perlite have served as industry standards in greenhouse substrates for over 50 years. The continued availability of peat, paralleled with its inert characteristics, as well as its ability to stay generally pathogen-free have all contributed to its success in the horticulture industry. Expanded perlite has long been used as an amendment in container mediums to provide air space to container substrates without adding to bulk density or affecting substrate pH and EC. However, due to increased restrictions on the harvesting of peat, as well as fluctuations in fuel prices necessary for shipping, the future availability of peat is a largely unknown factor in greenhouse production. Additionally, growers consider perlite to be a general nuisance due to the lung and eye irritation problems. Because of these problems, researchers have focused on identifying and evaluating possible alternatives to standard substrates. These studies evaluated three possible substrate alternatives for use in greenhouse products, including fresh sweetgum (SG), hickory (H), and eastern redcedar (RC), in addition to WholeTree (WT) substrate. Three greenhouse annual crops (petunia, impatiens, and vinca) were planted in varying ratios of these species mixed with peat. Plants grown with SG and H as amendments did not perform as well as a traditional peat:perlite mix with respect to flower number, growth indices, and plant dry weight. However, plants grown in RC tended to be equivalent to those grown in a traditional mix. Data showed that greenhouse producers could amend their standard greenhouse substrate with up to 50% eastern redcedar with little to no differences in plant growth.

Index words: *WholeTree*, container media, redcedar, hickory, sweetgum, peat, perlite

Species used in this study: sweetgum (*Liquidambar styraciflua* L.); hickory (*Carya sp.* Nutt.); eastern redcedar (*Juniperus virginiana* L.); loblolly (*Pinus taeda* L.); 'Dreams Sky Blue' Petunia (*Petunia ×hybrida* Juss. 'Dreams Sky Blue'), 'Cooler Peppermint' vinca (*Catharanthus roseus* (L.) G.Don 'Cooler Peppermint'), and 'Super Elfin Salmon' impatiens (*Impatiens walleriana* Hook.f. 'Super Elfin Salmon').

Significance to the Nursery Industry

With potential shortages of peat for horticultural use, recent research has focused on identifying and evaluating potential alternatives to peat for use in the greenhouse production of annual crops. Growers would also find it beneficial to find a perlite replacement due to the overall dusty nature of perlite. Our data shows that greenhouse producers could amend their standard greenhouse substrate with up to 50% freshly cut eastern redcedar with little to no differences in plant growth. Data from this study also showed the potential for using hardwood alternatives such as sweetgum and hickory, although standard greenhouse practices concerning fertilization, watering practices, etc. might need to be adjusted.

Introduction

Peat has served as the standard greenhouse industry substrate for the past forty to fifty years due to several inherit qualities. Peat embodies several crucial physical characteristics of an ideal greenhouse container substrate, and is generally pathogen-free.

Peat availability is decreasing due to increased regulations and restrictions on the harvesting of peat. These restrictions, paralleled with constantly fluctuating fuel and shipping prices of peat from Canada, have caused growers to seek alternative greenhouse substrates with equivalent physical characteristics (25).

Also, growers are concerned about amending their container substrates with perlite. Up until now, perlite has simply been considered a general nuisance due to its dusty nature. However, recent literature has shown that heavy exposure to perlite may cause persistent reactive airway disfunctive syndrome (6), and a decrease in the lung transfer factor, or carbon monoxide (CO) diffusing capacity (19). These health issues have caused growers to seek alternative greenhouse substrate amendments with equivalent characteristics to perlite.

High wood fiber substrates have been the focus of much research over the past several years (1, 2, 3, 7, 8, 9, 12, 13, 14, 23). Up until now, this research has mainly focused on substrates composed of whole pine trees, chipped pine logs, and residual material left on the forest floor after harvesting at pine plantations.

In this study, three low-value forest trees were evaluated as amendments to a standard peat/perlite mix, including sweetgum (SG) (*Liquidambar styraciflua* L.), hickory (H) (*Carya sp.* Nutt.) and eastern redcedar (RC) (*Juniperus virginiana* L.). SG (family *Hamamelidaceae*) is a medium to fast growing tree (.30-.91 m per year; 1-3 ft per year) which can reach heights of 18.3-22.9 m (60 to 75 ft) or taller (5). While a few select cultivars of SG are used in the landscape, there is limited value to the wood once harvested. Different species of H (family *Juglandaceae*) can grow to 18.3 m (60 ft) or taller, are tap-rooted, and therefore difficult to transplant into a landscape (5). They are native to the eastern and southern parts of the United States (species dependent) and are often a part of native hardwood stands across the southeast. The last of the species tested in this study, RC (family *Cupressaceae*) is a coniferous species native to all of east and central North America, primarily east of the Rocky Mountains growing to between 12.2-15.2 m (40 and 50 ft) tall, and reaching spreads of between 2.4-6.1 m (8 and 20 ft) (5). RC does have use as an excellent landscape species when grown as a specific cultivar, but those found native to traditional hardwood forests are thought to be somewhat invasive (11). All of these species are currently viewed as either 'trash trees' or low-value pulpwood trees to the forest industry, indicating they could have the potential to become economical and viable amendments in standard greenhouse substrates.

Previous research has evaluated whole trees and tree barks, other than pine, as substrate amendments (4, 16, 20). In 1975, results showed that the best growth of two azalea species was from 'pine shavings followed by cedar shavings' (20). Later, Kenna and Whitcomb (1985) evaluated hardwood chips of both post oak (*Quercus stellata* Wangh.) and Siberian elm (*Ulmus pumila* L.) as substrate amendments to grow Pyracantha (*Pyracantha* ×'Mojave') and Formosan sweetgum (*Liquidambar formosana* Hance.). The authors noted that both species grew as well in the hardwood amended substrates as in the traditional pine bark substrate. In a separate study, it was reported that substrates amended with as much as 25% hardwood bark could ‘be used successfully as a media for the production of a wide range of woody ornamentals’ (4).

Current research has evaluated the use of RC in the containerized production of woody ornamentals (11, 21). Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) were evaluated in 6 different substrate combinations containing pine bark and varying volumetric ratios of RC (11). Four fertilizer regimes were also evaluated [0.81 kg $N \cdot m^{-3}$ CRF, 1.6 kg $N \cdot m^{-3}$ CRF, 0.4 kg $N \cdot m^{-3}$ Urea (46-0-0), or no fertilizer at all]. Chinese pistache height was similar to the 100% bark treatment for the substrates amended with 5%, 20%, and 40% cedar, but less height was seen in substrates amended with 10% and 80% cedar. Similarly, shoot dry weight was less in the 10% and 80% cedar-amended substrates than in the 100% pine bark standard, but all the other treatments (5%, 20% and 40% cedar-amended substrates) performed equally as well as the standard mix. The author reported no problems with substrate shrinkage or visible deficiencies in common nutrients (11). Starr et al. (2010) assessed RC as a possible substrate alternative for the growth of containerized *Acer saccharinum* from seed. Substrate mixes were pine bark with varying volumetric rates of RC; pine bark was mixed with either 0%, 5%, 10%, 20%, 40% or 80% (by vol) of RC and 20% sand. Two rates of CRF (4.5 kg $N \cdot m^{-3}$ and 8.9 kg $N \cdot m^{-3}$) were also tested. By 76 days after transplanting (DAT), plants grown in 80% RC had grown the least (plant height = 12.9 cm), although plants grown in up to 20% cedar produced plants similar in caliper, root dry weight, and shoot dry weight. Fertilizer was also noted to be a significant factor for growth, since plants grew to greater heights with the higher fertilizer rates than those with the lower fertilizer rate. The authors suggested that the lack of sufficient growth in the 80% RC substrate may have been due to inadequate physical properties.

While existing studies have only evaluated the growth of woody ornamentals in nursery substrates amended with cedar and hardwoods, limited research has been conducted on greenhouse-grown crops. The objective of this study was to determine if growers could amend their standard greenhouse substrates with up to 50% SG, H, or RC, without reducing the quality of three annual crops. Positive results from this study could have the potential to meet the substrate demands created by peat shortages and worker safety problems associated with perlite use.

Materials and Methods

SG [avg. diameter at breast height (DBH) = 12.6 cm (4.97 in)] and H [avg. DBH = 13.0 cm (5.10 in)] were harvested from the forest on February 16, 2009 and RC [avg. DBH = 12.6 cm (4.95 in)] was cut on February 17, 2009. All trees were de-limbed at the time of cutting. SG, H and RC were chipped through a Vermeer BC1400XL chipper on February 19, 2009. Fresh WT chips were obtained from Young's Plant Farm (Auburn, AL) on February 19, 2009. WT chips were originally obtained from a pine plantation in Macon County, Alabama, and were prepared by chipping freshly cut 20 to 25 cm (8 to 10 in) caliper loblolly pines (Pinus taeda L.) with a Woodsman Model 334 Biomass Chipper (Woodsman, LLC Farwell, Michigan). All wood was then ground further through a 0.64 cm (0.25 in) screen in a swinging hammer-mill (No. 30; C.S. Bell, Tifton, OH) on February 23, 2009 (for Exp. 1) and May 7, 2009 (for Exp. 2). SG, H RC, and WT chips that were not ground through the hammer-mill in Feb. 2009 were stored in large plastic containers with lids until May 2009 when they were ground as in Exp. 1.

Nine treatments were evaluated in this study including a grower's standard (GS) control consisting of 75:25 (v:v) peat(P):perlite. Remaining treatments consisted of 75:25 (v:v) and 50:50 (v:v) ratios of P:SG, P:H, P:RC, and P:WT. All substrates were amended prior to planting with 4 lb·yd^{-3} (2.37 kg·m^{-3}) 15N-3.9P-10.0K (15-9-12) OsmocotePlus control release fertilizer (3-4 month) (The Scotts Company, Marysville, OH) and 3.0 kg·m^{-3}(5 lb·yd^{-3}) dolomitic limestone. AquaGro-L® wetting agent (Aquatrols Corporation, Paulsboro, NJ) was incorporated at mixing at a rate of 154.7 mL·m^{-3} (4 oz·yd^{-3}).

Three species were used in this study, which was initiated on February 25, 2009 (Exp. 1) and May 8, 2009 (Exp. 2) at the Paterson Greenhouse Complex at Auburn University. 'Dreams Sky Blue' Petunia (*Petunia ×hybrida* Juss. 'Dreams Sky Blue'), 'Cooler Peppermint' vinca (*Catharanthus roseus* (L.) G.Don 'Cooler Peppermint'), and 'Super Elfin Salmon' impatiens (*Impatiens walleriana* Hook.f. 'Super Elfin Salmon') were planted into 1.21 L (1.28 quart) containers with two plugs (from 288 plug flat) per pot in both experiments. Plants were placed on greenhouse benches and watered by hand as needed. The experimental design was a randomized complete block design with 8 single pot replications per treatment. Each species was treated as its own experiment. Data were analyzed using Tukeys Honestly Significant Difference test ($p \leq 0.05$) in a statistical software package (SAS® Institute version 9.1.3, Cary, N.C.).

Physical properties [substrate air space (AS), water holding capacity (WHC), total porosity (TP)] were determined using the North Carolina State University porometer method (n=3) (10). Bulk density (BD) was determined from 347.5 cm^3 (21.2 in^3) samples dried in a 105C (221F) forced air oven for 48 hours (n=3). Particle size distribution (PSD) analysis was determined by passing a 100 g sample [dried in a 76.7C (170F) forced air oven] through a series of sieves (n=3). Sieves were shaken for three minutes with a Ro-Tap sieve shaker (Ro-Tap RX-29, W.S. Tyler, Mentor, OH). Pour-through leachates were obtained from 'Super Elfin Salmon' impatiens at 1, 15, 30 and 45 days after planting (DAP) in order to determine substrate pH and electrical conductivity (EC) (n=4) (22). Substrate shrinkage was evaluated on each species at termination (46 DAP for Exp. 1; 47 DAP for Exp. 2) by measuring distance (in cm) from the top of the pot to the top of the substrate (n=8). Flower number was evaluated at termination, where only open blooms and blooms showing color were counted towards the total number on each plant (n=8). Growth indices [(height + width1 + width2)/3] (cm) were also measured at termination (n=8). Plant dry weights (PDW) were determined after samples were dried at 76.7C (170F) for 72 hours (n=4). Root growth was assessed at study termination on a scale from 1-10, where 1 was assigned to plants with less than 10% root ball coverage, and 10 was assigned to plants with between 90-100% root ball coverage (n=8). Tissue nutrient content was determined using 25-30 recently matured leaves of 'Dreams Sky Blue' petunia in each experiment (n=4). Leaf nitrogen (N) 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). Experiments were terminated on April 12, 2009 (Exp. 1) and June 24, 2009 (Exp. 2).

Results and Discussion

Physical properties. There is no best management practice guide for obtaining desired physical characteristics in a greenhouse substrate equivalent to the BMP Guide for Producing Nursery Crops (24). There are however, some published optimal ranges for AS, WHC and TP (15). For the purposes of this discussion, the authors have elected to evaluate the substrates in this study with the AS, WHC and TP recommendations from Jenkins and Jarrell (15), and the BD recommendation from Yeager et al., 2007. All container substrate AS percentages in Exp. 1 were within the recommended range (10-20% by vol) (Table 3.1). Values ranged from 10.2% (75:25 P:RC) to 16.8% (50:50 P:H), and all AS percentages were similar to the GS (11.8%). Container substrate AS percentages tended to be lower in Exp. 2, where values ranged from 5.9% (75:25 P:SG) to 15.4% (50:50 P:RC). This could be due to the fact that the alternative material was stored for three months before Exp. 2, and may have decomposed slightly. Additionally, the packing of the material for determination of physical properties could have occurred differently from Exp. 1 to Exp. 2. Only three treatments from Exp. 2 had container AS values within the recommended range; 50:50 P:WT (12.3%), 50:50 P:H (11.3%) and 50:50 P:RC (15.4%). Given that container AS percentages were towards the lower end of the recommended range in Exp. 1, and even below that range in Exp. 2, it follows that substrate WHC percentages would be higher than normal. The recommended range for percent substrate WHC is between 50-65%; below that range, substrates often drain too quickly. The range of substrate WHC percentages for Exp. 1 was between 72.2% (GS) and 81.6% (75:25 P:RC). Only four treatments were similar to the GS; 75:25 P:WT (74.9%), 50:50 P:WT (77.0%), 50:50 P:H (75.7%) and 50:50 P:RC (76.0%). In Exp. 2, substrate WHC percentages ranged from 74.9% (50:50 P:WT) to 84.7% (75:25 P:SG). With only one exception [50:50 P:WT (74.9%)], all treatments had similar WHC percentages to that of the GS (82.0%). All percent values for TP of substrates were higher than the recommended range (60 to 75%). In Exp. 1, the only treatment with a similar TP value to the GS (83.9%) was 75:25 P:WT (86.7%). In Exp. 2, the 75:25 P:WT treatment (89.8%) was similar to the GS (88.8%), however three other treatments also had similar TP values; 75:25 P:SG (90.5%), 75:25 P:H (88.4%), and 50:50 P:WT (87.2%). BD values for all treatments across both experiments were less than the recommended range (0.19-1.70 $g{\cdot}cm^{-3}$) (24). In Exp. 1, all treatments were similar to the GS (0.15 $g{\cdot}cm^{-3}$). While all treatments were not similar to the GS in Exp. 2 (0.15 $g{\cdot}cm^{-3}$), all BD values fell within the same tight range as in Exp. 1 (0.13 $g{\cdot}cm^{-3}$ to 0.16 $g{\cdot}cm^{-3}$). In both experiments, the 75:25 P:SG treatment had one of the lowest BD values (0.13 $g{\cdot}cm^{-3}$ for both Exp. 1 and Exp. 2).

Particle size distribution (PSD). Analysis of PSD in Exp. 1 showed that there were no differences across any treatment for the distribution of particles left on the 9.50 mm and 6.35 mm screen (Table 3.2). In smaller screen sizes, many differences occurred. Therefore, in order to better interpret the data, the authors grouped the screens into three distinct categories: coarse (3.35-9.50 mm), medium (1.00-2.36 mm) and fine (0.00-0.50 mm). In Exp. 1, coarse particles for all treatments ranged from 6.5% to 11.1%. Coarse particles are responsible for aeration in a substrate. The 50:50 P:WT treatment (11.1%)

had more coarse particles than any other treatment, although five other treatments had statistically similar values, including 75:25 P:WT (8.6%), 75:25 P:H (8.3%), 75:25 P:RC (8.7%), 50:50 P:SG (8.9%), and 50:50 P:H (9.8%). Medium particles were greatest in the 50:50 P:SG (50.0%) and 50:50 P:RC (50.7) treatments, although both were similar to the other two 50:50 (v:v) treatments. The 75:25 P:perlite GS had the least medium particles of those tested (34.7%). The GS had more fine particles (0.00-0.50 mm) (57.5%) than any other treatment, although several other substrates did have similar values [75:25 P:WT (51.5%), 75:25 P:SG (54.7%), and 75:25 P:H (52.1%)]. This is logical, since the GS also had more particles in the pan (3.1%) than any other substrate tested. Fine particles are necessary in a container substrate to maintain adequate water holding properties.

In Exp. 2, the 50:50 P:RC treatment had the most coarse particles of any treatment (21.7%), however both the 50:50 P:SG (16.8%) and the 50:50 P:H (18.1%) treatments had similar values (Table 3.3). The 75:25 P:H treatment had the least coarse particles of any substrate tested (5.4%). Medium particles across treatments in Exp. 2 ranged from 52.5% (50:50 P:H) to 30.9% (75:25 P:H). Only two treatments were similar to the GS (35.8%); 75:25 P:WT and 75:25 P:SG (both 32.6%). Just as with Exp. 1, the GS in Exp. 2 had more distribution of particles in the bottom pan of the set of sieves (2.9%) than any other treatment. However, the GS did not have the most fine particles. The 75:25 P:H treatment had the most fine particles (60.4%), although the 75:25 P:WT (56.8%) and 75:25 P:SG (53.4%) treatments had similar amounts to the 75:25 P:H treatment.

pH and EC. The recommended range for pH of *Impatiens walleriana* is between 5.5 and 6.0 (17). In Exp. 1, all treatments (4.8-5.4) were below that range at 1 DAP

(Table 3.4). At 14 DAP, the pH of all treatments had climbed to within the ideal range, except for the GS (5.4). Throughout the rest of Exp. 1, treatments remained consistent, and by 45 DAP, only 50:50 P:SG (6.1) and 50:50 P:H (6.1) were slightly over the recommended range, and were the only treatments not similar to the GS (5.5) by study termination. In general, treatments containing RC tended to have similar pH values to the GS treatment, except at 1 DAP, where 75:25 P:RC (5.1) and 50:50 P:RC (5.2) both exhibited higher pH values than the GS (4.8). In Experiment 2, at 14, 30, and 45 DAP, 50:50 P:H had higher pH levels (6.2, 6.7, 6.4, respectively) than the GS (5.6, 6.2, 5.9, respectively). pH values for 50:50 P:SG tended to be higher than those for the GS throughout Exp. 2, except at 14 DAP, where the values were similar. Substrate pH values for the 75:25 P:RC treatment were similar to those of the GS at all testing dates in Exp. 2. However, higher percentages of RC in the substrate (50%) tended to raise pH values to levels higher than in the GS. Evidence of this can be seen at 30 and 45 DAP where pH values for 50:50 P:RC treatments (6.5 and 6.3, respectively) were higher than those for the GS control (6.2 and 5.9, respectively). Treatments containing WT had similar pH values to the GS at each testing date in Exp. 2. For the most part, pH values were slightly higher in Exp. 2 than in Exp. 1, although the general trends between substrates were consistent across both experiments.

The recommended range for substrate EC levels of *Impatiens walleriana* is between 1.25 and 2.0 $mS{\cdot}cm^{-1}$ (17). At both 1 and 14 DAP (Exp. 1), EC levels were much lower for all treatments compared to the GS (1.8 $mS{\cdot}cm^{-1}$ and 1.6 $mS{\cdot}cm^{-1}$, respectively) (Table 3.4). By 30 DAP however, all treatments were similar to the GS (0.6 $mS{\cdot}cm^{-1}$), however EC values for 50:50 P:H (0.7 $mS{\cdot}cm^{-1}$) was higher than the EC values for the following treatments: 75:25 P:WT, 75:25 P:SG, 75:25 P:RC, and 50:50 P:WT (all of which had a mean EC of 0.4 mS·cm^{-1}). In Exp. 2, substrate EC levels for all treatments were similar to the GS (1.2 mS·cm^{-1}) at 1 DAP except for the 50:50 P:RC treatment (0.7 mS·cm^{-1}). At 14 DAP, the only treatments dissimilar to the GS (2.4 mS·cm^{-1}) were the 50:50 blends of both P:SG (1.0 mS·cm^{-1}) and P:H (0.7 mS·cm^{-1}). All other treatments, including all 75:25 blends of P:WT (1.3 mS·cm^{-1}), P:RC (1.7 mS·cm^{-1}), P:SG (2.2 mS·cm^{-1}), and P:H (2.0 mS·cm^{-1}), as well as the 50:50 blends of both P:WT (1.4 mS·cm^{-1}) and P:RC (1.4 mS·cm^{-1}) were similar to the GS (2.4 mS·cm^{-1}). There were no differences among any substrate EC levels at 30 DAP for Exp. 1. By study termination (45 DAP), no differences were observed among any treatments for either experiment.

Shrinkage. In Exp. 1 with petunia, only two treatments had shrinkage greater than in the GS (1.8 cm); 75:25 P:SG (2.4 cm) and 50:50 P:RC (2.4 cm) (Table 3.5). With impatiens, all treatments were similar to the GS (2.3 cm), and the only difference among treatments was between 75:25 P:H (2.8 cm) and 50:50 P:WT (2.0 cm). With respect to vinca grown in Exp. 1, shrinkage among all treatments were similar to the GS (1.3 cm), with the exception of the 75:25 P:H treatment (2.0 cm). Shrinkage tended to be less in Exp. 2. This could be due to the fact that Exp. 2 was initiated 81 days after the trees were harvested, giving the substrate components time to slightly decompose. For petunia, there were no differences among all treatments with respect to shrinkage. For impatiens, the only treatment differing from the GS (1.3 cm) was the 75:25 P:RC (1.9 cm) treatment. With vinca, all treatments had similar shrinkage values to the GS (0.8 cm).

Flower number. In Exp. 1, the only treatment to have similar petunia flower number to the GS was the 75:25 P:WT treatment (Table 3.6). In evaluating impatiens flower number, four treatments had similar flower counts to that seen in the GS (59.1), including 75:25 P:WT (50.5), 75:25 P:SG (39.1), 75:25 P:RC (41.8), and 50:50 P:WT (41.8). For vinca, the only treatments similar to the GS were 75:25 P:WT and 75:25 P:RC. All substrate treatments containing SG or H had less flowers than those containing 25% WT or RC, or the GS. In Exp. 2, petunia flower number for all treatments were similar to the GS, except for the 50:50 (v:v) P:H treatment. With impatiens, treatments with RC and WT were similar to the GS (both v:v ratios of each), while treatments with H and SG had less flowers. Only two treatments (75:25 P:RC and 50:50 P:RC) were similar to the GS with respect to flower number in vinca. Other treatments, including those with WT, H and SG had fewer flowers than the GS in Exp. 2. Preliminary studies evaluating WT showed similarities to the current study. In a study by Fain et al., (8), flower number of lantana and petunia generally decreased as the volume of WT increased in the substrate.

Growth indices. Petunia growth indices from Exp. 1 indicated that only the 75:25 P:WT and 75:25 P:RC treatments were similar to the GS (Table 3.7). For both impatiens and vinca, three treatments were similar to the GS (19.7 and 21.0, respectively); 75:25 P:WT (19.2 and 19.4, respectively), 75:25 P:RC (17.1 and 19.8, respectively), and 50:50 P:WT (17.9 and 18.5, respectively). All other substrate treatments exhibited less growth than plants grown in the GS. Results were similar with few exceptions in Exp. 2. Petunias in the following treatments were similar in size to those in the GS (26.7): 75:25 P:WT (26.1), 75:25 P:H (24.9), 75:25 P:RC (26.1), 50:50 P:WT (26.4), and 50:50 P:RC

(26.3). Both substrate treatments containing SG [75:25 P:SG (23.2) and 50:50 P:SG (22.2)], as well as 50:50 P:H (18.1) had less growth than that exhibited in the GS. With impatiens, the only 75:25 (v:v) treatment not similar to the GS (22.4) was 75:25 P:H (18.5). When the volume of the alternative was increased from 25% to 50%, only treatments containing WT and RC remained similar in growth to the GS. Vinca growth in the GS (25.6) for Exp. 2 was similar to three treatments, including 75:25 P:WT (24.0), 75:25 P:RC (25.6) and 50:50 P:RC (25.1). Treatments containing SG and H did not perform well. Overall, growth was numerically greater for all treatments in Exp. 2 compared to Exp. 1. The authors attributed this to the fact that the alternative wood substrates had aged approximately 80 days prior to initiating Exp. 2, while the age at initiation of Exp. 1 was only 8 days.

In a similar study evaluating the growth of containerized silver maple (*Acer saccharinum*) from seed in several cedar-amended substrates, growth decreased as the amount of cedar in the pot was increased to 80% (by vol) (21). Although no specific data was given, this general lack of growth was attributed to undesirable physical properties in such a heavily cedar-amended substrate (i.e. - high air space, low container capacity). While results for air space and container capacity were not out of range for the current study, a generally comparable trend occurred in that air space increased with an increase in cedar, sweetgum, and hickory, and container capacity decreased. Any differences in the studies may be in the processing of the material. Cedar from the study evaluating silver maple growth was ground through a 0.75 in (19 mm) screen, while all material from the current study was ground through a 0.25 in (6.3 mm) screen.

Plant dry weight. Petunia PDW (Exp. 1) was greater in the GS substrate mix (10.4 g) than in any other substrate (Table 3.8). When comparing treatments within similar v:v ratios, treatments containing RC and WT had higher PDW than treatments containing SG and H. For instance, 75:25 P:WT (7.7 g) and 75:25 P:RC (7.6 g) had greater PDW in Exp. 1 than petunias in 75:25 P:SG (3.8 g) or 75:25 P:H (4.6 g). With impatiens in Exp. 1, the only treatment to have a similar PDW to the GS (4.6 g) was the 75:25 P:WT treatment (3.5 g). For vinca in Exp. 1, plants grown in the GS had the highest PDW (7.7 g). In Exp. 2, Petunia PDW in 75:25 P:RC (14.4 g), P:WT (13.4 g), 50:50 P:RC (13.3 g) and P:WT (12.3 g) were similar to GS PDW (13.2 g). The 75:25 P:H (10.3 g) treatment was the only treatment containing H or SG to be similar to the GS. For impatiens and vinca in Exp. 2, substrate treatments containing RC were the only treatments similar to the GS. PDW of plants in treatments containing H and SG had the least PDW. In general, PDW was greater in Exp. 2 than respective treatments in Exp. 1. Again, this could be attributed to the substrate aging between experiments. Also, Exp. 1 was initiated in February 2008, while Exp. 2 was initiated in May 2008. The warmer temperatures and longer daylengths may have positively affected growth, and subsequently, PDW.

Root growth. All petunia had similar root growth ratings to those grown in the GS in Exp. 1 (5.0) (Table 3.9). For impatiens in Exp. 1, all but two treatments exhibited similar, or greater, root growth to plants grown in the GS (4.1); plants grown in 50:50 P:WT (7.0) had more root growth than the GS, while plants grown in 50:50 P:SG (1.4) had less. There were no differences across any treatment with respect to root growth for vinca in Exp. 1. Root ratings were somewhat similar in Exp. 2, where all treatments were similar to the GS (7.4) with petunia. With impatiens and vinca, all treatments containing 25% of the alternative substrate material were observed to have similar root ratings to the GS (6.4 for impatiens; 7.1 for vinca). The only two treatments in both plant species to have dissimilar root ratings to the GS were 50:50 P:SG (1.9 for impatiens; 4.4 for vinca) and 50:50 P:H (1.5 for impatiens; 3.9 for vinca).

Tissue nutrient content. Tissue N levels of petunia in both Exp. 1 (1.38 to 2.99%) and Exp. 2 (1.57 to 2.82%) were all below the sufficiency range of 3.85 to 7.60% (18) (Table 3.10). In Exp. 1, percentage N was highest in the GS (2.99%), and least in any substrate treatment containing H [75:25 P:H (1.58%) and 50:50 P:H (1.38%)]. The only treatments with similar percentage N values to the GS in Exp. 1 were 75:25 P:SG (2.30%), 50:50 P:WT (2.25%) and 50:50 P:RC (2.33%), while in Exp. 2, only treatments with RC [75:25 P:RC (2.44%) and 50:50 P:RC (2.35%)] were similar to the GS (2.82%). Values for P were less than the recommended range (0.47 to 0.93%) for all treatments in both experiments. However, all treatments were similar to the GS (0.22% for Exp. 1, 0.25% for Exp. 2) with respect to P in both experiments with only one exception in Exp. 2 [50:50 P:H (0.15%)]. In Exp. 1 and 2, all treatments had equal or higher K levels than the GS (1.59% in Exp. 1, 0.89% in Exp. 2). There were no differences across any treatments concerning Ca content in Exp. 1, although the range of values for Ca (0.60 to 0.70%) was less than the recommended range (1.20 to 2.81%). Ca levels were higher in Exp. 2, and all levels were similar to the GS (1.05%), except for 50:50 P:SG (1.66%). All Mg levels were within the recommended range of 0.36 to 1.37%, and all treatments were similar to the GS (1.11%). Similar results were obtained with Mg in Exp. 2. All Mn levels were within the recommended range (44 to 177 ppm) for both experiments. While some of the Cu levels were slightly above the recommended range of 3 to 19 ppm in Exp. 2, there were no differences across any treatments for Cu in either experiment. For the most part, B values were within the recommended range (18 to 43 ppm) for all treatments in both experiments. B levels for 50:50 P:WT (14 ppm in Exp. 1 and 11 ppm in Exp. 2) and 50:50 P:RC (13 ppm in Exp. 1 and 9 ppm in Exp. 2) were the only two treatments less than the recommended range. The only treatment in Exp. 1 with an Fe level similar to the GS (309 ppm) was the 75:25 P:H (157 ppm) treatment, and the only treatments outside the recommended range (84 to 168 ppm) were the GS, 50:50 P:SG (70 ppm), and 50:50 P:H (51 ppm). Results for Fe content in Exp. 2 were higher than in Exp. 1. Fe levels were different in four treatments compared to the GS (469 ppm), including 75:25 P:H (164 ppm), 50:50 P:WT (152 ppm), 50:50 P:H (124 ppm), and 50:50 P:RC (166 ppm). Coincidentally, these four treatments were also the only four within the recommended range for Fe. The GS had the highest Na value (5695 ppm) in Exp. 1, and no other treatment had a similar value. Na levels in Exp. 2 were slightly higher, but were within the recommended range (3067 to 10896 ppm) with the exception of the GS (11311 ppm). Al and Zn values in Exp. 1 (19 to 31 ppm for Al; 17 to 28 ppm for Zn) were less than the recommended sufficiency ranges (50 to 92 ppm for Al; 33 to 85 ppm for Zn), but there were no differences across treatments for either element. Although Al levels were higher in Exp. 2 (31 to 120 ppm), there were still no differences among treatments. Zn levels were also higher in Exp. 2 (42 to 82 ppm), but they were all within the recommended range.

Conclusion

In general, these data show that while physical properties were similar, plant growth was different across substrate treatments. Throughout the study, treatments with RC as an amendment tended to be comparable to the traditional GS. Plants in treatments with RC also performed equal to or better than plants in WT. Plants grown with SG and H as amendments differed significantly from the GS with respect to flower number, growth indices, SPAD values, and PDW. SG and H are not recommended as amendments for annual plant production with current greenhouse practices. Additional studies are in place to determine if different fertility regimes could improve the growth and flowering of plants in these alternative substrates. While results from this study concerning using RC as an amendment in the GH production of three annual crops were promising, additional trials with a greater number of plant species would be necessary before advising growers to make a switch in their own production practices.

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Table 3.1. Physical properties[z] of nine substrates containing peat, perlite, *WholeTree* , hickory, sweetgum, and redcedar[y].

Substrate	Air Space[x]		Substrate water holding capacity[w]		Total Porosity[v]		Bulk density ($g \cdot cm^{-3}$)[u]	
	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1	Exp. 2
75:25 Peat:Perlite	11.8 ab[t]	6.8 c	72.2 e	82.0 abc	83.9 c	88.8 de	0.15 abc	0.15 ab
75:25 Peat:Wholetree	11.8 ab	6.5 c	74.9 de	83.3 ab	86.7 bc	89.8 cd	0.14 bc	0.13 d
75:25 Peat:Sweetgum	10.8 ab	5.9 c	81.0 ab	84.7 a	91.9 a	90.5 bcd	0.13 c	0.13 d
75:25 Peat:Hickory	10.5 ab	8.8 bc	78.1 abcd	79.6 bc	88.7 b	88.4 de	0.16 a	0.14 bcd
75:25 Peat:Redcedar	10.2 b	8.6 bc	81.6 a	83.9 a	91.9 a	92.6 ab	0.15 ab	0.13 d
50:50 Peat:Wholetree	15.0 ab	12.3 ab	77.0 abcde	74.9 d	92.0 a	87.2 e	0.15 ab	0.13 d
50:50 Peat:Sweetgum	12.8 ab	9.3 bc	80.8 abc	82.2 ab	93.5 a	91.5 abc	0.14 bc	0.14 bcd
50:50 Peat:Hickory	16.8 ab	11.3 ab	75.7 cde	80.9 abc	92.5 a	92.1 abc	0.14 bc	0.16 a
50:50 Peat:Redcedar	17.1 a	15.4 a	76.0 bcde	78.1 cd	93.0 a	93.5 a	0.14 bc	0.15 abc
Optimal range for Greenhouse Subustrates[s]	10-20%		50-65%		60-75%		N/A	
Recommended Range for Nursery Crops[r]	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] *WholeTree* , hickory, sweetgum and redcedar processed through 0.64 cm (0.25 in) screen.

[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 105.0°C (221.0°F) for 48 hrs; $1\ g \cdot cm^{-3} = 62.43\ lb \cdot ft^{-3}$.

[t] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at $\alpha=0.05$ (n=3).

[s] Recommended ranges as reported by Jenkins and Jarrell, 1989. Predicting physical and chemical properties of container mixtures.

[r] Recommended ranges as reported by Yeager, et al., 2007. Best Management Practices: Guide for Producing Nursery Crops.

Table 3.2. Particle size distribution analysis[z] of nine substrates containing peat, perlite, *WholeTree* , sweetgum, hickory, and redcedar[y] (Experiment 1)[x].

		Substrates								
U.S. standard	sieve opening (mm)[w]	75:25 Peat:Perlite	75:25 Peat:WholeTree	75:25 Peat:Sweetgum	75:25 Peat:Hickory	75:25 Peat:Redcedar	50:50 Peat:WholeTree	50:50 Peat:Sweetgum	50:50 Peat:Hickory	50:50 Peat:Redcedar
3/8	9.50	0.0 [v, ns]	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0
1/4	6.35	0.1 [ns]	0.1	0.3	0.3	0.5	0.0	0.3	0.5	0.3
6	3.35	7.7 bc	8.5 abc	6.1 c	7.9 bc	7.9 bc	11.1 a	8.6 abc	9.3 ab	7.6 bc
8	2.36	12.3 bcd	12.1 cd	10.7 d	11.1 cd	11.9 cd	16.6 a	15.6 a	14.1 abc	15.3 ab
10	2.00	4.4 cd	4.3 d	4.2 d	4.6 cd	5.4 bc	5.7 b	5.9 b	5.7 b	7.1 a
14	1.40	9.1 d	11.5 c	11.2 cd	11.5 c	13.3 bc	13.9 ab	15.5 ab	15.1 ab	15.8 a
18	1.00	8.9 e	9.4 de	10.8 bcd	9.7 cde	11.8 ab	11.2 abcd	12.9 a	11.3 abc	12.5 ab
35	0.50	16.3 f	19.1 cde	22.8 a	20.1 bc	21.2 b	18.8 cde	19.7 bcd	18.1 e	18.4 de
60	0.25	16.4 ab	17.5 ab	18.3 a	17.6 ab	14.5 bc	12.4 c	11.7 c	12.6 c	12.0 c
140	0.11	15.7 a	11.0 b	9.8 bcd	10.3 bc	7.1 cde	6.0 de	5.1 e	7.1 cde	6.5 cde
270	0.05	6.1 a	2.8 bc	2.7 bc	2.9 b	1.8 bc	1.6 bc	1.3 c	2.5 bc	1.8 bc
pan	0.00	3.1 a	1.1 b	1.1 b	1.1 b	0.7 bcd	0.5 cd	0.5 d	1.2 b	1.0 bc
Texture[u]										
Coarse		7.8 bc	8.6 abc	6.5 c	8.3 abc	8.7 abc	11.1 a	8.9 abc	9.8 ab	7.9 bc
Medium		34.7 d	37.3 cd	36.9 cd	37.0 cd	42.3 bc	47.5 ab	50.0 a	46.2 ab	50.7 a
Fine		57.5 a	51.5 ab	54.7 a	52.1 ab	45.3 bc	39.3 c	38.3 c	42.5 c	39.7 c

[z] Particle size distribution determined by passing a 100 g [76.7°C (170.0°F) forced air oven for 120 hours] sample through a series of sieves. Sieves were shaken for three minutes with a Ro-Tap sieve shaker (Ro-Tap RX-29, W.S. Tyler, Mentor, OH).

[y] *WholeTree* , hickory, sweetgum and redcedar processed through 0.64 cm (0.25 in) screen.

[x] Particle size distribution analysis determined before the addition of incorporated amendments.

[w] 1 mm = 0.0394 in.

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

[u] Coarse = 3.35-9.50 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.

[ns] Means in row not significantly different.

Table 3.3. Particle size distribution[z] analysis of nine substrates containing peat, perlite, *WholeTree* , sweetgum, hickory, and redcedar[y] (Experiment 2)[x].

		Substrates								
U.S. standard	sieve opening (mm)[w]	75:25 Peat:Perlite	75:25 Peat:WholeTree	75:25 Peat:Sweetgum	75:25 Peat:Hickory	75:25 Peat:Redcedar	50:50 Peat:WholeTree	50:50 Peat:Sweetgum	50:50 Peat:Hickory	50:50 Peat:Redcedar
3/8	9.50	0.5 d[w]	1.2 cd	4.1 abc	0.6 d	4.3 ab	1.1 cd	3.4 abcd	1.5 bcd	6.4 a
1/4	6.35	0.4 d	1.0 cd	2.2 bc	0.3 d	3.2 ab	2.5 bc	3.4 ab	3.0 b	4.9 a
6	3.35	9.7 b	7.3 c	6.9 c	4.5 d	6.4 cd	15.0 a	10.0 b	13.6 a	10.4 b
8	2.36	9.3 c	9.6 c	8.3 c	8.3 c	8.3 c	17.6 a	13.1 b	17.1 a	14.4 b
10	2.00	4.1 c	4.2 c	3.5 c	4.0 c	3.9 c	7.2 a	5.4 b	7.8 a	7.1 a
14	1.40	10.3 d	8.9 e	9.5 de	9.4 de	9.8 de	13.2 b	11.8 c	15.2 a	14.6 a
18	1.00	12.1 ab	9.9 c	11.3 b	9.2 c	9.4 c	11.2 b	12.5 a	12.4 ab	11.6 ab
35	0.50	22.5 a	21.6 ab	22.9 ab	19.1 c	18.2 cd	16.2 de	19.7 bc	15.3 e	15.5 e
60	0.25	15.2 bc	19.8 a	18.3 ab	20.5 a	18.0 ab	9.0 d	12.5 c	7.9 d	9.1 d
140	0.11	8.6 c	11.6 b	9.2 c	15.7 a	13.2 b	4.1 d	5.5 d	3.8 d	4.1 d
270	0.05	3.4 a	2.8 b	2.3 cd	3.9 a	3.4 a	1.1 d	1.3 d	1.1 d	1.1 d
pan	0.00	2.9 a	1.0 bc	0.8 cd	1.2 bc	1.3 b	0.5 d	0.5 d	0.5 d	0.5 d
Texture[u]										
Coarse		10.6 cd	9.4 cd	13.2 bc	5.4 d	13.9 bc	18.5 ab	16.8 ab	18.1 ab	21.7 a
Medium		35.8 d	32.6 de	32.6 de	30.9 e	31.4 e	49.2 ab	42.9 c	52.5 a	47.8 b
Fine		52.7 b	56.8 ab	53.4 ab	60.4 a	54.2 ab	30.8 d	39.5 c	28.6 d	30.3 d

[z] Particle size distribution determined by passing a 100 g [76.7°C (170.0°F) forced air oven for 120 hours] sample through a series of sieves. Sieves were shaken for three minutes with a Ro-Tap sieve shaker (Ro-Tap RX-29, W.S. Tyler, Mentor, OH).

[y] *WholeTree* , hickory, sweetgum and redcedar processed through 0.64 cm (0.25 in) screen.

[x] Particle size distribution analysis determined before the addition of incorporated amendments.

[w] 1 mm = 0.0394 in.

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

[u] Coarse = 3.35-9.50 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.

Table 3.4. Effect of nine substrates containing peat, perlite, *WholeTree* , sweetgum, hickory, and redcedar[z] on pH and electrical conductivity (EC) in impatiens[y].

	1 DAP[x]				14 DAP			
	Exp. 1		Exp. 2		Exp. 1		Exp. 2	
Substrate	pH	EC[w] ($mS \cdot cm^{-1}$)[v]	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)
75:25 Peat:Perlite	4.8 cd[u]	1.8 a	5.2 bc	1.2 a	5.4 b	1.6 a	5.6 b	2.4 a
75:25 Peat:Wholetree	5.0 bcd	1.0 b	5.2 bc	1.1 ab	5.7 ab	0.6 cde	5.7 b	1.3 abc
75:25 Peat:Sweetgum	5.2 ab	0.8 b	5.3 abc	1.0 ab	5.7 ab	0.5 e	5.7 b	2.2 ab
75:25 Peat:Hickory	5.1 bcd	1.2 b	4.9 c	1.2 a	5.6 ab	1.0 bcd	5.7 b	2.0 abc
75:25 Peat:Redcedar	5.1 ab	0.8 b	5.4 ab	1.1 ab	5.6 ab	0.8 bcde	5.7 b	1.7 abc
50:50 Peat:Wholetree	5.1 bcd	0.9 b	5.5 ab	0.8 ab	5.8 ab	0.4 e	5.9 ab	1.4 abc
50:50 Peat:Sweetgum	4.8 d	1.1 b	5.7 a	0.9 ab	5.8 ab	0.6 de	6.0 ab	1.0 bc
50:50 Peat:Hickory	5.4 a	0.7 b	4.9 c	1.1 ab	5.9 a	1.1 b	6.2 a	0.7 c
50:50 Peat:Redcedar	5.2 ab	1.1 b	5.6 ab	0.7 b	5.8 ab	1.1 bc	5.9 ab	1.4 abc

	30 DAP				45 DAP			
	Exp. 1		Exp. 2		Exp. 1		Exp. 2	
Substrate	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)
75:25 Peat:Perlite	5.5 b	0.6 ab	6.2 d	0.9 [ns]	5.5 b	0.2 [ns]	5.9 b	0.4 [ns]
75:25 Peat:Wholetree	5.7 ab	0.4 b	6.2 d	0.6	5.9 ab	0.3	6.1 ab	0.4
75:25 Peat:Sweetgum	5.7 ab	0.4 b	6.3 cd	0.9	5.6 ab	0.2	6.1 ab	0.5
75:25 Peat:Hickory	5.6 ab	0.4 ab	6.4 bcd	0.9	5.9 ab	0.2	6.3 a	0.3
75:25 Peat:Redcedar	5.8 ab	0.4 b	6.3 cd	1.0	5.6 ab	0.3	6.1 ab	0.3
50:50 Peat:Wholetree	5.9 ab	0.4 b	6.4 bcd	0.5	5.8 ab	0.3	6.2 ab	0.3
50:50 Peat:Sweetgum	6.0 a	0.5 ab	6.6 ab	0.9	6.1 a	0.3	6.3 a	0.5
50:50 Peat:Hickory	5.9 ab	0.7 a	6.7 a	0.7	6.1 a	0.3	6.4 a	0.5
50:50 Peat:Redcedar	5.9 ab	0.5 ab	6.5 abc	0.6	6.0 ab	0.3	6.3 a	0.4

[z] *WholeTree* , hickory, sweetgum and redcedar processed through 0.64 cm (0.25 in) screen.

[y] pH and EC of solution determined using pour-through method on 'Super Elfin Salmon' impatiens.

[x] DAP = days after planting.

[w] EC = electrical conductivity.

[v] $1\ mS \cdot cm^{-1} = 1\ mmho \cdot cm^{-1}$.

[u] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at $\alpha=0.05$ (n=4).

[ns] Means in column not significantly different.

Table 3.5. Effect of substrate on shrinkage[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals in substrates containing peat, perlite, *WholeTree* , sweetgum, hickory and redcedar.

	Petunia		Impatiens		Vinca	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
75:25 Peat:Perlite	1.8 b	1.3 [ns]	2.3 ab	1.3 b	1.3 b	0.8 ab
75:25 Peat:Wholetree	2.2 ab	1.3	2.3 ab	1.6 ab	1.6 ab	1.2 ab
75:25 Peat:Sweetgum	2.5 a	1.2	2.2 ab	1.4 ab	1.9 ab	1.0 ab
75:25 Peat:Hickory	2.4 ab	1.3	2.8 a	1.4 ab	2.0 a	0.8 b
75:25 Peat:Redcedar	2.3 ab	1.7	2.7 ab	1.9 a	1.9 ab	1.2 ab
50:50 Peat:Wholetree	2.1 ab	1.2	2.0 b	1.7 ab	1.6 ab	1.0 ab
50:50 Peat:Sweetgum	2.1 ab	1.2	2.3 ab	1.2 b	1.6 ab	1.0 ab
50:50 Peat:Hickory	2.3 ab	1.0	2.3 ab	1.1 b	1.8 ab	1.0 ab
50:50 Peat:Redcedar	2.5 a	1.5	2.2 ab	1.4 ab	1.9 ab	1.4 a

[z] Shrinkage reported as cm from top of pot to top of media.

[y] DAP = days after planting.

[x] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at α=0.05 (n=8).

[ns] Means in column not significantly different.

Table 3.6. Effect of substrate on flower number[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals in substrates containing peat, perlite, *WholeTree* , sweetgum, hickory and redcedar.

	Petunia		Impatiens		Vinca	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
75:25 Peat:Perlite	16.6 a[x]	10.8 ab	59.1 a	70.3 a	8.5 a	27.3 a
75:25 Peat:Wholetree	12.5 ab	9.8 abc	50.5 ab	53.6 ab	8.0 a	18.0 bc
75:25 Peat:Sweetgum	4.8 de	9.3 abc	39.1 abc	45.1 b	2.5 bcd	8.6 de
75:25 Peat:Hickory	7.6 bcd	11.0 ab	37.8 bc	38.1 bc	3.5 bcd	11.0 de
75:25 Peat:Redcedar	10.8 bc	8.3 abc	41.8 abc	52.8 ab	6.8 a	27.8 a
50:50 Peat:Wholetree	7.9 bcd	12.3 a	41.8 abc	55.5 ab	4.0 bc	14.9 cd
50:50 Peat:Sweetgum	1.4 e	7.1 bc	14.4 d	18.4 c	1.4 d	6.1 e
50:50 Peat:Hickory	2.8 de	5.4 c	35.6 bcd	16.7 c	1.8 cd	6.0 e
50:50 Peat:Redcedar	6.6 cde	9.0 abc	22.1 cd	58.6 ab	4.3 b	21.6 ab

[z] Flower number recorded as number of flowers with open blooms.

[y] DAP = days after planting.

[x] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at α=0.05 (n=8).

Table 3.7. Effect of substrate on growth indices[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals in substrates containing peat, perlite, *WholeTree* , sweetgum, hickory and redcedar.

	Petunia		Impatiens		Vinca	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
75:25 Peat:Perlite	25.3 a[x]	26.7 a	19.7 a	22.4 a	21.0 a	25.6 a
75:25 Peat:Wholetree	22.7 ab	26.1 ab	19.2 a	21.0 ab	19.4 ab	24.0 ab
75:25 Peat:Sweetgum	17.5 cd	23.2 bc	15.9 bc	19.3 ab	14.6 d	20.3 c
75:25 Peat:Hickory	18.4 cd	24.9 abc	15.3 bc	18.5 b	15.6 cd	20.0 c
75:25 Peat:Redcedar	22.2 ab	26.1 ab	17.1 ab	21.9 a	19.8 ab	25.6 a
50:50 Peat:Wholetree	20.6 bc	26.4 ab	17.9 ab	21.1 ab	18.5 ab	23.2 b
50:50 Peat:Sweetgum	12.8 e	22.2 c	10.0 d	14.4 c	11.0 e	16.2 d
50:50 Peat:Hickory	15.7 de	18.1 d	13.8 c	13.6 c	11.2 e	14.4 d
50:50 Peat:Redcedar	20.7 bc	26.3 ab	14.1 c	21.8 a	18.2 bc	25.1 ab

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

[y] DAP = days after planting.

[x] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at α=0.05 (n=8).

Table 3.8. Effect of substrate on dry weights[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals in substrates containing peat, perlite, *WholeTree* , sweetgum, hickory and redcedar.

	Petunia		Impatiens		Vinca	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
75:25 Peat:Perlite	10.4 a[x]	13.2 ab[x]	4.6 a	7.8 a	7.7 a	11.6 a
75:25 Peat:Wholetree	7.7 b	13.4 ab	3.5 ab	4.9 bcd	5.7 bc	9.3 bc
75:25 Peat:Sweetgum	3.8 cd	7.6 cd	1.6 cd	3.7 cd	2.7 ef	7.3 d
75:25 Peat:Hickory	4.6 cd	10.3 bc	1.7 cd	3.3 de	3.6 de	6.5 d
75:25 Peat:Redcedar	7.6 b	14.4 a	3.1 b	5.8 abc	5.9 b	10.9 ab
50:50 Peat:Wholetree	5.7 bc	12.3 ab	2.8 bc	4.5 bcd	4.4 cd	8.5 cd
50:50 Peat:Sweetgum	1.6 de	7.3 cd	0.5 d	1.1 f	1.1 g	3.1 e
50:50 Peat:Hickory	3.0 d	5.1 d	1.4 d	1.3 ef	1.3 fg	2.3 e
50:50 Peat:Redcedar	7.1 bc	13.3 ab	1.8 cd	6.6 ab	4.4 cd	10.0 abc

[z] Dry weights (g) determined by drying the above-soil portion of the plant in a 76.7°C (170.0°F) forced air oven for 72 hours.

[y] DAP = days after planting.

[x] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at $\alpha=0.05$ (n=8).

Table 3.9. Effect of nine substrates containing peat, perlite, *WholeTree* , sweetgum, hickory and redcedar on root growth[z] of three annual species.

	Petunia		Impatiens		Vinca	
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
75:25 Peat:Perlite	5.0 ab[y]	7.4 ab	4.1 bc	6.4 ab	5.1 [ns]	7.1 a
75:25 Peat:Wholetree	5.1 ab	8.8 a	5.6 ab	6.1 ab	4.3	7.4 a
75:25 Peat:Sweetgum	5.5 ab	7.9 ab	3.0 cd	4.5 b	4.0	6.5 ab
75:25 Peat:Hickory	5.5 ab	8.3 a	5.1 abc	4.9 b	5.1	5.9 abc
75:25 Peat:Redcedar	6.3 ab	6.0 b	5.9 ab	6.1 ab	4.3	6.8 a
50:50 Peat:Wholetree	6.6 ab	8.6 a	7.0 a	6.8 ab	5.1	7.0 a
50:50 Peat:Sweetgum	4.1 b	8.8 a	1.4 d	1.9 c	3.4	4.4 bc
50:50 Peat:Hickory	5.6 ab	7.3 ab	3.8 bcd	1.5 c	3.4	3.9 c
50:50 Peat:Redcedar	7.6 a	8.6 a	4.8 abc	7.4 a	5.3	7.1 a

[z] Root growth assessed at study termination (45 days after planting) on 1-5 scale (1 - less than 20% root ball coverage, 5 - between 80-100% root ball coverage).

[y] Means within column followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference test at $\alpha=0.05$ (n=8).

[ns] Means not significantly different.

Table 3.10. Tissue nutrient content of *Petunia* x *hybrida* 'Dreams Sky Blue' grown in nine substrates containing peat, perlite, *WholeTree* , sweetgum, hickory, and redcedar.

	Tissue nutrient content^{z} for Exp. 1											
Substrate	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm^{y})	Cu (ppm)	B (ppm)	Fe (ppm)	Na (ppm)	Al (ppm)	Zn (ppm)
75:25 Peat:Perlite	2.99 a^{w}	0.22 abc	1.59 d	0.61 ^{ns}	1.11 abc	138 a	12 ^{ns}	24 a	309 a	5695 a	31 ^{ns}	20 ^{ns}
75:25 Peat:Wholetree	2.16 b	0.21 abc	2.56 cd	0.60	1.10 abc	104 ab	11	19 a	114 b	3166 b	23	21
75:25 Peat:Sweetgum	2.30 ab	0.25 a	3.72 bc	0.66	1.19 a	114 ab	15	22 a	133 b	3588 b	22	24
75:25 Peat:Hickory	1.58 bc	0.18 bc	4.37 ab	0.69	1.08 abc	131 ab	16	21 a	157 ab	2688 b	25	22
75:25 Peat:Redcedar	2.14 bc	0.23 abc	2.10 d	0.65	1.09 abc	84 ab	16	22 a	103 b	3864 b	21	19
50:50 Peat:Wholetree	2.25 ab	0.26 a	3.70 bc	0.60	1.08 abc	130 ab	12	14 b	111 b	2532 b	25	26
50:50 Peat:Sweetgum	1.63 bc	0.24 ab	5.40 a	0.70	1.15 ab	129 ab	9	22 a	70 b	3250 b	21	18
50:50 Peat:Hickory	1.38 c	0.17 c	4.72 ab	0.63	0.95 bc	91 ab	12	12 b	51 b	2062 b	23	17
50:50 Peat:Redcedar	2.33 ab	0.24 ab	2.21 d	0.62	0.88 c	76 b	19	13 b	95 b	2984 b	19	28
	Tissue nutrient content for Exp. 2											
75:25 Peat:Perlite	2.82 a	0.25 a	0.89 f	1.05 b	1.24 ab	93 cd	25 ^{ns}	24 ab	469 a	11311 a	67 ^{ns}	44 b
75:25 Peat:Wholetree	2.16 bc	0.19 ab	1.12 ef	1.13 ab	1.25 ab	105 abc	15	23 ab	251 ab	10025 ab	40	42 b
75:25 Peat:Sweetgum	1.82 cd	0.17 ab	1.64 def	1.30 ab	1.22 ab	139 ab	31	23 ab	233 ab	7510 cd	46	50 ab
75:25 Peat:Hickory	1.92 bcd	0.17 ab	1.80 cde	1.15 ab	1.20 ab	150 a	22	32 a	164 b	7774 cd	39	50 ab
75:25 Peat:Redcedar	2.44 ab	0.24 a	1.08 ef	1.40 ab	1.29 a	101 bc	21	27 ab	340 ab	9216 bc	33	44 b
50:50 Peat:Wholetree	2.08 bcd	0.22 ab	2.45 bc	1.10 ab	1.10 ab	64 cd	17	11 c	152 b	7307 cd	38	46 ab
50:50 Peat:Sweetgum	1.87 cd	0.21 ab	2.61 b	1.66 a	1.27 a	106 abc	17	30 a	259 ab	6925 d	31	57 ab
50:50 Peat:Hickory	1.57 d	0.15 b	4.28 a	1.44 ab	1.27 a	92 cd	44	18 bc	124 b	6744 d	75	82 a
50:50 Peat:Redcedar	2.35 abc	0.23 ab	1.95 bcd	1.16 ab	0.99 b	51 d	21	9 c	166 b	7617 cd	120	45 b
Sufficiency Range^{x}	3.85-7.60	0.47-0.93	3.13-6.65	1.20-2.81	0.36-1.37	44-177	3-19	18-43	84-168	3067-10896	50-92	33-85

[z] Tissue analysis performed on 15-20 most recently matured leaves per plant at 45 days after planting; N = nitrogen, P=phosphorus, K = potassium, Ca = calcium, Mg = magnesium, Mn = manganese, Fe = iron, Cu = copper, B = boron, Na = sodium, Al = aluminum, Zn = zinc.

[y] 1 ppm = 1 mg·kg^{-1}.

[x] Sufficiency range of *Petunia* x *hybrida* published by Mills and Jones (1996).

[w] Means within column followed by the same latter are not significantly different based on Tukey's Honestly Significant Difference test at α=0.05 (n=8).

[ns] Means not significantly different.

CHAPTER IV

FINAL DISCUSSION

The purpose of this work was to determine both how far growers could extend their pine bark supplies with WholeTree (WT) or clean chip residual (CCR), and to determine the viability of several low-value forest trees as substrate components for annual production. These specific objectives were part of a national effort to identify and evaluate possible alternative substrates for both the nursery and greenhouse industries. In evaluating these alternatives, we were looking for products that are locally available, easily adaptable to a number of crops, sustainable, and economical.

With regard to our first objective, we evaluated two pine-based substrate alternatives to determine how far existing bark-based substrates could be amended without negative effects on plant growth (Chapter 2). Lantana, spirea, azalea, tea olive, ligustrum, and holly were evaluated in nine substrate treatments. CCR and WT were mixed at 25, 50, 75, and 100% by volume with pine bark. For the most part, air space (AS) and total porosity (TP) values were within the recommended range (10 to 30% for AS, 50 to 85% for TP), and similar to the pine bark:sand nursery standard. While there were a few differences in pH and electrical conductivity (EC) between CCR and WT early in the study, there were no differences across treatments by study termination (365 days after planting). There were little to no differences in plant growth for all species tested at study termination.

In Chapter 3, we evaluated three low-value forest trees (sweetgum, hickory, and redcedar) as possible amendments to standard greenhouse substrates. Sweetgum, hickory and redcedar were cut, chipped, and milled through a ¼ in (0.64 cm) screen before mixing with either 50 or 75% peat (by volume). Growth of petunia, vinca and impatiens was evaluated in the nine substrate treatments. At 45 days after planting, only the 50:50 peat:hickory and 50:50 peat:sweetgum (v:v) had dissimilar (higher) pH values than the peat:perlite standard. Treatments amended with redcedar were comparable to the traditional peat/perlite standard throughout the study. However, plants grown in sweetgum and hickory-amended substrates differed significantly from the standard with respect to flower number, growth indices, and plant dry weight.

These studies show that CCR and WT can be used successfully as amendments in container nursery substrates at up to 75% (by volume). Additionally, while sweetgum and hickory were not suitable as substrate amendments in the greenhouse production of annuals, redcedar worked just as well as the peat:perlite standard. These studies have demonstrated that there are sources of locally available substrates, which are economical and sustainable.