Evaluation of Distilled Eastern Red Cedar (*Juniperus virginiana* L.) as an Alternative Substrate Component in Production of Greenhouse-Grown Annuals

by

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Abstract

Peat moss and perlite are the core components found in soilless greenhouse substrates today and are thus in high demand commercially. Due to both environmental and economic concerns associated with peat harvest and production, and the health and economic concerns accompanying perlite, there has been an increase in research efforts concerning alternatives. A majority of the viable alternatives available to growers are wood based substrates. Many of these substrates are readily available and could be considered more sustainable, depending on geographic location. Recently, eastern red cedar (*Juniperus virginiana*) has been considered as a potential alternative. The cedar used in these experiments was obtained from CedarSafe, an exporter of cedar oil for the perfume industry and closet lining. Eastern Red Cedar logs (*Juniperus virginiana* L.) arrive at the facility and are debarked. The logs are then shaved and the shavings are sent through a hammer mill to pass a 1.27 cm screen (0.5 in). The milled cedar is then conveyed to a set of boilers where it undergoes a steam distillation process. This process extracts a percentage of the oil from the milled particles. The oil is then sequestered and sold to varying business markets. CedarSafe is left with this post-distilled cedar biomass that has no marketable value. However, our research aims to determine if post-distilled cedar can be used in proportional combination with peat moss in order to produce a successful greenhouse substrate.

The objective of our first experiment was to incorporate post-distilled cedar, in varying volumetric concentrations, as a substrate component and compare it to a grower's standard peat-lite mix. There were six treatments implemented: 100% peat-lite (PL), 20:80 cedar (C):PL, 40:60

C:PL, 60:40 C:PL, 80:20 C:PL, and 100% C. From our collected data we observed that substrates containing up to 40% cedar had equal if not better growth for petunias (*Petunia ×hybrida* ‘Celebrity Blue’) and impatiens (*Impatiens walleriana* ‘Extreme Violet’) than the standard peat-lite mix. Therefore, growers could amend their substrates with up to 40% cedar and see little to no change in marketable plant growth.

In a second experiment, post-distilled eastern red cedar was compared to a pre-distilled eastern red cedar substrate. Pre (C) and post-distilled cedar (DC) were mixed, in volumetric combination, with an industry standard peat moss (PM). The six treatments formulated in this experiment included: 60:40 C:PM, 40:60 C:PM, 20:80 C:PM, 60:40 DC:PM, 40:60 DC:PM, and 20:80 DC:PM. The substrates were planted with either petunia (*Petunia ×hybrida* ‘Dreams Burgundy’) or vinca (*Catharanthus roseus* ‘Cooler Rose’) placed in a greenhouse and watered as needed until termination. Data taken after termination indicated that DC substrates performed equal to, if not better than, C substrates. This could be due, in part, to the distillation process that our cedar biomass undergoes. The act of removing a percentage of the cedar’s oil, and the high heat involved, may positively affect DC substrate characteristics and result in superior plant growth. This cedar could potentially be a viable alternative for the horticulture industry and replace portions of PM and perlite in the production of greenhouse annuals.

The objective of our final study was to mimic the beneficial characteristics of perlite in substrates by adding distilled cedar and rice hulls to peat moss and comparing them to peat-lite mixes of concordant percentages. Treatments were amended at 10%, 20%, and 30% for each component. The species used included petunia (*Petunia ×hybrida* ‘Dreams Sky Blue’) and marigold (*Tagetes erecta* ‘Antigua Yellow’). Petunia results indicated that PL treatments performed marginally better than substrates containing DC and RH in one of the two experiments. However, for marigold, no difference was observed between treatments in almost all growth parameters for both experiments. The data indicated that growers could substitute DC or RH for P and yield viable annual crops.

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I. Literature Review

Introduction

Floriculture crops are an integral part of the American economy. The total floriculture crop value at wholesale for the United States was $4.08 billion in 2011 (USDA 2012). The majority of ornamental crops in the United States are grown in greenhouses using containerized production. Containerized production is highly efficient and provides uniform growth for marketable plants. The substrate in which the aforementioned crops are grown in can be regarded as the key component in the production process. Container substrates need to possess certain qualities in order to successfully yield a profitable and uniform crop. These qualities include, but are not limited to: the ability to retain water; sequester nutrients essential to plant growth; and allow for the flow of oxygen and drainage of water. Originally, container substrates were composed of topsoil; however, it became gradually more difficult to obtain topsoil. Also, the characteristics of topsoil, such as, nutrient content, weed seed presence, and drainage were difficult to predict. Without proper sterilization a grower could not always expect a profitable crop. Therefore, in the early 1960s researchers at Cornell introduced soilless substrates. These substrates were known as the Cornell peat-lite mixes and were most often composed of sphagnum peat moss and vermiculite or perlite. The combination of these materials offered growers the advantage of having readily available soil that could produce a uniform crop season to season (Boodley and Sheldrake 1977).

Peat moss (PM) and perlite (P) are still the key components in soilless greenhouse substrates today. The reason for the long reign of PM and P can be attributed to their superior properties in production of highly marketable plants. Peat moss is harvested from bogs around the world and shipped to growers. The ability of PM to hold large quantities of water, provide volumes of air, and store plant nutrients in a easily accessible form all attribute to its desirability among growers. The low pH of PM can be used to formulate a variety of growing media options. Also, PM is known to have little to no existence of weed seed and pathogens and PM can be stored indefinitely until needed (Robertson 1993). Perlite is a naturally occurring volcanic glass or amorphous aluminum silicate that expands when heated to 800 - 1100° C. Once expanded it becomes processed P, with characteristics that include a low density, high surface area, and a low thermal conductivity (Polatli et al., 2001). It lends air-filled porosity to substrates; an important physical property that growers desire in greenhouse mixes. This porosity allows for gas exchange and drainage to occur between the roots of the plant and the atmosphere outside (Bunt 1988).

In recent years, PM and P have become increasingly scarce resulting in a higher demand among growers. This demand has brought to light the expense associated with production and shipping of these soilless substrate components. In September 2011, the Canadian Sphagnum Peat Moss Association (CSPMA) issued a press release stating that the harvest season for PM in Canada had effectively come to an end due to unfavorable weather conditions. As a result only 15% to 30% of the targeted peat bogs in Eastern Canada were harvested. The hardest hit areas were Quebec and New Brunswick, which account for 60% to 70% of all Canada's peat production. Therefore, it was evident that the industry was facing one of its poorest peat harvest seasons to date. Another concern, concurrent with these issues, has long been voiced in regards to the ability of peat bogs to regenerate (about 2 mm per year) at a speed matching that of harvesting rates. Peat-lands cover over 400 million ha of land area around the world (Robertson 1993). Extraction of PM requires the clearance of all surface vegetation and site drainage. These methods are thought to result in irreversible damage to the ecosystem (Alexander et al., 2008). In spring 1990, the European Peat Campaign Consortium launched the Peat Campaign. Their thoughts being: “Society cannot continue to outstrip the capacity of natural resources to renew themselves.” They believe that society is driven primarily by economic obligations and that they had been exploiting natural resources, such as PM, for profit. One of the chief objectives of the campaign was to develop and introduce environmentally and economically sustainable alternatives to PM (Barkham 1993). Researchers are pursuing PM replacement both nationally and internationally. This replacement is being carried out through progressive PM reduction using alternative materials such as timber by-products (Alexander et al., 2008). In recent years, a significant amount of resources have been invested in the testing of PM alternatives, and a large number of alternatives have been evaluated. Successful examples of alternatives include coir, composts, wood fiber products, and bark and composted bark. Examples of these components include the research initiatives on coir, Pine Chips, Pine Tree Substrate, Clean Chip Residual, WholeTree and eastern red cedar.

Expanded P has long been used as an amendment due to its ability to add air space (AS) to container substrates without adding to the bulk density (BD) or affecting substrate pH and electrical conductivity (EC). Although P and similar products have been considered beneficial for plant growth, research has long identified characteristics of P that could be potentially harmful to those who come in contact with it. Perlite dust is a nuisance, causing lung and eye irritation in cases involving over-exposure. Polatli et al. (2001) investigated workers pulmonary function when tested in conjunction with P exposure. A chest radiogram was conducted on 36 perlite-exposed workers and 22 non-exposed workers. The workers indicated a significant obstruction to airflow in small airways (Polatli et al., 2001). Another study was conducted after an accidental P spill in Taiwan exposed 24 workers to extremely high amounts of P dust. They were followed for more than six months and it was discovered that three workers developed persisted respiratory symptoms and tested positive for reactive airway dysfunction syndrome (Du et al., 2010). Due to these issues and concerns, researchers have been interested in finding replacement substrate options for P. Recent research has focused on identifying and evaluating potential P alternatives for use in the greenhouse production of annual crops. Numerous types of P alternatives have been tested. A few of those alternatives include: cedar, rice hulls, corncob, and polystyrene beads.

Alternative Substrate Components

Coir

Arenas et al. (2002) conducted a study comparing sixteen substrate mixes prepared with a combination of PM, coir, vermiculite, or P. Treatments were evaluated in order to establish the optimum growing media for tomato (*Lycopersicon esculentum* Mill.) transplants. In summer the highest root dry weight (RDW), stem diameter, and leaf area were reported for ranges of 50% to 75%:25% to 50% PM:vermiculite. In winter, the greatest results were attained in eight different substrates. Coir at 50% was the highest amount incorporated into a substrate that attained positive results. Transplants grown with more than 50% coir exhibited reduced plant growth when compared to peat-grown transplants. Fruit yields appeared to be unaffected by transplant substrate (Arenas et al., 2002).

Guerin et al. (2001) assessed the growth of Laurustinus viburnum (*Viburnum tinus* L.) an ornamental shrub in PM alternative substrates. Plants were grown in a number of different substrates in two varying climates. Six different substrates were tested within these two climates. A mixture (1:1) of PM:pine bark (PB) compost was used in both climates as a control. Containers, measuring 4 L (1.06 gal), were planted with six plants and watered by drip irrigation. Data was collected at varying intervals throughout the experiment. Data collected included: plant height, dry mass, and leaf area. In both climates, substrates performed the same whether height, dry mass or leaf area were considered. The experiment indicated that substrate performance varies with the application of PM; therefore, alternative substrates can produce equal if not better quality plants when compared to those using PM (Guerin et al., 2001).

Cotton Gin Compost

Jackson et al. (2005), compared cotton gin compost (CGC) as a substrate to an industry standard PB blend. Shoot and root growth in four substrate blends containing, by volume, 6:1 PB:sand (S), 4.5:1.5:1 PB:CGC:S, 1:1 PB:CGC, or 1.5:4.5:1 PB:CGC:S were evaluated using boxwood (*Buxus microphylla* Sieb. & Zucc. 'Winter Gem'), dwarf nandina (*Nandina domestica* Thunb.'Firepower') and azalea (*Rhododendron indicum* L. & Sweet 'Midnight Flare'). Plants were grown for nine months on a container pad in Auburn, AL. The study was repeated, but 'Renee Mitchell' azalea was used as a replacement for 'Midnight Flare' azalea. In addition to growth measurements, substrates were analyzed to determine physical and chemical properties. In both experiments, growth indices (GI) of all cultivars in substrates containing CGC were similar to or greater than those of the control blend (Jackson et al., 2005).

Cole et al. (2005) evaluated azalea (*Rhododendron indicum* L. 'Formosa') in CGC at varying percentages to grow. The four blends included: 100% PB (by volume), 1:1 PB:CGC, 3:1 PB:CGC, and 3:1 PB:PM (PT). Each of these treatments was watered at three different irrigation levels [600, 1200, and 1800 $mL \cdot d^{-1}$ (20.3, 40.6, and 60.9 fl oz·d)] in a polyethylene-covered greenhouse. The azaleas were grown for 4 months in 7.6 L (2.0 gal) containers and evaluated biweekly using a growth index. Roots were assessed at the end of the study using a 0 (no root growth) to 5 (root bound) scale (RR). Leachates were collected every 30 days and substrate physical properties were evaluated for each treatment. No difference was found in plant growth across irrigation and substrate treatments. Visual RR was greatest (4.5) for azaleas grown in 3:1 PB:PT. The two PB:CGC blends had greater water holding capacity (WHC) when compared to 100% PB. The substrate containing 1:1 PB:CGC had the greatest WHC among all four substrates. With an increase in irrigation volume there tended to be an increase in pH and a decrease in EC (Cole et al., 2005).

Pine Chips / Pine Tree Substrate

Wright and Browder (2005) compared ground *Pinus taeda* L. logs (including bark)[pine chips (PC)] to ground PB as a potential container substrate for Japanese holly (*Ilex crenata* Thunb. ‘Chesapeake’), azalea (*Rhododendron obtusum* Planch. ‘Karen’) and marigold (*Tagetes erecta* Big.‘Inca Gold’). Substrate treatments were 100% PC, 100% PB and 75:25 PC:PB (v:v). Plant dry weights were higher for marigold grown in 100% PB compared to 100% PC, but not different from plants grown in 75:25 PC:PB. Plant dry weights of azalea were higher in 100% PB. There was no difference in shoot dry weight (SDW) for Japanese holly between the three substrates. Plant RDW was highest for 75:25 PC:PB. Percent AS for PC was higher than the PB substrate, but there was no difference between the three substrates for container capacity (CC) and available water. Substrate EC was lower for PC than PB; this could be due to the larger particle size of the PC when compared to PB. These factors could account for the cases where larger plants developed with the PB substrate. It can be concluded, from the data taken, that PC offer potential as a container substrate for greenhouse and nursery crops (Wright and Browder 2005).

Wright et al. (2006) compared pine wood chips (PC) to PB for use as a container substrate for the production of a wide range of woody species. The PC substrate was prepared by grinding coarsely ground debarked pine logs (*Pinus taeda* L.) in a hammer mill to pass a 0.64 cm (0.25 in) screen. Two different substrates were evaluated throughout the study. Plant SDW of 13 of 18 species in the April planting was not different between PB and PC. Plant SDW for 6 of 10 species in the May planting was higher in PB compared to PC. Reduced growth in some plants could be attributed to lower nutrient availability in substrates containing PC. Results indicate that, with adjustments to fertility, PC can be a suitable substrate for container production of woody ornamental plants (Wright et al., 2006).

A 100% pine chip (PC) substrate could also be a suitable container substrate. However, it would be advantageous to adjust particle size in order to manipulate the physical properties of the substrate to support plant nutrient and water requirements. The particle size of a 100% PC substrate affects physical properties of the substrate such as AS and CC. In conclusion, a suitable container media could be achieved by using PC substrates that have adequate particle sizes concordant with the favorable characteristics needed to produce greenhouse crops (Saunders et al., 2006).

Wright et al. (2008) performed additional experiments assessing the characteristics of pine tree substrate (PTS) as an alternative substrate. The PTS was produced by further grinding coarse loblolly pine chips (including bark) (*Pinus taeda* L.) routinely produced for the paper industry to pass through a hammer mill fitted with 0.48 cm (0.19 in) screen. The objective of these experiments was to compare the fertilizer requirements for growth of chrysanthemum

(*Chrysanthemum* ×*grandiflorum* Ramat. Kitam.'Baton Rouge') in PTS or a commercial peat-lite (PL) substrate. The PL substrate was composed of 45% PM, 15% P, 15% vermiculite, and 25% bark. Plants were grown in a greenhouse and fertilized with varying rates of a 20N–4.4P–16.6K-soluble fertilizer ranging from 50 to 400 $mg{\cdot}L^{-1}$ nitrogen (N) with each irrigation. In both studies, about 100 $mg{\cdot}L^{-1}$ N more fertilizer was required for PTS than PL to obtain similar growth. Substrate EC values were higher for PL substrates than PTS substrates. This is most likely due to differentiations in particle size between the two substrates. This demonstrates that PTS can be used to grow a traditional greenhouse crop if attention is given to fertilizer requirements (Wright et al., 2008).

Pine tree substrate (PTS) is produced from freshly harvested loblolly pine trees (*Pinus taeda* L.) that are delimbed, chipped, and ground in a hammer mill to a desired particle size. Loblolly pine is an abundant and fast growing native tree species to the southeastern United States. Research has been conducted on PTS in order to determine physical properties, adequate plant growth and fertility management, decomposition rates, and post-transplant performance of plants grown in PTS. Recent research initiatives have indicated that PTS can be manufactured in order to supplement exemplary growth of plants within a wide range of horticultural crops. Studies concerning fertility of plants grown in PTS indicate that additional fertilizer is often required to produce a marketable plant. However, growth can be achieved similar to that in traditional PM and PB substrates if sufficient fertility requirements are met. Another quality that can be attributed to PTS is that fact that little to no shrinkage or substrate decomposition is observed, including nursery studies performed over an extended period of time. It can thus be concluded that PTS can be utilized as a reliable, consistent, renewable, and economic alternative to traditional substrates for both nursery and greenhouse crop production (Jackson and Wright 2009a).

Jackson et al. (2008) grew poinsettias (*Euphorbia pulcherrima* Willd. Ex Klotzsch 'Prestige') at different fertilizer rates in three PTS treatments. Substrates used in the study included peat-lite (PL), PTS (including bark) produced with a 0.24 cm (0.09 in) screen (PTS1), PTS produced with a 0.48 cm (0.19 in) screen (PTS2), and PTS produced with a 0.48 cm (0.19 in) screen and amended with 25% PM (v:v) (PTS3). Poinsettias were fertilized at irrigation with 100, 200, 300, or 400 $mg{\cdot}L^{-1}$ nitrogen (N). Plant SDW and GI were higher in PL at 100 $mg{\cdot}L^{-1}$ N, but similar for all substrates at 300 $mg{\cdot}L^{-1}$ N. Bract length was generally the same or longer in all PTS-grown plants when compared to standard substrates. Initial and final AS was higher in all PTSs compared with PL and CC of PTS1 was equal to PL initially and at the end of the experiment. The initial and final CC of PTS2 was lower than PL. The incorporation of 25% PM (PTS3) increased SDW and bract length at lower fertilizer rates compared with 0.48 cm (0.19 in) PTS alone (PTS2). This study demonstrated that poinsettia could be successfully grown in a PTS with small particles (0.24 cm screen) or a PTS with large particles (0.48 cm screen) when amended with 25% PM (Jackson et al., 2008).

Jackson et al. (2009) compared substrate solution nitrogen (N) availability, N immobilization, and nutrient leaching in a pine tree substrate (PTS), peat-lite (PL), and aged PB in greenhouse conditions. Substrates used in this study were PTS (including bark) ground through a 0.24 cm (0.09 in) hammer mill screen, PL, and aged PB. A short-term N immobilization study was conducted and a second medium-term study was also conducted to evaluate the amount of N immobilized in each substrate when fertilized with 100, 200, 300, or 400 $mg{\cdot}L^{-1}$ N. Also, substrate carbon dioxide (CO^2) efflux (mmol $CO^2{\cdot}m^{-2}{\cdot}s^{-1}$) was measured as an assessment of microbial activity. A leaching study on all three substrates was also conducted to determine the amount of nitrate nitrogen (NO^3-N), phosphorus, and potassium leached over 14 weeks under greenhouse conditions. Nitrogen immobilization was highest in PTS followed by PB and PL in both the short- and medium-term studies. Nitrogen immobilization increased as fertilizer rate increased from 100 $mg \cdot L^{-1}$ N to 200 $mg \cdot L^{-1}$ N in PL and from 100 $mg \cdot L^{-1}$ N to 300 $mg \cdot L^{-1}$ N for PB and PTS. Nitrogen immobilization was generally highest in all substrates 2 weeks after potting. Substrate CO^2 efflux levels were highest in PTS followed by PB and PL at each measurement. Nitrate leaching over 14 weeks was lower in PTS than in PB or PL. This work indicates increased microbial activity and N immobilization can be observed in PTS compared with PB and PL. Increased N immobilization in PTS explains the lower nutrient levels observed in PTS. Also, these results further justify the additional fertilizer required for comparable plant growth to PL and PB (Jackson et al., 2009b).

Further work by Jackson et al. (2009c) evaluated the effect of limestone additions to pine tree substrate (including bark) (PTS) and PTS amended with PM on pH and growth of marigold (*T. erecta* Big. 'Inca Gold') and geranium (*Pelargonium ×hortorum* L.H. Bailey 'Rocky Mountain White'). Three PTS treatments (v:v): 100% PTS, 75:25 PTS:PM, and 50:50 PTS:PM were compared to a PM:P (4:1 v:v; PL) control. Each substrate was amended with various rates of dolomitic limestone. Irrespective of limestone rate, pH was highest in 100% PTS and decreased with the addition of PM. Therefore, the PL control had the lowest pH. As percent PM increased from 25% to 50%, more limestone was required to adjust pH to a specific level. This indicated that PTS is more weakly buffered against pH change than PM. Additions of limestone increased growth of marigold when grown in PTS containing PM or in the PL control. Geranium growth was higher in PTS containing PM (25% or 50%) and PL than in 100% PTS at all limestone rates. This research establishes that PTS has a naturally higher pH than PL, and the additions of PM to PTS require pH adjustment of the substrate for optimal plant growth (Jackson et al., 2009c).

Clean Chip Residual

Clean Chip Residual (CCR), a by-product of thinning pine plantations, is composed of about 50% wood, 40% bark and 10% needles. Two CCR particle sizes were used alone or in combination with PM (PM) (4:1 by vol) and compared to control treatments PB and PB:PM. Substrates composed of 100% PB or 100% CCR had high AS and low WHC which resulted in less available water to plants. There were no differences in GI at Poplarville for six of eight species and for three of seven species at Auburn. The remaining four species at Auburn were only slightly smaller when grown in 100% CCR. Plant SDW was greatest in substrates containing PM. Results indicated that the rate of fertilizer evaluated in this experiment was sufficient to provide nutrients for plants grown in PB/PM blends, but plants grown in 100% CCR may require additional fertilizer to increase SDW. Adequate growth of perennial plants was achieved in substrates composed of CCR, especially with the addition of adequate percentages of PM (Boyer et al., 2008a).

Boyer et al. (2008b) also evaluated CCR as an alternative substrate component for the production of annual bedding plants. Two CCR particle sizes of 1.27 cm (0.5 in) and 1.91 cm (0.75 in) were used alone or in combination with 10% (9:1) or 20% (4:1) PM (by volume). These substrates were compared with control treatments of PB and PB blends (10% and 20% PM). Three annual species used in this experiment included: ageratum (*Ageratum houstonianum* Mill. ‘Blue Hawaii’), salvia (*Salvia ×superba* Stapf. ‘Vista Purple’) and impatiens (*Impatiens walleriana* Hook.f. ‘Coral’ or ‘White’). There were no differences observed in GI or SDW of ageratum. The largest salvia was in PB:PM and the largest impatiens were in PB-based substrates at Auburn. The GI of ageratum at Poplarville was similar among treatments. However, plants grown in 4:1 1.27 cm CCR: PM were the largest. Salvia was largest in 4:1 CCR:PM and PB:PM, and although there were no differences in GI for impatiens at Poplarville, the greatest SDW occurred with PB:PM. At termination, two of the three annual species tested had similar growth when compared with standard PB substrates at both locations. This study demonstrates that CCR can be considered a viable greenhouse alternative substrate in the production of ageratum, salvia, and impatiens (Boyer et. al, 2008b).

WholeTree

WholeTree (WT) is a biomass derived from processed whole pine trees (aboveground portions). Fain et al. (2008a) evaluated the potential for WT as a container substrate. Three species [loblolly pine (*Pinus taeda* L.), slash pine (*Pinus elliottii* Englem.), and longleaf pine (*Pinus palustris* Mill.)] of 8- 10-year-old pine trees were harvested at ground level and the entire tree was chipped with a tree chipper. Chips from each tree species were processed with a hammer mill to pass through a 0.95 cm (0.37 in) screen. Containers were filled with substrates and planted with a single liner of annual vinca (*Catharanthus roseus* L. 'Little Blanche'). At 54 days after potting (DAP), SDW was 15% greater for plants grown in 100% PB substrate compared with plants grown in the three WT substrates. However, there were no differences in plant GI for any substrates at 54 DAP. Plant tissue macronutrient content was similar among all substrates. Root growth was similar among all treatments. Based on these results, WT substrates derived from loblolly pine, slash pine, or longleaf pine have potential as an alternative, sustainable source for producing short-term horticultural crops (Fain et al., 2008a).

Fain et al. (2008b) assessed varying WT particle sizes in the production of greenhouse annuals. The WT was processed to pass 0.48 (0.19 in), 0.64 (0.25 in) or 0.95 cm (0.37 in) screen. The resulting three WT substrates were used alone or mixed with 20% or 50% (by volume) PM and compared to an industry standard mix of 8:1:1 (by volume) PM:vermiculite:P (peat-lite). The study evaluated the production of marigold (*T. patula* L. 'Little Hero Yellow') and petunia (*Petunia ×hybrida* Vilm. 'Dreams Pink') in these substrates. At 34 days after potting (DAP) there were no differences in BC for marigold. Petunias grown in the peat-lite substrate had more than double the BC than observed on plants grown in other substrates. At 28 DAP, petunias grown in any 100% WT or 4:1 WT:PM substrate were smaller than plants in any 4:1 WT:PM or the peat-lite substrate. At 28 DAP petunias grown in peat-lite substrates were also larger than those grown in any 4:1 WT:PM substrate; however, all plants were considered marketable. Petunia tissue N concentrations were all below the sufficiency range and it is possible a nitrogen sink in the WT substrates could explain some of the differences in final growth. The much higher than recommended pH for all substrates containing WT most likely contributed to the lack of performance petunia exhibited in these substrates when compared to the peat-lite substrate. Results of this experiment indicated that WT substrates are a potential alternative to conventional greenhouse substrates especially when combined with PM. However, further research concerning nutrient deficiencies needed to be conducted in order to ensure optimal plant growth (Fain et al., 2008b).

Fain et al. (2008c) evaluated a WT substrate with starter fertilizer in the production of greenhouse-grown petunia (*P. ×hybrida* Vilm. 'Dreams Purple') and marigold (*T. patula* L. 'Hero Spry'). Loblolly pines (*Pinus taeda* L.) were harvested at ground level, chipped, and processed through a hammer mill to pass a 0.64 cm (0.25 in) screen. The resulting WT substrate was used alone or combination with 20% or 50% (by volume) PM and compared with an industry standard peat-lite (PL) mix of 8:1:1 PM:vermiculite:P (by volume). A 7N–1.3P–8.3K starter fertilizer (SF) was added to each substrate at 0.0, 1.19, 2.37, or 3.56 kg·m^{-3} (0.0, 2.62, 5.23, or 7.85 lb·yd^{-3}). Percent CC was greatest for PL substrates and decreased as the percentage of PM in the substrate decreased. Subsequently, WT had 35% less CC than PL. Percent AS was greatest for the WT substrates and decreased as the percentage of WT decreased. Consequently, PL substrates possessed 33% less AS than WT. In general, petunia dry weight was greatest for any substrate containing PM with a SF rate of 2.37 kg·m^{-3} (5.23 lb·yd^{-3}) or greater. The exception was that petunia grown in WT at 3.56 kg·m^{-3} (7.85 lb·yd^{-3}) SF had similar SDW when compared to all other treatments. Marigold SDW was similar for all substrates where at least 2.37 kg·m^{-3} (5.23 lb·yd^{-3}) SF was used. Results from this study indicate that, with the addition of a sufficient starter nutrient charge, WT is an adequate substrate component and could potentially replace the majority of PM in the production of petunia and marigold. Furthermore, the wide range of particle sizes achieved from the production of WT substrate provided needed structure and could eliminate the necessity for expensive aggregates such as P. The most promising aspect of WT is the possibility of an economically sustainable greenhouse substrate, which could be accessible in close proximity to horticulture production areas throughout the southeast (Fain et al., 2008c).

Gaches et al. (2010) conducted two experiments to compare WT and chipped pine logs to an industry standard PM in the production of either impatiens (*Impatiens walleriana* Hook.f.) or vinca (*Catharanthus roseus* L.). Treatments were composed of 1:1 WT:PM or chipped pine logs:PM. Results indicated that GI, RR, and bloom count (BC) were all similar for both species. Chipped pine longs differed slightly from the WT mixes in SDW, which had greater weights than that of WT. Plant response showed no differences in pH and EC between the two substrates.

It was concluded that WT and chipped pine log substrate, mixed with at least 50% PM, are interchangeable. The differences were insignificant for the most part, with both showing great promise as substrates for greenhouse plant production (Gaches et al., 2010).

Aging WT may also impact plant growth and physical properties (Griffin 2010). Petunia (*P.* ×*hybrida* Vilm. ‘Dreams White’) and marigold (*T. patula* L. ‘Little Hero Yellow’) were grown in 1:1 (v:v) fresh WT:PM (FWTP) and 1:1 (v:v) aged WT:PM (AWTP). For Experiment 1, AWTP had a lower total porosity (TP) as compared to FWTP. For AWTP there was a lower AS compared to FWTP; AWTP had a greater CC than FWTP. Substrate BD was similar in Experiment 1. There was no difference in TP in Experiment 2; however, all other physical properties followed a similar trend to Experiment 1. In both experiments, marigolds grown in AWTP generally had a lower leachate pH and a higher EC than those grown in FWTP. This was similar in petunia although differences were not present throughout the entire study. In both species, plants grown in AWTP resulted in greater GI and higher BC when grown in AWTP as compared to FWTP. Aged WT in this study provided a more suitable substrate component for greenhouse grown annuals than fresh WT. A recommendation was made to allow WT substrates to go through an initial aging process in order to achieve superior plant growth (Griffin 2010).

Juniperus virginiana

In recent years an interest in using eastern red cedar (*Juniperus virginiana* L.) as an alternative substrate component, reducing the amount of PM and/or P, has risen. In many parts of the United States, eastern red cedar (RC) is considered a weed species that will establish on unmanaged land and out-compete native grasses. Throughout the Great Plains and the Midwest, RC is reducing available land for grazing, altering the soil hydrology, and affecting vertebrate populations. The problem of over population associated with RC makes it an appealing option as a substrate alternative.

Griffin et al. (2009) evaluated RC as a substrate in the production of woody plants. The results indicated no visible signs of nutrient deficiencies, substrate shrinkage, or allelopathy associated with RC. Therefore, RC could be used as a substrate without the concern of its physical and chemical makeup interfering with plant growth (Griffin et al., 2009).

Murphy et al. (2010) evaluated RC as an alternative for greenhouse use, as well as sweetgum (*Liquidambar styraciflua* L.) (SG) and hickory (*Carya* spp. Nutt.) (H). Three greenhouse annual crops were utilized in this study: petunia (*P.* ×*hybrida* Vilm. 'Dreams Sky Blue'), vinca (*C. roseus* L. 'Cooler Peppermint'), and impatiens (*I. walleriana* Hook.f. 'Super Elfin Salmon'). They were planted in varying ratios of the three wood species, which were combined separately with PM at percentages of 50% and 25% by volume. The wood fiber treatments were compared to a grower's standard mix consisting of 75:25 PM:P. Plants grown in SG and H did not perform as well as plants in the grower's standard substrate with respect to BC, GI, and SDW. However, plants grown in RC tended to be equivalent to those grown in the grower's standard. Data indicated that greenhouse producers could amend their standard greenhouse substrate with up to 50% RC and observe little to no difference in plant growth and overall plant quality (Murphy et al., 2010).

In the Midwest, Starr et al. (2010) evaluated the growth of bald cypress (*Taxodium distichum* L. Rich.) in pine bark and sand substrates amended with RC. RC is harvested under the premise of its nocuous characteristics as a weed species. Treatments were prepared by mixing 0, 5, 10, 20, or 80% (by volume) RC chips (RCC) with sand (20% by volume). PB occupied the remaining volume of the substrate. While there were statistical differences in plant dry weight, especially at the highest RCC content, plant height was not significantly affected. This suggests that RCC could be a promising replacement for PB. It can therefore be concluded that RCC could be used as a potential PB replacement or amendment for bald cypress in container-grown production systems (Starr et al., 2010).

Starr et al. (2011) also evaluated RCC in the production of rudbeckia (*Rudbeckia fulgida* var. *fulgida* Ait.). Eastern RCC could be used as a substrate for container-grown rudbeckia, with chips at 0.48 cm (0.19 in) screen size performing the best when compared to a PB substrate (Starr et al., 2011).

In addition to the replacement of PM, the physical nature of RC tends to add substrate porosity that is normally achieved with the addition of P. Therefore, we believe a reduction or elimination in the need for P might be realized with the use of cedar as a substrate component. Murphy et al. (2011) evaluated the effects fertilizer had on RC and two other low-value trees and their potential as P alternatives in the production of petunia (*P.* ×*hybrida* Vilm. 'Celebrity Blue') and vinca (*C. roseus* L. 'Cooler Rose'). Collected data indicated that petunias and vinca grown in a 75:25 PM:RC substrate were comparable to plants grown in a traditional 75:25 PM:P substrate. Furthermore, the data indicated that an increase in liquid fertilizer from 100 ppm N to 300 ppm N had little to no effect on BC or SDW of petunias in sweetgum, hickory or RC substrates. Overall, the study exhibited the ability of RC to act as an alternative to P in the production of petunia and vinca crops (Murphy et al., 2011).

Rice hulls

Rice hulls are a waste product of the rice milling industry. It has been estimated that almost 34 million tons of fresh rice hulls are produced annually in the United States (Kamath and Proctor 1998). Rice hulls are generally considered an agricultural waste and, thus, could potentially have a lower market value in comparison to P.

Tomato (*Lycopersicum esculentum* Mill. ‘Better Boy’), marigold (*T. patula* L. ‘Bonanza Yellow’), geranium (*P.* ×*hortorum* Bailey ‘Orbit Cardinal’), vinca (*C. roseus* L. ‘Cooler Blush’), impatiens (*I. walleriana* Hook.f. ‘Dazzler Rose Star’), and pansy (*Viola* ×*wittrockiana* Gams. ‘Bingo Azure’) were grown in fourteen sphagnum peat-based substrates containing P or parboiled fresh rice hulls (PFH) at 10%, 15%, 20%, 25%, 30%, 35%, or 40% (v:v). The RDW of vinca and geranium were not different among plants grown in the substrates. Tomatoes grown in 10%, 15%, 25%, 30%, and 35% PFH had considerably higher RDW than those grown in concordant perlite-containing substrates (Evans and Gachukia 2004). Impatiens grown in 35% PFH had higher RDW than those grown in 35% P. There were no differences in impatiens or marigold RDW among the remaining substrates containing equivalent amounts of PFH or P. The RDW of impatiens, marigold, and pansy grown in perlite-containing substrates were not different from those grown in PFH-containing substrates across all substrate percentages. No difference in SDW of vinca, geranium, impatiens, and marigold occurred between concordant P and PFH-containing substrates. Tomatoes grown in 10% to 15% P had SDW that were not different from those grown in equivalent PFH-containing substrates. The SDW of pansies grown in 10%, 25%, 30%, 35%, and 40% P were not different from those grown in PFH substrates. Data gathered in the study indicated that PFH would be an adequate alternative to P in the production of annual crops (Evans and Gachukia 2004).

In another experiment Evans and Gachukia (2007) produced ten substrates by blending P or parboiled fresh rice hulls (PFH) to produce rooting substrates. The substrates contained 20%, 30%, 40%, 50%, or 60% (by volume) P or PFH, with the remainder being PM. All substrates containing PFH had higher TP than substrates containing a concordant amount of P. The AS was not different between substrates containing 20% P or PFH. However, the AS was higher in PFH-containing substrates than in equivalent substrates composed of P when the amount of PFH or P was at least 40%. As the amount of P or PFH was increased, the AS increased. At 30% or higher PFH, the substrates containing PFH had a lower WHC than concordant P substrates. As the percentage P or PFH was increased, the WHC decreased. The differences in BD were not excessive enough to be of practical significance. Inclusion of PFH in the substrate provided for drainage and air-filled pore space as did P. However, less PFH would be required in a substrate to provide the same air-filled pore space as P when more than 20% P or PFH is used (Evans and Gachukia 2007).

Corncob

Another possible alternative to P is processed corncobs. The harvesting of corn (*Zea mays* L.) often leaves corncobs as a byproduct and these are used for many different products in commercial industry. A positive quality associated with corncob is its label as a waste byproduct of the corn feed and seed industry, which requires less energy to produce than P. Because it is a byproduct, there is no foreseeable rise in feed and seed market prices with the procurement of corncob. Weldon et al. (2010) determined the effects of corncob (CC), blended with a base substrate containing 70:30 PB:PM (v:v) (PBP), compared to P. The six treatments formulated included: 9:1 PBP:CC (v:v), 8:2 PBP:CC, 7:3 PBP:CC, 9:1 PBP:P, 8:2 PBP:P and 7:3 PBP:P. The treatments were planted with either impatiens (*I. walleriana* Hook.f. ‘Dazzler Cranberry’) or petunia (*P.* ×*hybrida* Vilm. ‘Dream Rose’). Substrates containing corncob had higher AS and TP than perlite-containing substrates. Corncob substrates also had a uniform particle size, whereas P substrate particle size was inconsistent. Impatiens GI were similar for all treatments except for the 7:3 PBP:CC, which was smaller than all other treatments. Impatiens BC were similar among all treatments. Petunia BC in 9:1 PBP:CC had twice the number of blooms compared with BC in 7:3 PBP:P. Impatiens SDW were comparable among all treatments that contained 10% or 20% CC or P. Data provided by this study suggests that corncob could potentially be a suitable organic substitute for P in greenhouse annual production (Weldon et al., 2010).

Weldon (2012) also observed the effect of nitrogen fertilizer rates on CC substrates in the production of petunia (*P. ×hybrida* Vilm. 'Rambling Sugar Plum'). Treatments were produced by combining PM with soaked corncob, non-soaked corncob, or P at a ratio of 80:20 (v:v). The treatments were amended with 0.9 (2), 1.8 (4), 2.72 (6), or 3.6 $kg{\cdot}m^{-3}$ (8 $lbs{\cdot}yd^{-3}$) of 13N-2.6P-13.8K slow-release fertilizer in two experiments. Container capacity was higher for CC substrates and there was a decrease over time in EC for both experiments. An increase in GI and SDW was observed with an increase in fertilizer rate for both experiments. Petunias grown in non-soaked and soaked CC substrates at the highest rate were similar to plants grown in P at 1.8 $kg{\cdot}m^{-3}$ (4 $lbs{\cdot}yd^{-3}$), 2.72 $kg{\cdot}m^{-3}$ (6 $lbs{\cdot}yd^{-3}$), and 3.6 $kg{\cdot}m^{-3}$ (8$lbs{\cdot}yd^{-3}$) for experiment 2. Results of this study indicated that an increase in fertilizer had a positive effect on the growth of petunias in CC amended substrates. Petunias in substrates with soaked corncob at a 3.6 $kg{\cdot}m^{-3}$ (8 $lbs{\cdot}yd^{-3}$) fertilizer rate in both experiments were similar to results in the peat-lite mix at 2.72 $kg{\cdot}m^{-3}$ (6 $lbs{\cdot}yd^{-3}$) with respect to GI, BC, and RR. This suggested that pre-soaking the CC before mixing could also have an effect on the growth of petunias. This study shows that CC can be a viable alternative to P, and that additional studies need to be conducted to determine the best nutrient management practices when utilizing CC as a substrate component (Weldon, 2012).

Polystyrene Beads

Polystyrene beads (PSB) are a byproduct of the polystyrene industry. A substrate containing PSB can produce similar plants to those grown in an equivalent perlite-containing substrate (Cole and Dunn 2002). In this study stem cuttings of rose-of-sharon (*Hibiscus syriacus* L. ‘Jeanne d’Arc’), barberry (*Berberis thunbergii* D.C. ‘Crimson Pygmy’), juniper (*Juniperus horizontalis* Moench. ‘Plumosa Compacta’), and arborvitae (*Thuja occidentalis* L. ‘Woodwardii’) were rooted in substrates consisting of 0%, 25%, 50%, 75%, or 100% (by volume) P or PSB mixed with PM. Statistically, more barberry cuttings rooted with PSB than with P. Percentage of rooted juniper cuttings decreased with an increase in PSB concentration. However, percentage of rooted arborvitae cuttings increased as PSB concentration increased. Arborvitae cuttings had a higher quantity of roots with 25% P than with 25% PSB, but arborvitae cuttings in 50%, 75%, or 100% PSB had more roots than cuttings in the concordant concentrations of P. Results indicate PSB could be an adequate substitute for P in rooting substrates for barberry, juniper, and arborvitae if suitable ratios of PM are applied (Cole and Dunn, 2002).

Other Alternatives

Laiche and Nash (1986) chronicled the growth of azalea (*Rhododendron indica* L. 'President Clay'), privet (*Ligustrum sinense* Lour. 'Variegata') and holly (*Ilex crenata* Thunb. 'Compacta') in media prepared from fresh PB, PB with wood, and pine tree chips. The physical properties of each substrate varied greatly. However, they all exhibited high hydraulic conductivity and low WHC. The results indicated that highest growth was obtained with fresh PB as the component of growth media and that increasing the wood content of organic components decreased its value for use in growth media. It was concluded that more research was needed in order to fully assess the value of these materials as alternative substrate components (Laiche and Nash 1986).

Jayasinghe et al. (2010a) performed multiple experiments testing the viability of various alternative substrates. The objective of the first study was to evaluate the potential cattle manure compost (CMC) and synthetic aggregates (SA) had as substrates and their effect on the growth of marigold (*T. patula*). The varying substrate treatments were prepared by mixing CMC at the rates of 0%, 20%, 40%, 60% and 100% with SA at 100%, 80%, 60%, 40% and 0%, respectively. A treatment of 100% PM was used as a control. Results from data collection indicated that CMC–SA based substrates possessed sufficient physical and chemical properties when compared to PM control treatments. The highest plant growth values were associated with the substrate treatment containing 40% CMC and 60% SA. When compared to the control treatment this substrate's data values increased over all parameters. In conclusion, it was established that potential benefits could arise from the utilization of CMC and SA as alternative substrates (Jayasinghe et al., 2010a).

In the same year, Jayasinghe et al. (2010b) implemented another experiment testing the effects sewage sludge sugarcane trash based compost (SSC) and SA had on the growth of lettuce (*Lactuca sativa* L.). Treatments evaluated included: SSC:PM 40:60, SA:PM 40:60, SSC:SA 60:40, SSC:SA:PM 40:20:40 and SSC:SA:PM 40:40:20; with 100% PM used as the control. In relation to plant growth data in the control treatment, plants grown in the SSC/SA based substrates reached better growth and nutrition (Jayasinghe et al., 2010b). Overall, using SSC/SA based substrates as alternative substrate components would be advantageous for the horticulture industry.

Vaughn et al. (2011) initiated two separate experiments that assessed ethanol-extracted, coarse-ground corn (*Zea mays* L. 'Silver Queen') tassels and their efficacy as a substrate replacement for PM. The corn tassels replaced PM at increasing levels (up to 50% v:v) varying the effects of substrate physical properties. The two identical greenhouse experiments were separated by time. Tomato (*Solanum lycopersicum* L. 'Red Robin') plants were grown in 6 L (1.6 gal) pots. Data collected for the first experiment indicated that all substrates were similar for total tomato yield per plant and number of fruit per plant. However, the substrate containing 50% tassel had significantly lower values when compared to the other substrates. No differences were found for plant height or average fruit weight among substrates. In the second experiment, no differences were found among any of the data sets. Extracted ground tassels might be utilized as a suitable replacement for PM in the production of greenhouse-grown tomatoes (Vaughn et al., 2011).

Weldon (2012) evaluated *Paulownia tomentosa* Steud. (PT) as a substrate alternative in the production of petunia (*P.* ×*hybrida* Vilm. 'Celebrity Rose') and dianthus (*Dianthus* ×*hybrida* L. 'Telstar Crimson'). Treatments containing PT were compared to a standard peat-lite (PL) mix. The results of this study indicated that PT amended substrates showed negative differences in growth when compared to the PL standard, casting doubt on whether PT could be a viable alternative substrate component. However, a possible explanation for reduced growth of plants in the PT amended substrates is N-immobilization from fresh PT fibers. It was concluded that further research needed to be conducted in order to address immobilization issues (Weldon, 2012).

Statement of Research Objectives

The research efforts presented in this thesis were conducted using cedar obtained from CedarSafe®, a company located in Huntsville, AL. CedarSafe® mainly produces cedar oil for the perfume industry and closet lining for the home improvement industry. Eastern red cedar logs (*Juniperus virginiana* L.) arrive at the facility and are debarked. The logs are then shaved and the shavings are sent through a hammer mill to pass a 1.27 cm screen (0.5 in). The milled cedar is then conveyed to a set of boilers where it undergoes a steam distillation process. This process extracts a percentage of the oil from the milled particles. The oil is then sequestered and sold to various commercial industries. CedarSafe® produces about 230 m^{-3} (300 yd^{-3}) of post-distilled cedar biomass a week. Acres of this potential cedar substrate are currently available on site at their facility. CedarSafe® contacted us with the opportunity of testing the aptitude of their post-distilled biomass to compete as a greenhouse substrate alternative. Our research objectives were to focus on assessing the potential of distilled cedar to act as a proportional replacement for PM and P in a greenhouse setting. We incorporated distilled cedar as a substrate component in the production of greenhouse-grown annuals in order to determine a substrate percentage at which these annuals would attain marketable growth. This cedar is unlike any other cedar substrate previously evaluated. The high heat involved in the distillation process could provide beneficial characteristics to the growing medium. We also wanted to avoid issues that other studies encountered when amending substrates with wood fiber alternatives; where fertilizer was required in order to attain adequate plant growth (Fain et al., 2008b; Fain et al., 2008c; and Weldon et. al, 2012).

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II. Distilled Eastern Red Cedar (*Juniperus virginiana* L.) as an Alternative Substrate in the Production of Greenhouse-Grown Annuals

Abstract

Peat moss is the main component used in soilless greenhouse substrates today and is thus in high demand commercially. Due to both environmental and economic concerns associated with peat harvest and production, an increased search for alternative substrates has occurred. A majority of the viable alternatives available to growers are wood based substrates. These substrates are readily available and could be considered more sustainable, depending on geographic location, than peat moss. A recent example of these wood based substrates is eastern red cedar (*Juniperus virginiana* L.). The objective of these experiments was to incorporate cedar, in varying volumetric concentrations, as a substrate component and compare it to a grower's standard peat-lite mix. From our data we observed that substrates containing up to 40% cedar had equal if not better growth for *Petunia ×hybrida* Vilm. 'Celebrity Blue' and *Impatiens walleriana* Hook.f. 'Extreme Violet' than the standard peat-lite mix. Therefore, growers could amend their substrates with up to 40% cedar and see little to no change in marketable plant growth.

Index words: peat moss, *Juniperus virginiana*, peat-lite

Species used in this study: *Petunia ×hybrida* Vilm. 'Celebrity Blue' and *Impatiens walleriana* Hook.f. 'Extreme Violet'

Significance to the Industry

Greenhouse substrates have been primarily peat based ever since the debut of Cornell peat-lite mixes in the 1960s (Boodley and Sheldrake, 1977). Excessive demand and poor harvest seasons for peat moss, in recent years, has caused shortages across the United States resulting in inflation of already high peat prices. This, in turn, has resulted in financial strain for growers in an increasingly harsh economic time. Post-distilled eastern red cedar (*Juniperus virginiana* L.) could be a potential alternative for peat moss in greenhouse substrates. This cedar is a residual biomass that is produced by CedarSafe®, a company located in Huntsville, AL. Due to the research efforts explained in this paper, this biomass is currently being marketed as a potential proportional replacement to peat moss and perlite in standard greenhouse mixes. Growers could incorporate this product into their business and ultimately alleviate some of the strain caused by the culmination of a difficult economic time and a shortage of peat availability.

Introduction

Peat moss (PM) and perlite (P) are still recognized as the components in soilless greenhouse substrates today. The reason for the long reign of PM and P can be attributed to their superior capability to produce marketable plants when compared to other substrate materials. Due to the growing demand for PM, and poor harvest seasons, the issue of peat bog preservation has been brought to light. Peat bogs are becoming scarcer leading to increased demand for protection of remaining bogs. Extraction of PM requires the clearance of all surface vegetation and site drainage. These methods are thought to result in irreversible damage to the ecosystem (Alexander et al., 2008). Another concern associated with PM distribution is the amount of energy required to produce and ship PM internationally. Peat moss has never been an inexpensive commodity for growers and these recent issues have exacerbated its increased expense. Perlite, another common media component, is also experiencing increased demand. Perlite is not only expensive to produce; there are also high amounts of energy required for both the production and shipping processes. Perlite dust is considered a nuisance, causing lung and eye irritation in cases involving over-exposure (Du et al., 2010). Due to these concerns, growers have been interested in finding replacement substrate options for both PM and P. In recent years, research regarding alternative substrates has steadily increased with an emphasis on local and regional sources of materials which are considered to be more sustainable. Numerous types of alternative substrates have been tested in greenhouse crops. Recent examples include the research initiatives on various wood fiber-based alternative substrates (Boyer et al., 2008; Fain et al., 2008; Wright et al., 2008).

Wright et al. (2008) performed experiments assessing the characteristics of pine tree substrate (PTS) as an alternative substrate. To produce PTS, debarked loblolly pine logs (*Pinus taeda* L.) are ground to pass through a hammer mill fitted with 0.48 cm (0.19 in) screen. The objective of the experiments was to better understand the fertilizer requirements for plant growth in PTS. In these experiments chrysanthemum (*Chrysanthemum ×grandiflorum* Ramat. Kitam. 'Baton Rouge') was grown in PTS or a commercial peat-lite (PL) substrate. Plants were placed in a greenhouse and fertilized at each watering. Fertilizer was applied in varying rates of a 20N–4.4P–16.6K-soluble fertilizer ranging from 50 to 400 $\text{mg}\cdot\text{L}^{-1}$ nitrogen (N). About 100 $\text{mg}\cdot\text{L}^{-1}$ N more fertilizer was required for PTS than PL to obtain similar growth in both experiments. EC values were higher for PL substrates than PTS substrates. This research proves that PTS can be used to grow a profitable greenhouse crop if fertilizer requirements are considered (Wright et al., 2008).

WholeTree (WT) is a biomass derived from processed whole pine trees (aboveground portions). Fain et al. (2008a), assessed varying *WholeTree* (WT) particle sizes in the production of greenhouse annuals. The WT was processed to pass a 0.48 (0.19 in), 0.64 (0.25 in), or 0.95 cm (0.37 in) screen. The resulting three WT substrates were used alone or mixed with 20% or 50% (by volume) PM and compared to an industry standard mix of 8:1:1 (by volume) PM:vermiculite:P (peat-lite). The study evaluated the production of marigold (*Tagetes patula* L. 'Little Hero Yellow') and petunia (*Petunia ×hybrida* Vilm. 'Dreams Pink') in these substrates. At 34 days after potting (DAP) there were no differences in flower number for marigold. Petunias grown in the peat-lite substrate had over twice the number of flowers than observed on plants grown in other substrates. At 28 DAP, petunias grown in any 100% WT or 4:1 WT:peat substrate had lower growth than plants in any 1:1 WT:peat or peat-lite substrate. At 28 DAP petunias grown in peat-lite substrates were also larger than those grown in any 4:1 WT:peat substrate; however, all plants were considered marketable. Petunia tissue N concentrations were all below the sufficiency range and it is possible a nitrogen sink in the WT substrates could explain some of the differences in final growth. The much higher than recommended pH for all substrates containing WT most likely contributed to the lack of performance petunia exhibited in these substrates when compared to the peat-lite substrate. Results of this experiment indicated that WT substrates are a potential alternative to conventional greenhouse substrates especially when combined with PM. However, further research concerning nutrient deficiencies needed to be conducted in order to ensure optimal plant growth (Fain et al., 2008a).

In a further study, Fain et al. (2008b) evaluated *WholeTree* (WT) substrate along with starter fertilizer in the production of greenhouse-grown petunia (*P.* ×*hybrida* Vilm. 'Dreams Purple') and marigold (*T. patula* L. 'Hero Spry'). Loblolly pines (*Pinus taeda* L.) were harvested at ground level, chipped, and processed through a hammer mill to pass a 0.64 cm (0.25 in) screen. The resulting WT substrate was used alone or combination with 20% or 50% (by volume) PM and compared with an industry standard peat-lite (PL) mix of 8:1:1 PM:vermiculite:P (by volume). A 7N–1.3P–8.3K starter fertilizer (SF) was added to each substrate at 0.0, 1.19, 2.37, or 3.56 $kg{\cdot}m^{-3}$ (0.0, 2.62, 5.23, or 7.85 $lb{\cdot}yd^{-3}$). Container capacity (CC) was greatest for PL substrates and decreased as the percentage of PM in the substrate decreased. Subsequently, WT had 35% less CC than PL. Air space (AS) was greatest for the WT substrates and decreased as the percentage of WT decreased. Consequently, PL substrates possessed 33% less AS than WT. In general, petunia dry weight was greatest for any substrate containing PM with a SF rate of 2.37 $kg{\cdot}m^{-3}$ (5.23 $lb{\cdot}yd^{-3}$) or greater. The exception was that petunia grown in WT at 3.56 $kg{\cdot}m^{-3}$ (7.85 $lb{\cdot}yd^{-3}$) SF had similar shoot dry weights when compared to all other treatments. Marigold shoot dry weights were similar for all substrates where at least 2.37 $kg{\cdot}m^{-3}$ (5.23 $lb{\cdot}yd^{-3}$) SF was used. Results from this study (Fain et al., 2008b) indicated that, with the addition of a sufficient starter nutrient charge, WT is an adequate substrate component and could potentially replace the majority of PM in the production of petunia and marigold. This mirrors the research initiative by Wright et al. (2008), where it was deduced that a fertilizer was required for similar growth in some treatments.

Clean Chip Residual (CCR) is a by-product of thinning pine plantations composed of about 50% wood, 40% bark and 10% needles. Boyer et al. (2008), conducted an experiment that evaluated CCR as an alternative to PM in the production of three annual species. The species used in this study included: ageratum (*Ageratum houstonianum* Mill. 'Blue Hawaii'), salvia (*Salvia ×superba* L. 'Vista Purple'), and impatiens (*Impatiens walleriana* Hook.f. 'Coral' or 'White'). Two CCR particle sizes were used alone or combined with 10% or 20% PM (by volume). These treatments were compared to control treatments containing pine bark (PB), and

PB blends (10% and 20% PM, by volume). Data collected indicated that there were no differences in growth indices (GI) or shoot dry weight (SDW) of ageratum. Salvia had the highest GI in substrates containing PB: PM and the largest impatiens were observed in PB-based substrates at Auburn. The GI of ageratum at Poplarville was similar among all treatments, but plants grown in 4:1 CCR:PM were the largest. Salvia was largest in 4:1 CCR:PM and PB:PM. The SDW were highest for plants grown in substrates containing PB: PM. This study demonstrates that CCR is a viable alternative substrate in greenhouse production of ageratum, salvia, and impatiens (Boyer et al., 2008).

In recent years an interest in using eastern red cedar (RC) (*Juniperus virginiana* L.) as an alternative substrate component for PM has risen. In many parts of the United States, RC is considered a weed species that will establish on unmanaged land and out-compete native grasses. Griffin et al. (2009), conducted a study where RC was evaluated as a substrate in the production of woody plants. The results of the study indicated that there were no visible signs of nutrient deficiencies, substrate shrinkage, or allelopathy associated with RC. Therefore, RC could be used as a substrate component without the concern of its physical and chemical makeup interfering with plant growth. Murphy et al. (2011), indicated greenhouse producers could amend standard greenhouse substrates with up to 50% RC and observe little to no difference in plant growth. Also, Starr et al. (2011), indicated that RC chips could be incorporated into a substrate for container-grown rudbeckia. Chips at 0.5 cm (0.2 in) screen size performed the best when compared to a pine bark substrate. In addition to the replacement of PM, the physical nature of RC tends to add substrate porosity normally achieved with the addition of P. Therefore, we believe a reduction or elimination in the need for P might also be realized with the use of RC as a substrate component.

The RC used in these experiments was obtained from CedarSafe®, a company located in Huntsville, AL. CedarSafe® mainly exports cedar oil for the perfume industry and closet lining. Cedar logs (*Juniperus virginiana* L.) arrive at the facility and are debarked. Logs are then shaved and the shavings are sent through a hammer mill to pass a 1.27 cm screen (0.5 in). The milled cedar is then conveyed to a set of boilers where it undergoes a steam distillation process. This process extracts a percentage of the oil from the milled particles. Oil is then sequestered and sold to varying business markets. At the time this study began CedarSafe® was left with this post-distilled cedar biomass that had no marketable value. This cedar is unlike any other cedar substrate discussed in similar research projects. High temperatures, resulting from the distillation process, may provide some added benefits to the cedar. The objective of this study was to incorporate post-distilled cedar in progressing percentages directly proportional to a peat-lite mix. All the treatments were compared to a standard greenhouse substrate mix in order to determine CedarSafe® cedar's potential as an alternative greenhouse substrate component.

Materials and Methods

Experiments were conducted at the Paterson Greenhouse Complex in Auburn, AL. Two experiments were conducted in a similar manner, but differing in the time of year (February 11, 2011 and April 15, 2011). In both experiments cedar (C) was used alone or in volumetric combination with an industry standard peat-lite (PL) base mix, 80% PM (Professional Grade, Berger Saint-Modeste, QC Canada) 20% P (Coarse Premium Grade, Sun Gro Horticulture Distribution Inc. Bellevue, WA). Six treatments were evaluated: 100% PL, 20:80 C:PL, 40:60 C:PL, 60:40 C:PL, 80:20 C:PL, and 100% Cedar. Substrate treatments were amended per cubic meter at mixing with: 2.26 kg (5 $\text{lbs}\cdot\text{yd}^{-3}$) lime (added only to PL base); 0.91 kg (2 $\text{lbs}\cdot\text{yd}^{-3}$) starter nutrient charge (7N-1.3P-8.3K, Greencare Fertilizers Inc. Kankakee, IL), 0.45 kg (1 $\text{lb}\cdot\text{yd}^{-}$

^{3}) Micromax (The Scott's Company LLC. Marysville, OH), 0.45 kg (1 lb·yd^{-3}) Gypsum (added only to 100% Cedar), and 2.72 kg (6 lbs·yd^{-3}) slow release fertilizer (13N-2.6P-13.3K, Harrell's LLC. Lakeland, FL). Aqua-Gro L was added at 118.3 mL per cubic meter (4 oz yd^{-3}). Containers, 1.2 L (0.32 gal) (06.00AZ COEX, Dillen Products Middlefield, OH), were filled with the substrates and two plugs [200 cell, each cell measuring 14 cm^{-3} (0.85 in^{-3}), flat] of either impatiens (*I. walleriana* Hook.f. 'Extreme Violet') or petunia (*P.* ×*hybrida* Vilm. 'Celebrity Blue') were planted into each container. Containers were placed in a twin wall polycarbonate greenhouse on elevated benches and hand watered as needed. Containers were arranged in a randomized complete block with 12 replications per treatment. Species were arranged as separate experiments.

Data collected for each experiment included initial substrate pH and EC (Accumet Excel XL50, Fisher Scientific, Pittsburgh, PA) using the pour-through method (Wright, 1986). Subsequent pH and EC analyses were conducted at 7, 14, 21, 28, 35 (Expt. 2), or 42 days after planting (DAP) (Expt. 1). At 35 (Expt. 2) or 42 DAP (Expt. 1) each plant's height and widths were recorded, in cm, and the mean was taken for growth index (GI) [(height+width1+width2)/3]. Bloom count (BC) for each plant was also recorded (flowers and buds showing color). Roots were visually inspected and rated on a scale of 0 (no visible roots) to 5 (roots visible over the entire substrate surface) (RR). At termination, shoots were removed at substrate surface, oven dried at 70°C (158°F) for 72 hours and weighed to determine shoot dry weight (SDW). Initial substrate airspace (AS), container capacity (CC), total porosity (TP), and bulk density (BD) (gm·cm^{-3}) were determined using the NCSU Porometer method (Fonteno and Hardin, 1995). Particle size distribution (PSD) was analyzed by passing three 100 g air-dried samples of each treatment through a series of sieves. The sieves were shaken for three minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations·min, 159 taps·min). Data was analyzed using Tukey's Studentized Range Test ($P \leq 0.05$) (SAS Institute version 9.1, Cary, NC).

Results and Discussion

For the purposes of this discussion, the author has chosen to evaluate the substrates in these experiments with the AS, CC and TP recommendations from Jenkins and Jarrell (1989). Treatments containing higher amounts of C had higher AS and lower CC (Table 1). Starr et al. (2011) also witnessed that substrates containing RC tended to have a higher AS and lower CC when compared to an industry standard substrate. In experiments 1 and 2, AS increased as percentages of C increased, with the exception of 20% C. This could be due to the small amount and size of C particles filling the pore space of the 80% PL and forming a substrate with a lower percentage of available AS. Experiment 1 AS percentages for 60% C and 80% C and experiment 2 AS percentages for 40% C and 60% C, were all within the recommended range of 10% to 20% (Jenkins and Jarrell, 1989). The CC for both experiments tended to decrease with increasing percentages of C. Similar results were observed by Fain et al. (2008b), when a decrease in CC was concurrent with an increase in *WholeTree* and a decrease in PM. Substrates containing 60% and 100% C had CC percentages that were within the recommended range of 50% to 65% (Jenkins and Jarrell, 1989). All other substrates had CC percentages that were higher than the recommended range. The TP for experiment 1 and experiment 2 were similar for all substrates, with the exception of 20% C in experiment 2. All of the substrates for both experiments possessed TP that were higher than the recommended range of 60% to 75% (Jenkins and Jarrell, 1989). The TP of all treatments in a study conducted by Murphy et al. (2011), were also higher than the recommended range set by Jenkins and Jarrell (1989). For experiment 1, BD increased with increasing percentages of C. Similar results were seen in experiment 2; however, all substrates containing C had a similar BD and were higher than the control. The BD of all treatments in experiment 1 and 2 were lower than the recommended range of 0.19 to 0.70 $g \cdot cm^{-3}$ (Yeager et al., 2007). The BD of RC substrates for Murphy et al. (2011), were all lower than the recommended range set by Yeager et al. (2007).

For experiment 1 substrates containing higher percentages of C possessed greater amounts of coarse and medium particles; however, they contained lower amounts of fine particles (Table 2). In experiment 2 all substrates possessed similar amounts of coarse particles. Nevertheless, the substrates containing higher percentages of C had greater amounts of medium particles when compared to substrates with greater PL content. As was seen in experiment 1, substrates containing lower amounts of C in experiment 2 possessed higher amounts of fine particles.

Results for pH and EC were comparable between both species for experiment 1 and experiment 2 (Table 3,4). At 14, 28, and 35 DAP substrates containing higher amounts of C had a higher pH than peat-lite substrates. At 0 DAP for experiment 1 substrates containing 20% to 60% C had higher EC values than substrates containing 80% C or more. At 0 DAP for experiment 2 EC values were similar amongst all the treatments. In both experiment 1 and 2, and for both petunia and impatiens, EC for 100% PL and 20% C were similar and higher than all other substrates. At 28 DAP, 80% C substrates had higher EC values when compared to the control treatment. When both species were terminated it was observed that EC values were similar amongst all treatments. Substrate EC values for experiment 2 at 14 and 28 DAP indicated that substrates containing higher amounts of C had a lower EC than those containing higher amounts of peat-lite. An increase in AS and a reduction in CC was observed occasionally for substrates containing higher amounts of C in both experiments. A similar trend was also observed (Boyer et al. 2008) where substrates composed of 100% CCR had high AS and low container CC which resulted in nutrient leaching and less available water to plants. Subsequently, these substrates would develop a lower EC overtime.

At termination (42 DAP for Expt. 1 and 35 DAP for Expt. 2) data was taken to determine GI, BC, RR, and SDW of each species within both studies (Table 5). For experiment 1 petunia GI indicated that substrates containing 20% C had 10% higher GI than the control treatment. It was also observed that 100% C substrates had 35% lower GI than 20% C substrates. In addition GI was similar for 40% C and 60% C substrates compared to the control. Petunia BC was similar when comparing the control with 20% C substrates. However, BC was reduced 22% to 58% with 40% to 100% C when compared to the control. The RR for petunia were similar among all treatments with the exception of 100% C substrates, which observed a 53% decrease in RR from 80% C substrates. Petunia SDW for experiment 1 were similar when comparing 20% and 40% C to the control treatment. Data for impatiens in experiment 1 indicated that there was no difference between 20% and 40% C when compared to the control for GI. The GI for impatiens grown in 60% C were only slightly lower (12%) than the 40% C treatment. Starr et al. (2010) observed similar results, in that, substrates containing up to 40% RC had GI comparable to the control treatment. Murphy et al. (2011) had comparable GI to the control (75:25 PM:P) in substrates containing up to 50% RC in the authors' first experiment. In the second experiment substrates containing 25% RC were similar to their control. Impatiens RR were similar to the control in substrates containing 20% to 60% C. Murphy et al. (2011) observed that root growth was comparable to their control treatment in up to 50% RC substrates for all annuals. Impatiens BC was similar for the 20% and 40% C treatments in experiment 1. However, they had 24% less blooms than the peat-lite standard. All other treatments displayed a 42% to 60% reduction in BC compared to the peat-lite standard. Impatiens SDW were highly variable amongst treatments. Substrates containing 20% C had 19% lower SDW than the control. The SDW for 40% C were 15% lower than 20% C substrates. The values decreased with an increasing rate of cedar. The GI for petunia in experiment 2 indicated that there was no difference found between 20% C substrates and the control. However, there was a 22% decrease in GI from when comparing 20% C and 100% C substrates. Petunia BC indicated that 20% C had 16% higher BC than the control. The BC for 20% and 40% C were similar; however, there was a 22% decrease from 40% C to 60% C. When comparing RR in petunia no difference was observed between the first three treatments. However, treatments containing 60% C or above had lower RR with 100% C having the lowest ratings. Petunia SDW were analyzed and it was observed that 20% C had 6% higher SDW than the control. There was a 64% decrease in SDW when comparing 20% C and 100% C substrates. Termination data for impatiens indicated that there was no difference found between 20% C and 40% C and the control among BC, RR, and SDW. Impatiens GI were similar for 20% C to 60% C when compared to the control. Substrates containing 100% C had the lowest values for GI, BC and SDW.

The data provided indicates, for both experiments, that petunias and impatiens grown in substrates containing 20% and 40% cedar were of equal, if not greater, quality than that of those grown in the standard peat-lite mix. The cedar provided by CedarSafe® would be an acceptable alternative component for greenhouse substrates replacing portions of PM and P.

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Table 1. Physical properties of cedar amended substrates.[z]

	Air space[y]		Container capacity[x]		Total porosity[w]		Bulk density[v] (g/cm^3)	
	(% vol)							
Substrates	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% Peat-lite	6.1 d[u]	8.1 dc[u]	77.9 a	76.1 a	84.0[NS t]	84.2 ab	0.14 c	0.11 b
20:80 Cedar:Peat-lite	4.7 d	4.4 d	77.5 a	76.1 a	82.2	80.5 b	0.16 b	0.15 a
40:60 Cedar:Peat-lite	7.8 d	12.7 c	74.7 a	70.1 b	82.5	82.7 ab	0.16 b	0.15 a
60:40 Cedar:Peat-lite	15.9 c	20.3 b	65.6 b	65.0 c	81.5	85.4 a	0.18 a	0.15 a
80:20 Cedar:Peat-lite	20.0 b	23.9 b	62.9 b	60.3 d	83.0	84.2 ab	0.18 a	0.16 a
100% Cedar	32.1 a	35.9 a	50.2 c	50.1 e	82.4	85.9 a	0.18 a	0.16 a

[z] Analysis performed using the NCSU porometer method.

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

[x] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[w] Total porosity is container capacity ÷ air space.

[v] Bulk density after forced-air drying at 105 °C (221 °F) for 48 h ($g/cm^3 = 62.4274\ lb/ft^3$).

[u] Tukey's Studentized Range Test ($P \leq 0.05$, $n = 3$).

[t] NS = no statistical difference observed.

Table 2. Particle size distribution of substrates.

	Experiment 1											Texture Group^{z}		
Substrates	1/4"	6	8	10	14	18	35	60	140	270	Pan	Coarse	Medium	Fine
100% Peat-lite	0.0 c^{yx}	6.1 c	8.4 d	3.7 d	9.2 f	9.7 d	24.9 a	22.7 a	11.8 a	2.6 a	0.9 a	6.1 d	31.0 e	62.9 a
20:80 Cedar:Peat-lite	0.5 abc	6.4 c	9.6 cd	4.7 d	11.7 e	10.7 c	22.9 b	20.0 b	10.2 a	2.3 a	0.9 a	6.9 cd	36.7 d	56.4 b
40:60 Cedar:Peat-lite	0.4 bc	7.4 bc	10.9 bc	6.0 c	14.2 d	13.3 b	23.3 ab	15.4 c	6.9 b	1.5 b	0.6 b	7.9 bc	44.4 c	47.7 c
60:40 Cedar:Peat-lite	0.6 abc	8.5 ab	12.0 ab	6.6 bc	16.9 c	14.1 b	20.6 c	13.3 c	5.7 bc	1.3 bc	0.5 b	9.1 b	49.5 b	41.4 d
80:20 Cedar:Peat-lite	0.9 ab	9.9 a	13.5 a	7.6 ab	18.4 b	15.4 a	19.0 cd	10.0 d	3.9 cd	0.9 cd	0.4 bc	10.8 a	54.8 a	34.4 e
100% Cedar	1.3 a	9.9 a	14.0 a	8.1 a	19.6 a	15.9 a	17.8 d	8.8 d	3.5 d	0.8 d	0.3 c	11.3 a	57.5 a	31.2 e
	Experiment 2											Texture Group^{z}		
	1/4"	6	8	10	14	18	35	60	140	270	Pan	Coarse	Medium	Fine
100% Peat-lite	0.0$^{NS\ w}$	12.2^{NS}	9.5 c	3.5 e	7.8 d	7.8 d	18.5 b	24.1 a	14.1 a	2.0 a	0.5^{NS}	12.0^{NS}	28.7 d	59.1 a
20:80 Cedar:Peat-lite	0.0	12.0	11.3 bc	4.8 d	13.5 c	12.5 c	23.7 a	14.5 b	5.9 bc	1.3 ab	0.6	12.0	42.0 c	46.0 b
40:60 Cedar:Peat-lite	0.0	9.4	12.4 bc	6.0 c	15.3 c	12.7 c	18.6 b	15.9 b	8.0 b	1.3 ab	0.2	9.4	46.5 c	44.1 b
60:40 Cedar:Peat-lite	0.2	8.0	12.9 b	7.9 b	19.2 b	14.2 b	17.1 bc	12.5 bc	6.7 bc	0.9 b	0.2	8.2	54.2 b	37.5 bc
80:20 Cedar:Peat-lite	0.3	7.7	14.4 ab	9.0 a	21.5 a	15.7 a	16.2 bc	9.5 cd	4.3 c	1.1 b	0.5	8.1	60.5 a	31.5 cd
100% Cedar	0.0	9.3	16.3 a	9.3 a	22.9 a	15.6 a	15.3 c	6.8 d	3.2 c	1.0 b	0.4	9.3	64.1 a	26.7 d

[z] Coarse ≥2.0mm; Medium <2.0 mm to ≥1.0mm; Fine <1.0mm.

[y] Percent weight of 100g sample collected on each screen.

[x] Tukey's Studentized Range Test ($P \leq 0.05$, n = 3).

[w] NS = no statistical difference observed.

Table 3. Effects of substrate on pH and electrical conductivity of greenhouse grown annuals for experiment 1.

			Petunia ×hybrida					
	0 DAP[z]		14 DAP		28 DAP		42 DAP	
Substrates	pH	EC[y]	pH	EC	pH	EC	pH	EC
100% Peat-lite	4.38 ab[x]	2.24 ab	4.87[NS w]	8.98 a	5.72 ab	0.62 b	5.48 b	0.35[NS]
20:80 Cedar:Peat-lite	4.19 abc	2.37 a	4.82	9.59 a	5.58 b	1.33 ab	5.27 b	0.74
40:60 Cedar:Peat-lite	4.15 bc	2.56 a	4.87	6.05 b	5.74 ab	0.90 ab	5.45 b	0.54
60:40 Cedar:Peat-lite	4.10 c	2.39 a	4.88	4.67 b	5.81 ab	1.22 ab	5.44 b	0.54
80:20 Cedar:Peat-lite	4.24 abc	1.66 b	4.78	4.18 b	5.81 ab	1.40 a	5.61 ab	0.40
100% Cedar	4.44 a	1.62 b	4.89	5.39 b	6.09 a	1.14 ab	6.07 a	0.35
			Impatiens walleriana					
	0 DAP		14 DAP		28 DAP		42 DAP	
	pH	EC	pH	EC	pH	EC	pH	EC
100% Peat-lite	4.38 ab	2.24 ab	4.96 ab	9.94 a	5.61 b	3.49 ab	5.42 d	0.39[NS]
20:80 Cedar:Peat-lite	4.19 abc	2.37 a	4.92 ab	9.08 a	5.61 b	2.71 ab	5.55 cd	0.42
40:60 Cedar:Peat-lite	4.15 bc	2.56 a	4.92 ab	5.44 b	5.69 ab	2.93 ab	5.65 bcd	0.48
60:40 Cedar:Peat-lite	4.10 c	2.39 a	4.96 ab	5.30 b	5.58 b	3.66 ab	5.83 abc	0.71
80:20 Cedar:Peat-lite	4.24 abc	1.66 b	4.77 b	4.63 b	5.33 c	3.97 a	5.92 ab	0.51
100% Cedar	4.44 a	1.62 b	5.04 a	3.68 b	5.87 a	2.09 b	6.07 a	0.50

[z] Days After Planting.

[y] Electrical Conductivity (dS/cm) of substrate solution using the pour through method.

[x] Tukey's Studentized Range Test ($P \leq 0.05$, n = 4).

[w] NS = no statistical difference observed.

Table 4. Effects of substrate on pH and electrical conductivity of greenhouse grown annuals for experiment 2.

			Petunia* ×*hybrida					
	0 DAP^{z}		14 DAP		28 DAP		42 DAP	
Substrates	pH	EC^{y}	pH	EC	pH	EC	pH	EC
100% Peat-lite	4.98 ab^{x}	2.27$^{NS\ w}$	5.11 b	8.62 a	5.27 b	1.13^{NS}	5.11 bc	0.96 a
20:80 Cedar:Peat-lite	4.99 ab	2.55	4.81 c	9.58 a	5.04 b	1.27	4.86 c	0.82 ab
40:60 Cedar:Peat-lite	4.83 ab	2.40	5.06 b	5.68 b	5.40 b	1.06	5.08 bc	0.77 ab
60:40 Cedar:Peat-lite	4.65 b	2.29	5.06 b	4.49 bc	5.40 b	0.71	5.23 b	0.48 ab
80:20 Cedar:Peat-lite	4.73 ab	2.03	4.94 bc	4.65 bc	5.53 ab	1.74	5.28 b	0.48 ab
100% Cedar	5.10 a	1.98	5.84 a	2.26 c	5.98 a	0.49	5.87 a	0.43 b

			Impatiens walleriana					
	0 DAP		14 DAP		28 DAP		42 DAP	
	pH	EC	pH	EC	pH	EC	pH	EC
100% Peat-lite	4.98 ab	2.27^{NS}	5.12 bc	9.79 a	5.10 d	2.21 a	5.09 bc	0.94^{NS}
20:80 Cedar:Peat-lite	4.99 ab	2.55	5.01 c	8.30 ab	4.98 d	2.51 a	4.73 d	0.89
40:60 Cedar:Peat-lite	4.83 ab	2.40	5.31 b	4.58 cd	5.21 cd	2.69 a	4.83 cd	0.82
60:40 Cedar:Peat-lite	4.65 b	2.29	4.99 c	5.31 cd	5.44 bc	2.19 ab	4.89 cd	0.84
80:20 Cedar:Peat-lite	4.73 ab	2.03	4.90 c	5.89 bc	5.63 b	1.39 ab	5.40 b	0.54
100% Cedar	5.10 a	1.98	5.62 a	2.99 d	6.19 a	0.59 b	5.82 a	0.34

[z] Days After Planting.

[y] Electrical Conductivity (dS/cm) of substrate solution using the pour through method.

[x] Tukey's Studentized Range Test ($P \leq 0.05$, n = 4).

[w] NS = no statistical difference observed.

Table 5. Use of cedar as an alternative substrate component.

	Growth Index[z]		Bloom Counts[y]		Root Rating[x]		Shoot Dry Weight[w]	
			Petunia ×hybrida					
Substrates	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% Peat-lite	28.4 b[v]	35.8 a	32.9 a	60.1 b	4.4 a	4.1 a	12.1 ab	12.2 ab
20:80 Cedar:Peat-lite	31.3 a	35.4 a	30.6 ab	69.7 a	4.5 a	4.1 a	13.4 a	12.9 a
40:60 Cedar:Peat-lite	29.5 ab	33.6 ab	25.4 bc	63.6 ab	4.4 a	3.8 a	11.5 ab	10.6 b
60:40 Cedar:Peat-lite	26.9 bc	30.9 bc	23.2 c	49.5 c	4.4 a	2.6 b	9.6 bc	8.3 c
80:20 Cedar:Peat-lite	24.6 c	29.2 cd	20.4 c	42.0 cd	3.5 a	2.8 b	7.2 c	7.1 cd
100% Cedar	20.2 d	27.6 d	13.7 d	36.9 d	1.6 b	1.3 c	3.9 d	5.7 d
			Impatiens walleriana					
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% Peat-lite	26.5 a	28.3 a	60.8 a	68.3 a	4.5 a	4.5[NS u]	10.6 a	13.3 a
20:80 Cedar:Peat-lite	26.0 a	28.6 a	46.7 b	68.0 a	4.4 a	4.9	8.6 b	12.9 a
40:60 Cedar:Peat-lite	25.0 a	28.0 a	46.4 b	63.9 a	4.1 a	5.0	7.3 c	11.8 a
60:40 Cedar:Peat-lite	21.9 b	26.9 a	35.1 c	49.0 b	4.4 a	5.0	5.4 d	9.2 b
80:20 Cedar:Peat-lite	18.8 c	24.1 b	22.9 d	41.7 b	3.4 b	5.0	3.3 e	6.5 c
100% Cedar	16.9 c	22.1 c	19.6 d	28.8 c	2.5 c	5.0	2.6 e	4.6 d

[z] Growth index = [(height+width1+width2)/3] (n = 12).

[y] Bloom count = number of blooms or buds showing color at 42 days (n = 12).

[x] Root ratings 0-5 scale (0 = no visible roots and 5 = roots visable on the entire container substrate interface) (n = 8).

[w] Shoot dry weight measured in grams (n = 8).

[v] Tukey's Studentized Range Test (P ≤ 0.05).

[u] NS = no statistical difference observed.

III. Pre- and Post-Distilled Eastern Red Cedar (*Juniperus virginiana* L.) as Alternative Substrate Components in the Production of Greenhouse-Grown Annuals

Abstract

Peat moss is considered a standard in soilless greenhouse substrates today and is thus in high demand commercially. The demand for peat moss has caused both economic and environmental concerns. These concerns have fueled a search for alternative substrate components that possess comparable qualities to that of the standard. In this experiment we evaluated post-distilled eastern red cedar (*Juniperus virginiana* L.) (DC), a potential alternative substrate component, and compare it to pre-distilled eastern red cedar (C). Each substrate component was mixed, in volumetric combination, with an industry standard peat moss (PM). The six treatments formulated in this experiment included: 60:40 C:PM, 40:60 C:PM, 20:80 C:PM, 60:40 DC:PM, 40:60 DC:PM, and 20:80 DC:PM. The substrates were planted with either petunia (*Petunia ×hybrida* Vilm. 'Dreams Burgundy') or vinca (*Catharanthus roseus* L. 'Cooler Rose') placed in a greenhouse and watered as needed until termination. Data taken after termination indicated that DC substrates performed equal to, if not better than, C substrates. This could be due, in part, to the distillation process that our cedar biomass undergoes. The act of removing a percentage of the cedar's oil, and the high heat involved, may positively affect DC substrate characteristics and result in superior plant growth. This cedar could potentially be a viable alternative for the horticulture industry and replace portions of PM and perlite in the production of greenhouse annuals.

Index Words: Peat moss, perlite, soilless substrate, annuals

Species used in this study: *Petunia ×hybrida* Vilm. 'Dreams Burgundy' and *Catharanthus roseus* L. 'Cooler Rose'

Significance to the Industry

Peat moss and perlite are the main components utilized in the formulation of greenhouse substrates. Despite their popularity, concerns associated with the production and processing of these materials have risen. These concerns have instigated numerous research efforts focused on finding alternatives that will fulfill grower's substrate requirements. In previous studies post-distilled cedar was found to be an editorial alternative substrate component in the production of greenhouse-grown annuals (Vandiver et al., 2011). The experiment indicated that a standard peat-lite mix (80:20 PM:P) could be amended with up to 40% cedar and be equal to, if not better than, the standard mix when growing annuals. The objective of this experiment was to compare the post-distilled cedar to cedar that has not undergone the distillation process. Our intent was to identify potential benefits or detriments that might be associated with distilling cedar substrates. The author believes that the distillation process may remove potentially harmful chemicals innate to cedar and other wood-fiber alternatives. Allelopathy, coined by Hans Molisch in 1937 (Molisch 1937), is defined as harmful and beneficial biochemical reactions between plants and microorganisms. There are five major categories of plant-produced chemical inhibitors: phenylpropanes, acetogenins, terpenoids, steroids, and alkaloids. These inhibitors are believed to obstruct plant growth in wood-fiber substrates, such as eastern red cedar. Gaches et al. (2010), tested aged vs. fresh *WholeTree* (WT) in the production of greenhouse annuals and found increased plant growth with higher GI, BC, and SDW for aged WT. It was assumed that needles in the fresh WT could be releasing chemical compounds into the substrate solution, which, in turn, was inhibiting plant growth. Subsequently, Gaches et al. (2011), tested the allelopathic properties of aged vs. fresh pine needles and their effect on lettuce seeds (*Lactuca sativa* L.) and found that fresh needles negatively effected seedling growth. Witcher et al. (2011), performed assays in order to potentially identify phytotoxicity in whole pine tree (WPT). Treatments of aged vs. fresh WPT, aged vs. fresh needles, pine bark, and peat moss were applied for use in the germination of seedlings. Our experiment indicated that the quality of plants grown in post-distilled cedar were equal to, if not greater than, those grown in pre-distilled cedar. Therefore, post-distilled cedar would be a viable alternative to peat moss in the production of greenhouse annuals. Furthermore, the distillation could positively affect our cedar substrate and provide a superior growing media for annuals when compared to non-distilled cedar.

Introduction

The two most common components in greenhouse media are peat moss (PM) and perlite (P). Due to an increasing demand for PM, the issue of peat bog preservation has been receiving attention. Another concern associated with peat production is the cost of shipping from Canada and Europe and the economic strain it puts on growers. On September 23, 2011 the Canadian Sphagnum Peat Moss Association (CSPMA) issued a press release stating that the harvesting season for peat in Canada had effectively come to an end. Due to unfavorable weather conditions only 15 to 30% of the targeted peat bogs in Eastern Canada were harvested. The hardest hit areas were Quebec and New Brunswick, which account for 60-70% of all Canada’s peat production. Therefore, it was concluded that the industry was facing one of its poorest peat harvest seasons to date. Perlite is also experiencing increased demand. Perlite is not only expensive to produce, but there are also high amounts of energy required for both the production and shipping processes. Another issue associated with P is that its dust is considered a health nuisance, causing lung and eye irritation in cases involving over-exposure (Du et al., 2010).

Due to these concerns, growers have been concerned with finding replacement substrate options for both PM and P. In recent years research regarding alternative substrates has steadily increased with an emphasis on local and regional sources of materials, which are considered to be more sustainable. Numerous types of alternative substrates have been tested in greenhouse crops. Recent examples include research efforts on Pine Tree Substrate, *WholeTree* (WT), and Clean Chip Residual (Wright et al. 2008, Fain et al. 2008a and 2008b, Boyer et al. 2008).

Eastern red cedar (*Juniperus virginiana* L.) is locally abundant and can be used as an alternative substrate component for PM (Vandiver et al. 2011). Research has shown that plants grown in substrates amended with eastern red cedar tended to have equivalent growth quality to those grown in a traditional peat-lite (PL) mix, but only when amended. Greenhouse producers could amend standard greenhouse substrates with up to 50% cedar and observe little to no difference in plant growth (Murphy et al. 2011). Starr et al. (2011) indicated that eastern red cedar chips could be used as a substrate for container-grown *Rudbeckia fulgida* var. *fulgida* Ait., with chips milled to pass a 0.5 cm screen size performing the best when compared to a pine bark substrate. In addition to the replacement of PM, the physical nature of cedar tends to add substrate porosity normally achieved with the addition of P. Therefore, we believe a reduction or elimination in the need for P might also be realized with the use of cedar as a substrate component.

One potential source of cedar for alternative substrates is CedarSafe®, a company located in Huntsville, AL. It is unlike cedar found in other substrate research projects, due to the fact that this cedar is a by-product of cedar oil production at the CedarSafe® facilities. The process begins with debarked eastern red cedar logs, which are shaved and then sent through a hammer mill to pass a 1.27 cm screen (0.5 in). The milled cedar is then conveyed to a set of boilers, where the material undergoes a steam distillation process, which extracts a percentage of the cedar oil. CedarSafe® currently has no market for the post-distilled cedar biomass. Post-distilled cedar could be utilized as an alternative substrate component in growing greenhouse annuals (Vandiver et al., 2011). The use of wood-fiber substrates such as cedar, however, has often been linked with concerns of allelopathy.

Gaches et al. (2010), conducted a study to determine growth differences in aged and fresh WT. Fresh loblolly pine (*Pinus taeda* L.) WT chips were ground in a hammer mill to pass a 0.95 cm (0.37 in) screen in order to produce fresh WT substrate. The material produced was stored in three separate 1.73 m^3 (2.3 yd^3) polypropylene bulk bags in full sun and aged. Temperature sensors were placed inside the center of each bag during filling, as well as on the outside of each bag to obtain inside bag temperature and ambient temperature for comparisons. On day 21, the average temperature inside the bags fell below the ambient temperature outside the bags. The material in these bulk bags was utilized as aged WT. WT from the same source, and processed the same, was used as fresh WT. The treatments included a 1:1 aged WT:peat substrate (AWP) or 1:1 fresh WT:peat substrate (FWP). The substrates were planted with uniform plugs of marigold (*Tagetes patula* L. 'Little Hero Yellow') and petunia (*Petunia ×hybrida* Vilm. 'Dreams White') two days after the fresh WT was milled and 94 days after the aged WT was milled. For both species, plants grown in AWP had higher growth indices, dry weight, and bloom counts. In petunias, plants grown in AWP had higher SPAD measurements than those grown in FWP. Root ratings for petunia were the same for plants grown in AWP and FWP however, marigolds grown in AWP had higher root ratings than those grown in FWP. In general, plants grown in AWP were more viable than those grown in FWP. Differences in plant growth may be attributed, at least partly, to differences in substrate physical properties. Increased AS and lower CC in the FWP over the AWP could have resulted in increased nutrient leaching as well as a decrease in water availability. Poor plant growth was also attributed to the possibility that needles in the fresh WT could be releasing chemical compounds into the substrate solution, which, in turn, was inhibiting plant growth (Gaches et al., 2010).

Subsequently, Gaches et al. (2011), conducted a bioassay testing the effects fresh vs. aged pine needles had on seed germination. Fresh pine needles were collected directly from 12-year-old loblolly pine trees. Aged pine needles were collected from the ground under the same pine trees. Five lettuce seeds (*Lactuca sativa* L.) were placed in separate Petri dishes. Five mL of the appropriate solution (fresh/aged) was poured into each Petri dish. After the incubation period, average germination percentage and average radicle length for seedlings in each Petri dish were calculated. There was no difference observed in germination percentage for lettuce seeds between treatments however, the radicle length of seeds germinated in aged needle leachate was greater than the radicle length of seeds germinated in fresh needle leachate. While seed germination was not inhibited by fresh pine needle leachate, post-germination growth of the seedlings was negatively affected in the presence of the fresh needle leachate. Results indicated that some chemical present in fresh pine needles might negatively affect radicle growth in fresh WT substrate.

Witcher et al. (2011), evaluated two types of biological assays (Phytotoxkit^{TM} and seedling growth test) in order to determine possible phytotoxic effects of whole pine tree substrates compared with traditional substrates. The species used in the Phytotoxkit^{TM} included: one monocot species (sorghum, *Sorghum saccharatum* L.) and two dicot species (cress, *Lepidium* *sativum* L. and mustard, *Sinapis alba* L.). Substrate treatments included a reference soil (RS), aged (WPTA) and fresh (WPTF) whole pine tree, aged (PNA) and fresh (PNF) pine needles, pine bark (PB), PM, and saline pine bark (SPB). Saline pine bark was included to produce an inhibitory effect on seed germination and initial root growth and served as a negative control for the test procedure. A seedling growth test was used to evaluate seed emergence and seedling root growth under a simulated production environment (Witcher et al., 2011). The species used included: one monocot species (oat, *Avena sativa* L. 'Jerry') and two dicot species (lettuce, *Lactuca sativa* L. 'Green Ice' and tomato, *Solanum lycopersicum* L. 'Brandywine'). Substrates included WPTA, WPTF, a PL substrate (3:1:1 PM:P:vermiculite v:v), and PB. Using the Phytotoxkit^{TM}, the lowest germination rates within a species occurred in PNF (cress) and SPB (mustard and sorghum). The greatest germination rate was 96.7% for mustard (RS, PB, and WPTA), 96.9% for sorghum (PNF and WPTA), and 97.0% for cress (RS). Root length for cress was 3.8 times greater in PB compared with PNF, and 2.3 times greater in PNA compared with PNF. Mustard root length was significantly greater in PNA compared with PNF. Sorghum root length was statistically lower in SPB compared with all other substrates and greatest overall in RS. In the seedling growth test, emergence rate was similar among all substrates for lettuce and oat, while tomato emergence rate was lowest for WPTF and greatest for WPTA. Total root length was greatest for PL in each species. Aging the whole pine tree material only affected tomato emergence and oat total root length. It was observed that WPTA and WPTF could be used for seed propagation of six plant species sensitive to various phytotoxic effects. Additionally, the seed germination/emergence rate in WPTA/WPTF was similar to that obtained in traditional substrate components, specifically PM and pine bark. In both experiments, root development was a more sensitive indicator of phytotoxicity compared with germination and emergence rate (Witcher et al., 2011).

Our intent for this experiment was to identify potential benefits or detriments that might be associated with distilling cedar substrates. Therefore, this experiment will compare post-distilled cedar to cedar that has not undergone distillation.

Materials and Methods

Experiments were conducted at the Paterson Greenhouse Complex in Auburn, AL. Two experiments were conducted in a similar manner, but differing in year (June 15, 2011 and June 21, 2012). In both experiments pre (C) and post-distilled cedar (DC) were used in volumetric combination with an industry standard PM. There were six treatments compared in this study: 60:40 C:PM, 40:60 C:PM, 20:80 C:PM, 60:40 DC:PM, 40: 60 DC:PM, and 20:80 DC:PM. Substrate treatments had the following amendments added per cubic meter at mixing: 2.27 kg (5 $\text{lbs}\cdot\text{yd}^{-3}$) lime; 0.91 kg (2 $\text{lbs}\cdot\text{yd}^{-3}$) starter nutrient charge (7N-1.3P-8.3K, Greencare Fertilizers Inc. Kankakee, IL), 0.45 kg (1 $\text{lb}\cdot\text{yd}^{-3}$) Micromax (The Scott's Company LLC. Marysville, OH), and 2.72 kg (6 $\text{lbs}\cdot\text{yd}^{-3}$) slow release fertilizer (13N-2.6P-13.3K, Harrell's LLC. Lakeland, FL). Aqua-Gro L was added at 118.3 mL per cubic meter (4 $\text{oz}\cdot\text{yd}^{-3}$). Containers, 1.2 L (0.32 gal) (06.00AZ COEX, Dillen Products Middlefield, OH), were filled with the substrates and either two plugs (200 14 cm^{-3} (0.85 in^{-3}) cell flat) of *Petunia ×hybrida* Vilm. 'Dreams Burgundy' or three plugs (200 14 cm^{-3} (0.85 in^{-3}) cell flat) of *Catharanthus roseus* L. 'Cooler Rose' were planted into each container. Containers were placed in a twin wall polycarbonate greenhouse on elevated benches and hand watered as needed. Containers were arranged in a randomized complete block with 12 replicates per treatment. Species were arranged as separate experiments.

Data collected for each experiment included initial substrate pH and EC (Accumet Excel XL50, Fisher Scientific, Pittsburgh, PA) using the pour-through method (Wright, 1986).

Subsequent pH and EC analyses were conducted at 7, 14, 21, 28, and 35 days after planting (DAP). At 35 DAP each plant's height and widths were recorded, in centimeters, and the mean was taken for growth index (GI) [(height+width1+width2)/3]. Bloom count (BC) for each plant was also recorded (flowers and buds showing color). Roots were visually inspected and rated on a scale of 0 (no visible roots) to 5 (roots visible over the entire substrate surface) (RR). At termination shoots were removed at substrate surface, oven dried at 70°C (158°F) for 72 hours and weighed to determine shoot dry weight (SDW). Initial substrate airspace (AS), container capacity (CC), total porosity (TP), and bulk density (BD) ($gm \cdot cm^{-3}$) were determined using the NCSU Porometer method (Fonteno and Hardin, 1995). Particle size distribution (PSD) was analyzed by passing three 100 g air-dried samples of each treatment through a series of sieves. The sieves were shaken for three minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations·min, 159 taps·min). Data was analyzed using Tukey's Studentized Range Test ($P \leq 0.05$) (SAS Institute version 9.1, Cary, NC).

Results and Discussions

Results from experiment 1 physical property measurements indicated that all treatments possessed a similar TP for substrates containing DC (Table 1). However, substrates containing C had varying TP percentages, with 20% C having the highest and 40% C the lowest. For experiment 2 there was no difference in TP among all substrates. The TP percentages for both experiments were higher than the recommended range (60% to 75%) set by Jenkins and Jarrell (1989). Similar results were observed in earlier studies concerning eastern red cedar (Vandiver et al., 2011). In both experiments as percentage of C and DC increased CC for that substrate decreased. Also, 60% C had the lowest CC among all substrates in experiment 1 and experiment 2. As was observed with TP, all substrates in both experiments had CC that were higher than the recommended range of 50% to 65% (Jenkins and Jarrell, 1989). Fain et al. (2008b), observed similar results when a decrease in *WholeTree* prompted a decrease in CC. For both experiments, as the percentage of DC increased there was an increase in AS. Substrates containing C for experiment 1 and 2 had highest AS percentages at 60%. For experiment 1 the lowest AS was observed in 40% C. However, in experiment 2, 20% C and 40% C had similar AS percentages. All substrates for both experiments were lower than the recommended range of 10% to 20%, with the exception of 60% C (10.63%). In both experiments BD increased with increasing percentages of C and DC. For both experiments, BD values were below the recommended range of 0.19 to 0.70 $g{\cdot}cm^{-3}$ set by Yeager et al. (2007), for nursery substrates. Similar results were observed in earlier experiments assessing eastern red cedar (Murphy et al., 2011, Vandiver et al., 2011). There was an apparent increase in BD from experiment 1 to experiment 2. This can be explained by a difference in procedure. A higher BD would generally result from tighter packing in porometers. Subsequently, the increase in BD would produce a decrease in AS and TP, which was seen when comparing experiment 1 and experiment 2.

Results for PSD indicated that as percentages of DC increased there was a decrease in coarse particles for both experiments (Table 2). However, in both experiments, 20% C and 40% C possessed similar percentages of coarse particles. In experiment 1 medium particle percentages increased with an increase in both C and DC. Similar results were seen in experiment 2; however, 40% C and 60% C had similar percentages of medium particles. For both experiments 20% C had the highest percentage of fine particles. In experiment 1 as percentage of DC increased there was a reduction in fine particles. Similar results were observed in experiment 2 regarding substrates containing C. Conversely, 40% C and 60% C had similar percentages of fine particles. Overall, substrates containing higher amounts of C and DC tended to be composed of greater percentages of medium particles and fewer amounts of coarse and fine particles.

Results for pH of both petunias and vinca in experiment 1 at 0, 7, 14, 21, 28, and 35 DAP indicated that as the percentage of cedar increased in a substrate the pH for that substrate also increased (Table 3). Also, for experiment 1, substrates containing C tended to have higher pH values than those containing DC. However, in experiment 2 most all pH values were similar for C and DC in both species at concordant percentages (Table 4). In experiment 1 EC values were similar across all substrates by 14 DAP for petunia and 21 DAP for vinca. Experiment 2 EC values were similar by 21 DAP for petunia and 35 DAP for vinca. In both experiments EC values for petunia and vinca tended to be higher for substrates composed of DC when compared to C. This could be attributed to the difference in chemical and physical properties that DC possesses after distillation. There were higher EC values observed for vinca in experiment 2 compared to experiment 1. We could attribute this to less frequent watering during experiment 2. The lower EC values in substrates containing higher amounts of C and DC could be attributed to leaching of nutrients throughout experiment 1 and 2. However, it could also be due to some absorption of nutrients into the cedar shortly after planting. Fain et al. (2008a) and Gaches et al. (2010) made similar conclusions when wood-fiber alternatives were incorporated as substrate components. For both experiments EC values became similar as each study reached its completion. This could be due to our fertilizer release rate (3-4 month), which would result in low nutrient availability at termination.

Data taken at termination for experiment 1 indicated that plants grown in treatments containing a smaller percentage of cedar had better growth data than those grown in higher percentages of cedar for both pre and post-distilled substrates (Table 5). In previous studies similar results were seen and were contributed mainly to the larger particle size of the cedar biomass and its leaching effects (Vandiver et al., 2011). Petunia BC were similar amongst pre and post-distilled cedar treatments when compared to substrates with the same percent. Bloom counts for vinca at 20 and 40% were comparable between pre and post-distilled cedar. However, in vinca, a bloom count increase of about 46% was observed in 60% post-distilled cedar when compared to 60% pre-distilled cedar. Root ratings for petunias and vinca were comparable at 20% in both C and DC substrates. However, plants grown in substrates containing 40 and 60% post-distilled cedar had higher root ratings than that of those grown in pre-distilled cedar. Shoot dry weights for petunias were similar between 20 and 60% cedar amended substrates. Overall, RR in experiment 1 were better for DC than C. A weight increase of about 30% was seen in 40% post-distilled cedar when compared to 40% pre-distilled cedar. For vinca a similarity was seen between 20 and 40% cedar amended substrates. However, a weight increase of about 28% was seen when comparing 60% post-distilled cedar to 60% pre-distilled cedar. Overall, 60% DC performed better than 60% C in three out of the four growth parameters measured. Experiment 2 data for petunia GI, BC, and RR were not different amongst treatments. However SDW data indicated that there was a 46% decrease from 20% DC to 60% DC. The GI of vinca indicated a 10% drop in size from 40% DC to 40% C. Similar results were observed when 20% DC was compared to 20% C. Vinca BC for 60% C were 15% lower than 60% DC treatments. The BC value for 20% C was 12% lower than that for 20% DC. There was no difference observed for RR and SDW of vinca. Overall, a difference was seen in growth parameters for experiment 2 when compared to experiment 1. The similarity between substrates at various growth parameters for experiment 2 could be attributed to watering practices during the study.

It can be concluded that DC substrates performed equal to, if not better than, C substrates. However, it may be species dependent. This could be due, in part, to the distillation process that our cedar biomass undergoes. The act of removing a percentage of the cedar's oil, and the high heat involved, may positively affect DC substrate characteristics and result in superior plant growth. This cedar could potentially be a viable alternative for the horticulture industry and replace portions of PM and P in the production of greenhouse-grown annuals.

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Table 1. Physical properties of cedar amended substrates.[z]

	Air space[y]		Container capacity[x]		Total porosity[w]		Bulk density[v]	
	(% vol)						(g/cm^3)	
Substrates	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
60% C[u]	10.63 a[t]	8.17 a	75.20 d	75.50 c	85.87 ab	83.70[NS s]	0.14 a	0.17 a
40% C	2.87 d	1.73 c	82.30 ab	82.43 ab	85.17 b	84.13	0.12 ab	0.16 ab
20% C	5.20 cd	2.90 c	84.23 a	84.63 a	89.43 a	87.50	0.10 b	0.14 b
60% DC	9.20 ab	6.50 ab	78.43 cd	78.53 bc	87.60 ab	85.03	0.13 a	0.16 ab
40% DC	7.30 abc	4.30 bc	79.50 bc	79.60 abc	86.77 ab	83.90	0.12 ab	0.15 ab
20% DC	5.77 bcd	3.17 c	83.10 ab	82.17 ab	88.80 ab	85.33	0.10 b	0.13 b

[z] Analysis performed using the NCSU porometer method.

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

[x] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[w] Total porosity is container capacity ÷ air space.

[v] Bulk density after forced-air drying at 105 °C (221 °F) for 48 h (g/cm^3 = 62.4274 lb/ft^3).

[u] Substrate treatments: pre-distilled cedar (C) and post-distilled cedar (DC) mixed (v:v) with an industry standard peat moss.

[t] Tukey's Studentized Range Test ($P \leq 0.05$, n = 3).

[s] NS = no statistical difference observed.

Table 2. Particle size distribution of substrates.

	Experiment 1											Texture Group[z]		
Substrates	1/4"	6	8	10	14	18	35	60	140	270	Pan	Coarse	Medium	Fine
60% C[y]	0.12[x] ^{NS}[w]	2.13 c[v]	6.38 b	5.13 b	19.68 a	18.54 a	24.03 a	14.35 bc	6.74 c	1.80 b	0.71 b	2.25 c	49.74 ab	47.64 bc
40% C	0.16	3.65 ab	7.54 a	5.09 b	17.47 b	16.98 b	23.95 ab	14.73 ab	7.17 bc	1.85 b	0.85 ab	3.81 ab	47.07 b	48.55 bc
20% C	0.07	3.86 ab	6.95 ab	4.06 c	14.83 c	15.00 c	24.55 a	16.78 a	9.32 a	2.47 a	1.05 a	3.94 ab	40.84 c	54.17 a
60% DC	0.11	2.71 bc	7.62 a	6.18 a	20.09 a	18.49 a	22.58 b	12.50 c	6.20 c	1.93 ab	0.87 ab	2.82 bc	52.38 a	44.08 c
40% DC	0.11	2.93 bc	7.32 ab	5.12 b	17.87 b	16.80 b	23.52 ab	14.54 bc	7.55 bc	2.05 ab	1.00 a	3.11 bc	47.10 b	48.66 bc
20% DC	0.11	4.23 a	7.50 a	4.66 bc	15.29 c	15.18 c	24.44 a	15.88 ab	8.52 ab	2.30 ab	1.10 a	4.45 a	42.62 c	52.24 ab
	Experiment 2											Texture Group[z]		
	1/4"	6	8	10	14	18	35	60	140	270	Pan	Coarse	Medium	Fine
60% C	0.43 c	2.77 c	4.83 b	4.00 a	15.10 ab	18.07 a	33.73 ^{NS}	15.57 bc	3.70 b	0.37 b	0.07 ^{NS}	3.20 c	42.00 a	53.43 bc
40% C	2.03 a	6.20 ab	6.60 a	4.17 a	14.07 ab	17.23 ab	31.90	13.20 c	3.50 b	0.47 ab	0.10	8.23 ab	42.07 a	49.17 c
20% C	1.57 abc	6.10 ab	5.13 b	2.80 b	9.77 d	12.20 d	31.23	20.33 a	8.20 a	0.80 a	0.13	7.67 ab	29.90 d	60.70 a
60% DC	0.63 bc	2.73 c	5.30 ab	4.03 a	15.37 a	16.73 ab	33.17	15.63 b	4.37 b	0.60 ab	0.13	3.37 c	41.43 ab	53.90 abc
40% DC	1.20 abc	3.80 bc	4.77 b	3.43 ab	13.40 b	15.90 bc	34.00	16.80 b	5.03 b	0.70 ab	0.10	5.00 bc	37.50 bc	56.63 ab
20% DC	1.80 ab	7.17 a	6.03 ab	3.63 a	11.60 c	14.53 c	31.77	16.90 b	4.87 b	0.73 a	0.13	8.97 a	35.80 c	54.40 abc

[z] Coarse ≥2.0mm; Medium <2.0 mm to ≥1.0mm; Fine <1.0mm.

[y] Substrate treatments: pre-distilled cedar (C) and post-distilled cedar (DC) mixed (v:v) with an industry standard peat moss.

[x] Percent weight of 100g sample collected on each screen.

[w] NS = no statistical difference observed.

[v] Tukey's Studentized Range Test (P≤ 0.05, n = 3).

Table 3. Effects of substrate on pH and electrical conductivity of greenhouse grown annuals for experiment 1.

	Petunia ×hybrida											
	0 DAP[z]		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP	
Substrates	pH	EC[y]	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
60% C[x]	5.01 b[w]	2.63 d	5.68 a	2.07 d	5.69 a	3.95[NS v]	5.91 a	3.16[NS]	6.21 a	1.19[NS]	5.95 a	0.82[NS]
40% C	4.61 d	2.88 d	5.00 cd	2.75 cd	5.46 ab	3.54	5.35 bc	3.22	5.38 c	1.69	5.29 ab	1.27
20% C	4.49 de	3.66 ab	4.89 d	3.06 c	5.26 bc	3.71	5.13 cd	3.81	5.12 c	2.00	5.28 ab	1.34
60% DC	5.17 a	2.92 cd	5.36 b	3.35 bc	5.56 ab	4.31	5.78 a	2.98	5.84 ab	1.42	5.90 a	0.88
40% DC	4.77 c	4.21 a	5.08 c	4.14 ab	5.39 abc	4.22	5.53 b	3.31	5.41 bc	1.43	5.37 ab	1.12
20% DC	4.47 e	3.54 bc	4.68 e	4.32 a	5.08 c	4.58	5.03 d	3.96	4.65 d	2.16	4.81 b	1.20

	Catharanthus roseus											
	0 DAP		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP	
	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
60% C	5.01 b	2.63 d	5.67 a	2.43 c	5.93 a	3.00 c	6.02 a	2.26[NS]	6.47 a	1.32[NS]	6.35 a	0.67[NS]
40% C	4.61 d	2.88 d	5.01 cd	2.71 c	5.36 bc	2.51 c	5.48 c	2.12	5.35 c	1.57	4.78 d	1.22
20% C	4.49 de	3.66 ab	4.83 de	3.57 b	5.40 b	3.08 bc	5.33 cd	2.52	4.91 d	1.41	4.66 d	1.67
60% DC	5.17 a	2.92 cd	5.34 b	3.64 b	5.60 b	3.30 bc	5.89 a	1.98	6.10 b	1.24	5.74 b	1.01
40% DC	4.77 c	4.21 a	5.17 bc	4.22 ab	5.40 b	4.05 ab	5.67 b	2.45	5.50 c	1.31	5.27 c	1.19
20% DC	4.47 e	3.54 bc	4.69 e	4.58 a	5.11 c	4.65 a	5.22 d	2.14	4.79 d	1.61	4.80 d	1.08

[z] Days After Planting.

[y] Electrical Conductivity (dS/cm) of substrate solution using the pour through method.

[x] Substrate treatments: pre-distilled cedar (C) and post-distilled cedar (DC) mixed (v:v) with an industry standard peat moss.

[w] Tukey's Studentized Range Test ($P \leq 0.05$, $n = 4$).

[v] NS = no statistical difference observed.

Table 4. Effects of substrate on pH and electrical conductivity of greenhouse grown annuals for experiment 2.

Petunia ×hybrida

	0 DAP[z]		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP	
Substrates	pH	EC[y]	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
60% C	5.11^{NS}[w]	4.73 b[v]	5.31 a	8.51 bc	5.34 ab	9.42 ab	5.74 a	5.61^{NS}	6.41 a	0.68^{NS}	6.47 a	2.59^{NS}
40% C	4.87	5.00 b	5.19 ab	8.74 bc	5.11 bc	11.17 ab	5.60 ab	4.22	6.23 ab	0.55	6.15 ab	0.69
20% C	4.80	5.31 b	4.78 d	12.82 a	4.92 c	11.42 a	5.14 b	5.96	5.98 b	0.57	5.69 c	1.08
60% DC	5.18	5.57 ab	5.38 a	6.98 c	5.49 a	6.90 b	5.72 a	4.18	6.49 a	0.47	6.48 a	0.72
40% DC	5.23	5.34 b	5.07 bc	11.46 ab	5.17 bc	12.96 a	5.51 ab	4.91	6.42 a	0.57	6.06 bc	1.1
20% DC	4.95	7.40 a	4.84 cd	14.43 a	5.04 c	13.69 a	5.54 ab	5.9	6.24 ab	0.55	5.73 c	0.97

Impatiens walleriana

	0 DAP[z]		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP	
	pH	EC[y]	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
60% C	5.11^{NS}	4.73 b	5.39 a	7.44 bc	5.48 a	8.28 b	5.74 a	8.25 ab	6.13 a	3.34 b	6.18 ab	1.11^{NS}
40% C	4.87	5.00 b	4.91 b	8.09 bc	5.18 b	10.80 ab	5.81 a	5.20 b	5.84 ab	3.96 ab	5.98 bcd	1.35
20% C	4.80	5.31 b	4.80 b	13.24 a	4.85 c	13.12 a	5.39 b	8.32 ab	5.85 ab	3.47 b	5.72 cd	1.65
60% DC	5.18	5.57 ab	5.37 a	5.51 c	5.36 a	9.41 b	5.91 a	5.19 b	5.94 a	3.65 b	6.43 a	0.79
40% DC	5.23	5.34 b	5.16 ab	10.44 ab	5.17 b	13.64 a	5.72 a	7.53 ab	5.90 ab	4.87 ab	6.05 bc	1.78
20% DC	4.95	7.40 a	4.91 b	13.11 a	4.99 c	13.29 a	5.43 b	10.09 a	5.60 b	6.94 a	5.66 d	2.39

[z] Days After Planting.

[y] Electrical Conductivity (dS/cm) of substrate solution using the pour through method.

[x] Substrate treatments: pre-distilled cedar (C) and post-distilled cedar (DC) mixed (v:v) with an industry standard peat moss.

[w] NS = no statistical difference observed.

[v] Tukey's Studentized Range Test ($P \leq 0.05$, $n = 4$).

Table 5. Use of cedar as an alternative substrate component.

	Growth Index^{z}		Bloom Counts^{y}		Root Rating^{x}		Shoot Dry Weight^{w}	
			Petunia ×hybrida					
Substrates	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
60% C^{v}	N/A	37.43 $^{NS\,t}$	16.08 b^{u}	33.42^{NS}	2.38 c	4.00^{NS}	6.01 b	12.75 ab
40% C	N/A	38.52	19.42 ab	36.58	2.50 c	4.00	7.00 b	13.45 a
20% C	N/A	37.84	22.33 a	36.83	2.75 bc	4.13	9.36 a	13.43 a
60% DC	N/A	38.34	20.25 ab	33.92	3.00 abc	4.75	6.55 b	10.21 b
40% DC	N/A	39.29	23.67 a	36.42	3.75 a	4.75	9.21 a	13.86 a
20% DC	N/A	38.23	23.08 a	37.50	3.63 ab	4.00	9.11 a	14.86 a
			Catharanthus roseus					
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
60% C	26.47 b	29.33 ab	11.33 e	20.17 b	1.88 c	3.00^{NS}	6.88 d	10.01^{NS}
40% C	28.48 a	28.75 b	18.42 cd	24.50 ab	2.00 c	3.38	9.39 bc	10.58
20% C	29.36 a	29.08 b	24.17 ab	24.58 ab	2.75 bc	3.13	10.73 a	9.78
60% DC	26.67 b	27.92 b	16.50 d	23.25 ab	3.75 ab	3.63	8.80 c	10.04
40% DC	28.85 a	31.58 a	21.25 bc	26.33 ab	4.25 a	3.63	10.30 ab	11.93
20% DC	28.54 a	31.67 a	27.00 a	27.58 a	3.50 ab	3.88	10.53 ab	11.08

[z] Growth index = [(height+width1+width2)/3] (n = 12).

[y] Bloom count = number of blooms or buds showing color at 42 days (n = 12).

[x] Root ratings 0-5 scale (0 = no visible roots and 5 = roots visable on the entire container substrate interface) (n = 8).

[w] Shoot dry weight measured in grams (n = 8).

[v] Substrate treatments: pre-distilled cedar (C) and post-distilled cedar (DC) mixed (v:v) with an industry standard peat moss.

[u] Tukey's Studentized Range Test ($P \leq 0.05$).

[t] NS = no statistical difference observed.

IV. A Comparison of Distilled Cedar, Perlite, and Rice Hulls as Substrate Components in the Production of Greenhouse-Grown Annuals

Abstract

An increase in demand for peat moss and perlite has resulted in an economic strain on growers that could potentially be alleviated with the introduction of alternative substrate components. Perlite is known to add necessary porosity to substrates that allows for flow of gas and water through containers. The objective of this study was to simulate the beneficial characteristics of perlite (P) in substrates by adding varying percentages of distilled cedar (*Juniperus virginiana* L.) (DC) and rice hulls (RH) to peat moss and comparing them to P mixes of concordant percentages. Treatments were amended at 10%, 20%, and 30% for each component. The species used included petunia and marigold. Results for experiment 1 indicated that petunia growth index (GI) and bloom count (BC) were similar between DC and P at given concentrations with the exception of GI at 10%. Petunia root rating (RR) was similar for all treatments, regardless of concentration, with the exception of RH having lower rooting than P at 30%. Shoot dry weight (SDW) for DC and P was similar at 30% in experiment 1. However, P outperformed DC and RH at all other percentages. For experiment 2 no differences were observed between DC, RH and P at all percentages in 3 out of the 4 growth parameters measured in both species. Overall, data for petunia and marigold indicated that plants would grow well in any of the nine substrates. Therefore we believe DC not only provides a promising replacement for peat moss, but a potential substitute for perlite as well.

Index words: alternative substrate, eastern red cedar, *Juniperus virginiana*

Species used in this study: *Petunia ×hybrida* Vilm. 'Dreams Sky Blue' and *Tagetes erecta* L. 'Antigua Yellow'

Significance to the Industry

Peat moss and perlite are the main components utilized in the formulation of greenhouse substrates. The prolific use of these resources has brought to light a need for alternatives that can be considered superior, both economically and environmentally. In previous studies post-distilled cedar was found to be a promising alternative substrate component in the production of greenhouse-grown annuals (Vandiver et al., 2011). The experiment indicated that a standard peat-lite (PL) mix (80:20 PM:P) could be amended with up to 40% cedar and be equal to, if not better than, the standard mix when growing annuals. In addition to the replacement of peat moss, the physical nature of cedar tends to add substrate porosity that is normally achieved with the addition of perlite. Murphy et al. (2011) conducted a study evaluating the effects of fertilizer on low value tree substrates, such as eastern red cedar, and their ability to produce quality annual crops as perlite alternatives. The study indicated that eastern red cedar could be used as a perlite alternative with adequate fertilizer rates (Murphy et al., 2011). Therefore, we believe a reduction or elimination in the need for perlite might be realized with the use of distilled cedar as a substrate component.

Introduction

Peat moss (PM) and P are the main components found in soilless greenhouse substrates today and are thus in high demand commercially. Perlite is a naturally occurring volcanic rock that expands when heated. It lends air-filled porosity to substrates; an important physical property that growers desire in greenhouse mixes. This porosity allows for gas exchange and drainage to occur between the roots of the plant and the atmosphere outside (Bunt 1988). Perlite is not only expensive to produce; there are also high amounts of energy required for both the production and shipping processes. In its dry state P produces a siliceous dust that is considered a nuisance, causing lung and eye irritation in cases involving over-exposure (Du et al., 2010). Due to these concerns, the industry has expressed an interest in finding replacement substrate options for P. In recent years research regarding P alternatives has steadily increased with an emphasis on local and regional sources of materials, which are considered to be more sustainable. Numerous types of alternatives have been tested in greenhouse crops. A few of these components, which have focused on P replacement, include: polystyrene beads (PSB), RH, HydRocks®, corncob (CC) and eastern red cedar (RC) (Cole and Dunn 2002; Evans and Gachukia 2007; Pickens et al., 2009; Weldon et al., 2010; Murphy et al. 2011).

Polystyrene beads are a byproduct of the polystyrene industry. In a study by Cole and Dunn (2002) a substrate containing PSB was found to produce similar plants to those grown in an equivalent perlite-containing substrate. In this study stem cuttings of rose-of-sharon (*Hibiscus syriacus* L. ‘Jeanne d’Arc’), barberry (*Berberis thunbergii* D.C. ‘Crimson Pygmy’), juniper (*Juniperus horizontalis* Moench. ‘Plumosa Compacta’), and arborvitae (*Thuja occidentalis* L. ‘Woodwardii’) were rooted in substrates consisting of 0%, 25%, 50%, 75%, or 100% (by volume) P or PSB mixed with PM. Statistically, more barberry cuttings rooted with PSB than with P. Percentage of rooted juniper cuttings decreased with an increase in PSB concentration. However, percentage of rooted arborvitae cuttings increased as PSB concentration increased. Arborvitae cuttings had a higher quantity of roots with 25% P than with 25% PSB, but arborvitae cuttings in 50%, 75%, or 100% PSB had more roots than cuttings in the concordant concentrations of P. Results indicate PSB could be an adequate substitute for P in rooting substrates for barberry, juniper, and arborvitae if suitable ratios of PM are applied (Cole and

Dunn 2002).

Rice hulls are a waste product of the rice milling industry. It has been estimated that almost 34 million tons of fresh RH are produced annually in the United States (Kamath and Proctor, 1998). Rice hulls are generally considered an agricultural waste and, thus, could potentially have a lower market value in comparison to P. Evans and Gachukia (2007), produced ten substrates by blending P or parboiled fresh RH (PFH) to produce rooting substrates. The substrates contained 20%, 30%, 40%, 50%, or 60% (by volume) P or PFH, with the remainder being PM. All substrates containing PFH had higher total porosity (TP) than substrates containing a concordant amount of P. Air space (AS) was similar with substrates containing 20% P or PFH. However, AS was higher in PFH-containing substrates than in equivalent substrates composed of P when the amount of PFH or P was at least 40%. As the amount of P or PFH increased, AS also increased. At 30% or higher PFH, the substrates containing PFH had a lower water holding capacity (WHC) than concordant P substrates. As the percentage of P or PFH was increased, WHC decreased. The differences in bulk density (BD) were not excessive enough to be of practical significance. Inclusion of PFH in the substrate provided for drainage and air-filled pore space as did P. However, less PFH would be required in a substrate to provide the same air-filled pore space as P when more than 20% P or PFH is used (Evans and Gachukia 2007).

HydRocks® is a light expanded clay aggregate marketed for horticulture applications available locally in the southeast. HydRocks® is formed by fully calcining clay at temperatures reaching up to 2000° F. HydRocks® is generally inert and pH neutral when compared to most substrate components. Pickens et al. (2009), conducted a experiment evaluating HydRocks® as a P substitute in PM based substrates. Six P samples were collected and were each sieved for 3 minutes. Three plugs of verbena (*Verbena ×hybrida* Voss. 'Aztec™ Red Velvet') and New

Guinea impatiens (*Impatiens hawkeri* Bull. ‘Celebrette Red’) were potted separately into hanging baskets. The baskets were filled with PM and amended with 15% P, 15% coarse P, 15% coarse HydRocks®, 7% reduced coarse P or 7% reduced coarse HydRocks® (v:v). Plants were grown for 13 weeks and then growth parameters were evaluated. Impatiens hanging baskets had no differences among treatments in marketability. Verbena hanging baskets marketability was dependent on treatment. Peat amended with 15% HydRocks® had the highest marketability rating and was similar to a 7% HydRocks® amendment. Peat amended with 7% coarse P had the lowest marketability. There was no difference in root density for impatiens grown in substrates containing P. Also no difference was observed for impatiens grown in treatments containing HydRocks®. HydRocks® treatments had almost three times the root density of P treatments. Verbena baskets were similar to the impatiens in root density. Plants grown in PM amended with 15% HydRocks® had the greatest density of roots among all treatments. Plants grown in HydRocks® substrates outperformed plants grown in P for both species with regards to marketability, root density, and SDW. Peat amended with 15% HydRocks® had the highest SDW across treatments. Shoot dry weights and shoot quality were not different between P and HydRocks®. HydRocks® treatments outperformed P treatments by 3-fold in most situations. Overall, results across all observations suggest HydRocks® as being a suitable P replacement in floriculture substrates (Pickens et al., 2009).

Another possible alternative to P is processed corncobs. The harvesting of corn (*Zea mays* L.) often leaves CC as a byproduct and this is used for many different products in commercial industry. A positive quality associated with CC is its label as a waste byproduct of the corn feed and seed industry, which requires less energy to produce than P. Because it is a byproduct, there is no foreseeable rise in feed and seed market prices with the procurement of CC. Weldon et al.

(2010) blended CC with a base substrate containing 70:30 pine bark (PB):PM (v:v) (PBP) and compared that to an industry standard P. The six treatments formulated included: 9:1 PBP:CC (v:v), 8:2 PBP:CC, 7:3 PBP:CC, 9:1 PBP:P, 8:2 PBP:P and 7:3 PBP:P. The treatments were planted with either impatiens (*Impatiens walleriana* Hook.f. 'Dazzler Cranberry') or petunia (*Petunia ×hybrida* Vilm. 'Dream Rose'). Substrates containing CC had higher AS and TP than perlite-containing substrates. Corncob substrates also had a uniform particle size, whereas P substrate particle size was inconsistent. Impatiens GI) were similar for all treatments except for the 7:3 PBP:CC, which was smaller than all other treatments. Impatiens BC was similar among all treatments. Petunia BC in 9:1 PBP:CC had twice the number of blooms compared with BC in 7:3 PBP:P Impatiens SDW were comparable among all treatments that contained 10% or 20% CC or P. The data provided by this study suggests that CC could potentially be a suitable organic substitute for P in greenhouse annual production (Weldon et al., 2010). However, a follow up study evaluating CC as an alternative to P in the production of greenhouse annuals, showed that CC did not perform as well as was seen in previous experiments. In this study CC or P was added to PM at rates of 10%, 20%, or 30% by volume. Containers were filled and planted with three plugs of petunia, impatiens or marigold. Results from physical properties analysis showed that WHC decreased with increasing percentages of CC. Growth index and SDW, for all species, were reduced with an increase in percentage of CC. Similar results were seen in RR and BC. Results from this experiment show that reduced growth was found in annuals grown in CC amended substrates compared to its perlite counterpart (Weldon 2012).

In recent years an interest in using RC (*Juniperus virginiana* L.) as an alternative substrate component has risen. Murphy et al. (2011) executed a study that evaluated the effects fertilizer had on RC and two other low-value trees and their potential as P alternatives in the production of annual petunia (*Petunia ×hybrida* Vilm. 'Celebrity Blue') and vinca (*Catharanthus roseus* L. 'Cooler Rose'). Data indicated that petunias and vinca grown in a 75:25 PM:RC substrate were comparable to plants grown in a traditional 75:25 PM:P substrate. Furthermore, the data indicated that an increase in liquid fertilizer from 100 ppm N to 300 ppm N had little to no effect on BC or SDW of petunias in sweetgum, hickory or RC substrates. Overall, the study exhibited the ability of RC to act as an alternative to P in the production of petunia and vinca crops (Murphy et al., 2011).

The cedar used in this study was obtained from CedarSafe®, a company located in Huntsville, AL. It is unlike cedar found in other substrate research projects. This cedar is a by-product of oil production at the CedarSafe® facilities. The logs are first debarked and shaved and then sent through a hammer mill to pass a 1.27 cm screen (0.5 in). It is then conveyed to a set of boilers, where the material undergoes a steam distillation process, which extracts a percentage of the cedar oil. CedarSafe® currently has limited market for the post-distilled cedar biomass. The objective of this study was to incorporate RH (Riceland Foods, Inc. Stuttgart, AR), DC and P (Coarse Premium Grade, Sun Gro Horticulture Distribution Inc. Bellevue, WA) into a PM substrate at proportional percentages. The varying substrates would be analyzed and compared as per their ability to facilitate growth of greenhouse annuals.

Materials and Methods

Experiments were conducted at the Paterson Greenhouse Complex in Auburn, AL. Two experiments were conducted in a similar manner, but differing in time of year (March 16, 2012 and July 3, 2012). In both experiments nine treatments were evaluated. The treatments were produced by adding RH, DC or P at 10%, 20% and 30% to a PM substrate. Treatments had the following amendments added per cubic meter at mixing: 2.26 kg (5 $\text{lbs}\cdot\text{yd}^{-3}$) lime, 0.907 kg (2 lbs·yd^{-3}) starter nutrient charge (7N-1.3P-8.3K, Greencare Fertilizers Inc. Kankakee, IL), 0.45 kg (1 lb·yd^{-3}) Micromax (The Scott's Company LLC. Marysville, OH), and 2.72 kg (6 lbs·yd^{-3}) slow release fertilizer (13N-2.6P-13.3K, Harrell's LLC. Lakeland, FL). Aqua-Gro L was added at 118.3 mL per cubic meter. Containers, 1.2 L (0.32 gal) (06.00 AZA COEX, Dillen Products Middlefield, OH), were filled with the substrates and two plugs (200 14 cm^{-3} (0.85 in^{-3}) cell flat) of either petunia (*Petunia ×hybrida* Vilm. 'Dreams Sky Blue') or marigold (*Tagetes erecta* L. 'Antigua Yellow') were planted into each container. Containers were placed in a twin wall polycarbonate greenhouse on elevated benches and hand watered as needed. Containers were arranged in a randomized complete block with 12 replicates per treatment. Species were arranged as separate experiments.

Data collected for each experiment included initial substrate pH and EC (Accumet Excel XL50, Fisher Scientific, Pittsburgh, PA) using the pour-through method (Wright, 1986). Subsequent pH and EC analyses were conducted at 7, 14, 21, 28, 35, and 42 days after planting (DAP). At 42 DAP each plant's height and widths were recorded, in centimeters, and the mean was taken for GI [(height+width1+width2)/3]. Bloom count for each plant was also recorded (flowers and buds showing color). Roots were visually inspected and rated on a scale of 0 (no visible roots) to 5 (roots visible over the entire substrate surface) to determine RR. At termination shoots were removed at substrate surface, oven dried at 70°C (158°F) for 72 hours and weighed to determine SDW. Initial substrate AS, CC, TP, and BD (gm·cm^{-3}) were determined using the NCSU Porometer method (Fonteno and Hardin, 1995). Particle size distribution (PSD) was analyzed by passing three 50 g (experiment 1) and three 100 g (experiment 2) air-dried samples of each treatment through a series of sieves. The sieves were shaken for three minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations·min, 159 taps·min).

Data was analyzed using Tukey's Studentized Range Test ($P \leq 0.05$) (SAS Institute version 9.1, Cary, NC).

Results and Discussion

Results for experiment 1 physical properties indicated that RH had a higher AS than DC and P at 30% (Table 1). However, at 10% and 20% no difference was observed for any treatment. Experiment 2 AS was similar for all substrates. All treatments in both experiments were lower than the recommended range (10% to 20%) set by Jenkins and Jarrell (1989). The highest CC was observed in substrates containing DC for both experiments at all concentrations, with the exception of 10% in experiment 2 where it was similar to RH. In both experiment 1 and experiment 2 P had lower CC than DC at given concentrations, but was similar to RH when compared to substrates of concordant percentages, with the exception of 30% in experiment 1 and 2. Substrates containing 20% RH and 20% P had similar CC in both experiments. In both experiments 30% P had the lowest CC when compared to other substrates at 30% concentration. Similar results were observed by Murphy et al. (2011) where they concluded that RC substrates had higher CC than P at concordant percentages. All substrates for both experiments possessed higher CC than the recommended range of 60% to 75% (Jenkins and Jarrell 1989). In both experiments TP for 10% DC was higher when compared to 10% P, but was similar to RH. Similar results were seen for 20% DC in experiment 2. Experiment 1 TP at 20% was similar for all substrates. Total porosity for DC was comparable to RH, and both were higher than P, in experiment 1 at 30%. Experiment 2 TP at 30% was highest for DC and lowest for P substrates. In most cases substrates containing P tended to have a lower TP overall. All substrates in both experiments, with the exception of 30% P, had higher TP than the recommended range of 60% to 75% (Jenkins and Jarrell 1989). Evans and Gachukia (2007) saw similar results for substrates containing up to 40% P. Also, all substrates containing RH in their experiment had higher TP than the recommended range (Evans and Gachukia 2007). There was no difference in BD between substrates at a given concentration for both experiments.

Results for PSD in both experiments indicated that P substrates at all percentages had the highest amount of coarse particles (Table 2). Substrates containing DC and RH possessed similar amounts of coarse particles at all percentages. For all percentages, with the exception of 10% in experiment 2, RH substrates contained the highest amount of medium particles. Fine particle amounts were similar for all substrates at 10% concentration in both experiments. For experiment 1 and experiment 2, DC and P at 20% and 30% tended to contain higher amounts of fine particles when compared to RH at similar percentages.

Results for pH in experiment 1 indicated that at 0 DAP pH values were similar for all substrates within a given percentage (Table 3). Similar results were observed for EC values at 20% in both species. Overall, pH values for experiment 1 tended to be higher for substrates containing higher percentages of RH, DC and P at 7, 14 and 21 DAP. No difference in pH was observed between substrates for marigold at a given percentage, with the exception of 30% at 7 DAP, where RH had the highest pH. For petunia, EC values were similar at 21, 35, and 42 DAP. Marigold EC values were similar at 14, 21, 28, and 35 DAP. For all other DAP in experiment 1 EC values tended to be higher for substrates containing P when compared to substrates of concordant percentages. In general, for experiment 2, marigold pH was not different for substrates at a given concentration (Table 4). Petunia pH in most cases, throughout the study, was not different at a given percentage; however, when there was a difference RH had a higher pH. At 7 DAP, for petunia, P EC was higher than DC at 10% and 20%, while no other difference was observed between substrates within a given percentage. Similar results where seen for marigold with 20% P having a higher EC than DC and all other substrates, within a given percentage, being comparable. At 14 DAP EC was similar for all substrates at a given percentage, with the exception of 30% P having a higher EC than RH at 30%. Experiment 2 EC values for petunia were similar for all treatments at 21, 35, and 42 DAP. Marigold EC values were similar at 14, 28, 35, and 42 DAP. As was observed in previous studies (Vandiver et al., 2011) EC values grew to be similar as each study reached its completion. The higher EC values observed in experiment 1, when compared to experiment 2, could be due to differences in watering practices associated with the time of year the studies were conducted.

At termination, experiment 1 GI for petunia was highest for P at 10% (Table 5). There was a decrease in GI of 8% to 12% for 10% DC and 10% RH respectively. Petunia GI was similar for P and DC at 20% and 30% concentrations. However, there was a decrease in GI of 14% and 22% for 20% RH and 30% RH respectively when compared to P at a similar percentage. At 30%, GI for RH was 16% lower than DC however, it was similar at 10% and 20% concentrations. For petunia BC, substrates containing DC and P were comparable at a given concentration. However, P outperformed RH at every component percentage. A difference in BC of 45% was observed for 30% RH compared to P at its concordant percentage. Petunia RR was similar amongst all treatments at 10% and 20%; however, 30% P had a higher RR than RH at a similar percentage. For marigold, in experiment 1, GI was similar at 10% and 20%; however, at 30% DC had a higher GI than RH. Growth measurements for BC, RR, and SDW of marigold were similar among all treatments. Experiment 2 petunia GI, BC and SDW revealed no difference between treatments at any percentage. Petunia RR was similar between substrates within a given percentage. For marigold, in experiment 2, 20% RH had the lowest RR of all treatments while all other treatments were similar. There was no difference observed for all other growth parameters measured at any percentage.

Experiment 1 data for marigold indicated that plants would grow well in any of the nine substrates. It was observed in experiment 2 that petunia and marigold grew equally well regardless of substrate type or percentage. Overall, with the exception of petunia SDW in experiment 1, growth data indicated that substrates performed well regardless of component concentration. Therefore we believe DC not only provides a promising replacement for peat moss, but a potential substitute for perlite as well.

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Table 1. Physical properties of cedar amended substrates.[z]

	Air space[y]		Container capacity[x]		Total porosity[w]		Bulk density[v]	
	---------------------------- (% vol)				------------------------------		(g/cm^3)	
Substrates	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
10% RH[u]	6.6 b[t]	3.60[NS s]	77.6 bc	78.7 ab	84.3 ab	82.3 ab	0.12 b	0.13 c
10% DC	5.4 b	2.97	82.4 a	82.3 a	87.8 a	85.3 a	0.11 b	0.14 bc
10% P	4.3 b	2.50	76.2 c	76.1 b	80.4 b	78.6 c	0.13 ab	0.16 abc
20% RH	8.4 ab	5.67	77.4 c	76.3 b	85.7 a	82.0 abc	0.14 ab	0.17 ab
20% DC	5.0 b	2.30	83.1 a	83.1 a	88.1 a	85.4 a	0.12 b	0.16 bc
20% P	6.4 b	3.73	77.5 c	77.4 b	83.9 ab	81.2 bc	0.11 b	0.14 bc
30% RH	11.2 a	5.53	75.0 c	75.6 b	86.2 a	81.1 bc	0.13 ab	0.16 abc
30% DC	5.1 b	2.67	82.0 ab	82.2 a	87.1 a	84.9 a	0.14 ab	0.17 ab
30% P	6.1 b	3.47	67.7 d	68.1 c	73.8 c	71.6 d	0.17 a	0.19 a

[z] Analysis performed using the NCSU porometer method.

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

[x] Container capacity is (wet weight - oven dry weight) ÷ volume of the sample.

[w] Total porosity is container capacity ÷ air space.

[v] Bulk density after forced-air drying at 105 °C (221 °F) for 48 h ($g/cm^3 = 62.4274\ lb/ft^3$).

[u] Substrate treatments: rice hulls (RH), post-distilled cedar (DC), and perlite (P) mixed (v:v) with an industry standard peat moss.

[t] Tukey's Studentized Range Test ($P \leq 0.05$, $n = 3$).

[s] NS = no statistical difference observed.

Table 2. Particle size distribution of substrates.

Experiment 1

Substrates	1/4"	6	8	10	14	18	35	60	140	270	Pan	Texture Group^z Coarse	Medium	Fine
10% RH^y	0.03$^{x\ NS\ w}$	1.30 b^v	2.37 c	1.73 b	7.57 c	6.00 bc	11.77 c	10.73 ab	7.20 abc	1.43 bc	0.27 cd	2.66 b	35.34 bc	62.80 a
10% DC	0.10	1.33 b	2.40 c	1.57 b	5.27 d	5.93 bc	14.83 a	11.73 ab	6.13 bc	1.10 c	0.20 d	2.86 b	30.34 cd	68.00 a
10% P	0.20	4.70 a	4.33 b	1.53 b	3.50 e	3.70 d	11.50 c	11.87 a	6.97 abc	1.47 bc	0.43 bc	9.80 a	26.14 d	64.46 a
20% RH	0.00	0.97 b	2.13 c	1.97 ab	9.50 b	6.73 b	11.37 c	9.87 abc	6.03 bc	1.33 bc	0.37 bcd	1.94 b	40.66 b	57.94 ab
20% DC	0.00	1.20 b	2.33 c	1.47 b	5.37 d	5.57 c	13.07 b	12.07 a	6.87 abc	1.40 bc	0.27 cd	2.40 b	29.46 cd	67.34 a
20% P	0.20	5.23 a	4.97 ab	1.60 b	3.10 e	2.90 d	8.67 e	11.27 ab	8.90 a	2.53 a	0.90 a	10.86 a	25.14 d	64.54 a
30% RH	0.00	0.70 b	2.10 c	2.57 a	12.13 a	7.93 a	10.37 d	8.00 c	4.80 c	1.17 c	0.37 bcd	1.40 b	49.46 a	49.40 b
30% DC	0.03	1.10 b	2.33 c	1.57 b	5.73 d	5.83 c	11.97 c	11.03 ab	7.43 ab	1.97 ab	0.50 b	2.26 b	30.94 cd	65.80 a
30% P	0.13	6.67 a	6.17 a	1.97 ab	3.27 e	2.97 d	8.00 e	9.37 bc	7.57 ab	2.43 a	1.07 a	13.60 a	28.74 cd	56.86 ab

Experiment 2

	1/4"	6	8	10	14	18	35	60	140	270	Pan	Texture Group^z Coarse	Medium	Fine
10% RH	0.00 b	2.03 def	4.67 ab	2.97 b	12.30 c	9.73 c	26.27 cd	18.13 ab	14.77 bcd	4.90 cd	0.87 ab	2.03 cd	29.67 bc	64.93 a
10% DC	0.00 b	3.00 d	6.27 ab	2.80 b	9.13 e	10.03 c	44.90 a	3.70 e	12.10 d	6.10 bc	1.63 ab	3.00 c	28.23 bc	68.43 a
10% P	0.03 b	4.63 c	7.10 ab	3.00 b	6.90 g	6.53 de	36.53 b	6.77 de	16.37 ab	8.40 a	2.57 ab	4.67 b	23.53 c	70.63 a
20% RH	0.00 b	1.77 ef	4.83 ab	3.93 a	18.13 b	13.03 b	30.60 bc	8.53 cde	11.47 d	2.30 e	0.77 b	1.77 cd	39.93 a	53.67 b
20% DC	0.00 b	2.50 de	5.57 ab	2.87 b	9.23 e	10.70 c	31.13 bc	15.83 abc	14.17 bcd	6.13 bc	1.40 ab	2.50 cd	28.37 bc	68.67 a
20% P	0.17 b	10.90 a	8.10 ab	4.23 a	8.17 f	7.27 d	16.73 e	13.87 bcd	13.73 bcd	7.60 ab	2.93 a	11.07 a	27.77 bc	54.87 b
30% RH	0.00 b	1.30 f	4.27 b	3.97 a	20.33 a	17.03 a	19.10 de	16.00 ab	12.57 cd	3.57 de	1.03 ab	1.30 d	45.60 a	52.27 b
30% DC	0.00 b	2.67 de	5.33 ab	3.20 b	10.40 d	12.63 b	22.57 de	20.13 ab	15.67 abc	5.20 cd	1.37 ab	2.67 cd	31.57 b	64.93 a
30% P	0.77 a	9.53 b	9.97 a	3.87 a	6.07 g	5.67 e	16.57 e	21.67 a	18.67 a	5.27 cd	1.23 ab	10.30 a	25.57 bc	63.40 a

[z] Coarse ≥2.0mm; Medium <2.0 mm to ≥1.0mm; Fine <1.0mm.

[y] Substrate treatments: rice hulls (RH), post-distilled cedar (DC), and perlite (P) mixed (v:v) with an industry standard peat moss.

[x] Percent weight of 100g sample collected on each screen.

[w] NS = no statistical difference observed.

[v] Tukey's Studentized Range Test (P≤ 0.05, n = 3).

Table 3. Effects of substrate on pH and electrical conductivity of greenhouse grown annuals in experiment 1.

	0 DAP[z]		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP		42 DAP	
Substrates	pH	EC[y]	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
	Petunia ×hybrida													
10% RH[x]	3.97 abc[w]	4.38 a	3.85 bc	10.02 abcd	3.89 bc	10.63 ab	3.83 bc	9.22[NS]	4.53 ab	1.85 ab	4.61 a	2.62[NS]	4.19 b	1.87[NS]
10% DC	3.97 abc	2.78 b	3.74 c	10.08 abcd	3.72 de	10.31 ab	3.75 c	7.89	3.90 ef	2.54 ab	4.24 bcd	2.60	3.80 bc	2.83
10% P	3.81 c	4.43 a	3.73 c	11.57 a	3.70 e	11.03 ab	3.70 c	9.42	3.75 f	2.35 ab	3.93 de	3.01	3.70 c	2.60
20% RH	3.88 bc	4.52 a	3.91 bc	9.28 bcd	3.87 bc	9.21 ab	3.83 bc	9.34	4.27 bcd	2.76 a	4.40 ab	3.10	4.22 b	2.14
20% DC	4.07 ab	4.02 a	4.16 a	9.07 cd	3.98 bc	9.88 ab	4.07 a	7.49	4.47 abc	1.28 b	4.26 bc	2.40	4.24 b	1.35
20% P	3.86 bc	4.64 a	3.90 bc	11.31 ab	3.85 cd	10.31 ab	3.98 ab	7.29	3.94 def	2.06 ab	3.85 e	2.33	3.90 bc	2.27
30% RH	4.15 a	3.51 ab	4.24 a	8.35 d	4.19 a	7.98 b	4.10 a	8.80	4.80 a	2.64 ab	4.59 a	2.91	4.73 a	1.53
30% DC	4.12 a	4.09 a	4.02 ab	10.68 abc	3.97 bc	9.18 ab	4.03 ab	8.12	4.15 cde	2.55 ab	4.02 cde	2.73	4.03 bc	2.47
30% P	4.12 a	3.43 ab	4.08 ab	10.75 abc	3.99 b	11.87 a	4.06 a	9.82	4.17 cde	1.66 ab	3.99 cde	2.00	4.15 bc	1.24
	Tagetes erecta													
	0 DAP		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP		42 DAP	
	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
10% RH	3.97 abc	4.38 a	3.89 bc	10.83 a	3.80 def	10.63[NS v]	3.81 cd	9.92[NS]	4.20 ab	2.46[NS]	3.98 b	4.47[NS]	3.93 b	2.85 ab
10% DC	3.97 abc	2.78 b	3.74 c	9.57 ab	3.77 ef	9.44	3.82 cd	7.21	3.86 b	2.79	4.06 b	5.16	3.81 b	2.65 ab
10% P	3.81 c	4.43 a	3.72 c	11.20 a	3.72 f	10.92	3.75 d	9.22	3.90 b	6.10	3.98 b	2.93	3.84 b	4.77 a
20% RH	3.88 bc	4.52 a	3.93 bc	9.18 ab	3.88 cde	9.63	3.89 bcd	8.22	4.26 ab	1.90	4.33 ab	2.81	4.09 b	1.69 ab
20% DC	4.07 ab	4.02 a	3.92 bc	11.06 a	4.00 bc	9.49	4.01 abc	7.54	4.00 ab	4.92	4.26 ab	3.10	4.15 ab	3.13 ab
20% P	3.86 bc	4.64 a	3.88 bc	11.19 a	3.93 cd	10.23	3.89 bcd	9.54	3.95 b	5.12	4.01 b	3.86	3.99 b	2.28 ab
30% RH	4.15 a	3.51 ab	4.38 a	7.70 b	4.17 a	9.02	4.18 a	7.51	4.64 a	1.90	4.55 a	3.17	4.55 a	1.45 b
30% DC	4.12 a	4.09 a	4.03 b	9.80 ab	4.08 ab	8.33	4.17 a	7.09	4.24 ab	3.49	4.21 ab	3.23	4.08 b	2.29 ab
30% P	4.12 a	3.43 ab	4.09 b	11.24 a	4.08 ab	11.27	4.09 ab	9.69	4.19 ab	3.70	4.11 b	4.16	4.12 ab	2.07 ab

[z] Days After Planting.

[y] Electrical Conductivity (dS/cm) of substrate solution using the pour through method.

[x] Substrate treatments: rice hulls (RH), post-distilled cedar (DC), and perlite (P) mixed (v:v) with an industry standard peat moss.

[w] Tukey's Studentized Range Test ($P \leq 0.05$, n = 4).

[v] NS = no statistical difference observed.

Table 4. Effects of substrate on pH and electrical conductivity of greenhouse grown annuals in experiment 2.

	Petunia ×hybrida													
	0 DAP^{z}		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP		42 DAP	
Substrates	pH	EC^{y}	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
10% RH^{x}	4.66 c^{w}	3.97 bc	5.07 d	13.56 ab	4.92 bc	9.79 ab	5.82 ab	1.50^{NS}	5.69 ab	1.56 ab	5.70 a	1.55^{NS}	5.33 b	2.07^{NS}
10% DC	4.90 bc	3.33 bc	5.10 d	10.64 b	4.76 d	9.60 ab	5.74 b	1.35	5.06 ef	2.25 ab	5.33 bcd	2.22	5.13 b	2.42
10% P	4.94 bc	4.36 abc	5.03 d	15.10 a	4.75 d	10.03 ab	5.87 ab	1.95	4.91 f	2.06 ab	5.02 de	2.11	5.52 ab	1.81
20% RH	4.65 c	4.77 ab	5.29 bc	12.52 ab	4.89 bcd	7.98 ab	5.93 ab	1.62	5.43 bcd	2.47 a	5.49 ab	2.05	5.44 ab	1.89
20% DC	4.51 c	6.89 a	5.18 cd	10.65 b	5.02 bc	8.84 ab	5.75 b	1.46	5.63 abc	0.99 b	5.35 bc	2.01	5.45 ab	1.58
20% P	4.96 bc	3.33 bc	5.10 d	16.17 a	4.87 cd	9.37 ab	5.73 b	2.21	5.10 def	1.77 ab	4.94 e	1.95	5.63 ab	1.99
30% RH	4.66 c	5.65 ab	5.40 ab	12.36 ab	5.22 a	7.12 b	6.05 ab	1.31	5.96 a	2.35 ab	5.68 a	1.96	5.56 ab	1.29
30% DC	5.22 ab	1.80 c	5.29 bc	13.16 ab	5.02 bc	8.27 ab	5.90 ab	1.45	5.31 cde	2.26 ab	5.11 cde	2.11	5.52 ab	2.24
30% P	5.72 a	3.27 bc	5.50 a	15.66 a	5.03 b	11.05 a	6.30 a	1.32	5.33 cde	1.37 ab	5.08 cde	1.61	6.00 a	2.37

	Tagetes erecta													
	0 DAP		7 DAP		14 DAP		21 DAP		28 DAP		35 DAP		42 DAP	
	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC	pH	EC
10% RH	4.66 c	3.97 bc	5.13 cd	13.68 abc	5.32 def	9.56$^{NS\,v}$	5.27 d	11.03 ab	5.40 ab	1.58^{NS}	5.20 b	1.38^{NS}	5.65 ab	0.63^{NS}
10% DC	4.90 bc	3.33 bc	5.08 d	13.39 abc	5.29 ef	8.38	5.23 d	10.57 ab	5.06 b	2.20	5.27 b	0.76	5.14 bc	0.60
10% P	4.94 bc	4.36 abc	5.09 d	15.46 a	5.24 f	9.85	5.33 cd	12.31 a	5.09 b	2.47	5.20 b	1.26	5.33 abc	1.08
20% RH	4.65 c	4.77 ab	5.20 cd	14.79 abc	5.40 cde	8.56	5.61 ab	7.23 ab	5.46 ab	1.49	5.55 ab	1.12	5.53 abc	1.02
20% DC	4.51 c	6.89 a	5.16 cd	11.94 c	5.52 bc	8.42	5.22 d	11.09 ab	5.20 ab	3.04	5.48 ab	1.02	5.13 c	1.16
20% P	4.96 bc	3.33 bc	5.15 cd	15.69 a	5.45 cd	9.16	5.38 bcd	11.31 ab	5.15 b	2.96	5.23 b	1.70	5.22 abc	1.05
30% RH	4.66 c	5.65 ab	5.37 b	12.18 bc	5.69 a	7.96	5.57 abc	8.41 ab	5.84 a	1.61	5.77 a	1.03	5.29 abc	0.88
30% DC	5.22 ab	1.80 c	5.26 bc	13.33 abc	5.60 ab	7.26	5.56 abc	6.09 b	5.44 ab	2.59	5.43 ab	1.24	5.16 bc	1.29
30% P	5.72 a	3.27 bc	5.54 a	15.09 ab	5.60 ab	10.20	5.66 a	9.11 ab	5.39 ab	2.44	5.33 b	1.67	5.68 a	1.90

[z] Days After Planting.

[y] Electrical Conductivity (dS/cm) of substrate solution using the pour through method.

[x] Substrate treatments: rice hulls (RH), post-distilled cedar (DC), and perlite (P) mixed (v:v) with an industry standard peat moss.

[w] Tukey's Studentized Range Test ($P \leq 0.05$, $n = 4$).

[v] NS = no statistical difference observed.

Table 5. Use of cedar as an alternative substrate component.

	Growth Index[z]		Bloom Counts[y]		Root Rating[x]		Shoot Dry Weight[w]	
			Petunia ×hybrida					
Substrates	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
10% RH[v]	31.5 d[u]	34.7^{NS}[t]	29.6 bc	23.4^{NS}	2.6 ab	2.5 c	11.7 cd	14.5^{NS}
10% DC	32.8 bcd	34.9	30.5 abc	23.0	2.6 ab	3.4 abc	13.3 bc	14.6
10% P	35.7 a	34.3	38.8 a	23.1	3.3 ab	3.6 abc	16.8 a	14.4
20% RH	30.2 d	34.3	25.8 cd	24.9	2.6 ab	2.9 bc	9.9 d	15.4
20% DC	32.3 bcd	32.4	30.3 bc	24.3	2.8 ab	3.1 abc	11.6 cd	14.0
20% P	35.0 ab	33.8	36.5 ab	24.6	3.4 ab	3.3 abc	15.9 ab	13.6
30% RH	26.7 e	34.5	20.0 d	25.5	2.3 b	3.4 abc	7.6 e	13.9
30% DC	31.9 cd	34.4	32.8 abc	23.6	2.6 ab	3.9 ab	14.6 abc	14.7
30% P	34.4 abc	34.5	36.7 ab	24.8	3.6 a	4.1 a	15.9 ab	15.3
			Tagetes erecta					
	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
10% RH	21.4 ab	27.9^{NS}	7.3^{NS}	2.5^{NS}	2.8^{NS}	4.5 ab	9.3^{NS}	12.1^{NS}
10% DC	21.3 ab	27.2	7.2	3.0	3.4	4.8 ab	9.0	11.4
10% P	21.3 ab	26.8	7.7	2.0	3.1	4.8 ab	8.5	11.8
20% RH	20.4 ab	27.1	6.8	1.9	2.9	4.1 c	8.5	12.1
20% DC	20.3 ab	26.5	6.8	1.6	2.8	5.0 a	8.0	11.5
20% P	21.0 ab	27.2	7.0	2.1	3.4	4.9 a	9.0	11.8
30% RH	19.1 b	26.2	7.5	2.2	3.1	4.8 ab	8.4	12.1
30% DC	22.6 a	26.6	6.6	2.4	3.3	4.8 ab	9.3	11.7
30% P	20.7 ab	26.1	6.7	2.4	3.5	4.9 a	9.2	12.0

[z] Growth index = [(height+width1+width2)/3] (n = 12).

[y] Bloom count = number of blooms or buds showing color at 42 days (n = 12).

[x] Root ratings 0-5 scale (0 = no visible roots and 5 = roots visable on the entire container substrate interface) (n = 8).

[w] Shoot dry weight measured in grams (n = 8).

[v] Substrate treatments: rice hulls (RH), post-distilled cedar (DC), and perlite (P) mixed (v:v) with an industry standard peat moss.

[u] Tukey's Studentized Range Test ($P \leq 0.05$).

[t] NS = no statistical difference observed.

V. Final Discussion

The purpose of these studies was to evaluate alternative substrate components in the production of greenhouse grown annuals. Currently peat moss (PM) and perlite (P) are the main components utilized in greenhouse substrates. In recent years PM and perlite P have become increasingly scarce, resulting in a higher demand among growers. This demand has brought to light the expense and health risks associated with production and shipping of these soilless substrate components. There are concerns regarding the ability of peat bogs to regenerate (about 2 mm per year) at a speed matching that of harvesting rates. Peat-lands cover over 400 million ha of land area around the world (Robertson 1993). Extraction of PM requires the clearance of all surface vegetation and site drainage. These methods are thought to result in irreversible damage to the ecosystem (Alexander et al., 2008). Researchers are pursuing PM replacement both nationally and internationally. This replacement is being carried out through progressive PM reduction using alternative materials such as timber by-products (Alexander et al., 2008). Expanded P has long been used as an amendment due to its ability to add air space (AS) to container substrates without adding to the bulk density (BD) or affecting substrate pH and electrical conductivity (EC). Although P and similar products have been considered beneficial for plant growth, research has long identified characteristics of P that could be potentially harmful to those who come in contact with it. Perlite dust is a nuisance, causing lung and eye irritation in cases involving over-exposure. A study published in 2001 by Polatli et al., investigated workers pulmonary function when tested in conjunction with P exposure. The workers indicated a significant obstruction to airflow in small airways (Polatli et al., 2001). Another study was conducted after an accidental P spill in Taiwan exposed 24 workers to extremely high amounts of P dust. It was discovered that three workers developed persisted respiratory symptoms and tested positive for reactive airway dysfunction syndrome (Du et al., 2010). Due to these issues and concerns, researchers have been interested in finding replacement substrate options for PM and P. A possible alternative for both PM and P replacement is eastern red cedar (RC) (*Juniperus virginiana* L.).

In chapter 1 petunias and impatiens grown in substrates containing 20% and 40% distilled cedar (DC) were of equal, if not greater, quality than that of those grown in the standard peat-lite mix. These data indicate that substrates containing up to 40% cedar would grow viable annual crops of both *Petunia ×hybrida* Vilm. 'Celebrity Blue' and *Impatiens walleriana* Hook.f. 'Extreme Violet' and possibly other greenhouse crops. Therefore, distilled cedar would be an acceptable alternative component for greenhouse substrates replacing portions of peat.

Chapter 2 concluded that DC substrates performed equal to, if not better than, cedar (C) substrates. However, data seemed to be species dependent. The act of removing a percentage of the cedar's oil, and the high heat involved, may positively affect DC substrate characteristics and result in superior plant growth. This cedar could potentially be a viable alternative for the horticulture industry and replace portions of peat moss and perlite in the production of greenhouse-grown annuals. Further research needs to be performed in order to evaluate chemical properties of distilled cedar.

In chapter 3 petunia growth index (GI) and bloom count (BC) were similar between DC and P at given concentrations with the exception of GI at 10% (experiment 1). Petunia root rating (RR) was similar for all treatments, regardless of concentration, except when comparing RH and

P at 30%. Shoot dry weight (SDW) was comparable between DC and P at 30% in experiment 1. However, P outperformed DC and RH at all other percentages. For experiment 2 no difference was observed between DC, RH and P at all percentages in 3 out of the 4 growth parameters measured in both species. . Overall, with the exception of petunia SDW in experiment 1, growth data indicated that substrates performed well regardless of component concentration. Therefore we believe DC not only provides a promising replacement for peat moss, but a potential substitute for perlite as well in the greenhouse crops tested.

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Appendix A

Introduction

Larvae of fungus gnats, *Bradysia* spp., can cause economic loss to horticultural producers by damaging young root systems during plant propagation, by spreading soil borne diseases, and by reducing the marketability of a crop (Cloyd and Zaborski 2004). Greenhouse producers routinely use insecticides to manage fungus gnat populations (Hamlen and Mead 1979). The fungus gnat life cycle consists of an egg, four larval stages, pupa, and adult. Fungus gnat adults, who typically live from 7 to 10 days, fly near the growing medium surface, causing minimal plant damage (Cloyd 2000). Damage to plants mainly occurs from larvae feeding on root tissue in the growing media (Meers and Cloyd 2005). Female fungus gnats lay their eggs within a given substrate. Little is known about the egg laying preference of female fungus gnats. Adult females prefer to lay eggs in media that is microbially active or that contains high amounts of peat moss or hardwood bark. However, egg-laying preference has not been demonstrated quantitatively (Meers and Cloyd 2005). There is some evidence that growing medium choice can influence fungus gnat populations with fungus gnats tending to prefer soilless growing media containing peat moss that is profusely moist (Baker 1994). The concern with fungus gnat egg-laying behavior is the uncertainty of knowing whether female fungus gnats lay eggs in the first available location or do the females search for a preferred location to lay eggs. Fungus gnats may not depend on the media components alone in the decision to lay eggs, but on a combination of factors (Olson et al. 2002). In performing our study we will test the hypothesis that fungus gnats prefer a moist soil environment and one that contains high percentages of peat moss. We would also like to observe percentage of fungus gnat adult emergence in varying cedar substrates.

Material and Methods

This study was conducted in three separate trials. Media treatments for these experiments included: Trt. 1- standard peatlite mix (80:20 peat:perlite), Trt. 2- 100% cedar, Trt. 3- 80:20 cedar:peat, Trt. 4-60:40 cedar:peat, Trt.5- 40:60 cedar:peat and Trt. 6- 20:80 cedar:peat. All treatments were inoculated with fungus gnat larvae collected from the Paterson Greenhouse Complex at Auburn University. Fungus gnat larvae were collected from moist substrates containing varying amounts of corncob. There were four replications for each treatment and these replications were encased in their own arena and placed in a growth chamber for the duration of each experiment. An arena consisted of a 4 in. pot, a 2-liter soda bottle and bridal veil mesh. A 2-liter bottle, rinsed with a 10% Clorox bleach solution and allowed to aerate for 24 hr., was cut in half and placed on top of the pot in contact with the soil. Bridal veil mesh was used to cover the lid of the bottle to allow for airflow within the apparatus, but not facilitate escape of emerging fungus gnats. After being covered with mesh they were placed in a growth chamber (Percival Incubator, Percival Scientific Inc., Perry, IA) set at 22°C, in a completely randomized design and watered by misting from a spray bottle daily. Inoculation of each arena began with the transportation of pots containing fungus gnat larvae from the greenhouse complex to the Entomology and Plant Pathology lab. Larvae were transferred using forceps to pots containing each treatment and then misted to prevent mortality. Each replication was inoculated with five fungus gnat larvae. Trials 1 and 2 were conducted this way, but for the third trial, mesh was added to the bottom of each pot in order to prevent escape. Arenas were checked daily for emergence of adult fungus gnats and percent emergence determined. Emergence was checked at each watering.

Conclusion

Out of all three trials, only one fungus gnat adult emerged. We suspect that handling mortality and other unknown factors contribute to the poor emergence. We believe that the study needs to be repeated with more refined methods in order to accurately determine the suitability of these alternative components for media pests like fungus gnat larvae.

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