Low-Value Trees as Alternative Substrates in Greenhouse Production of Three Annual Species[1]

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Abstract

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

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

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

Significance to the Nursery Industry

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

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Introduction

Peat has served as the standard greenhouse industry substrate for the past forty to fifty years due to several inherit qualities. Peat embodies several crucial physical characteristics of an ideal greenhouse container substrate, and is generally pathogen-free. Peat availability may decrease due to increased regulations and restrictions on the harvesting of peat. These restrictions, paralleled with constantly fluctuating fuel and shipping prices of peat from Canada, have caused growers to seek alternative greenhouse substrates with equivalent physical characteristics (25).

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

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

In this study, three low-value forest trees were evaluated as amendments to a standard peat/perlite mix, including sweetgum (SG) (*Liquidambar styraciflua* L.), hickory (H) (*Carya sp.* Nutt.) and eastern redcedar (RC) (*Juniperus virginiana* L.). SG (family *Hamamelidaceae*) is a medium to fast growing tree (0.30–0.91 m per year; 1–3 ft per year) which can reach heights of 18.3–22.9 m (60 to 75 ft) or taller (5). While a few select cultivars of SG are used in the landscape, there is limited value to the wood once harvested. Different species of H (family *Juglandaceae*) can grow to 18.3 m (60 ft) or taller, are tap-rooted, and therefore difficult to transplant into a landscape (5). They are native to the eastern and southern parts of the United States (species dependent) and are often a part of native hardwood stands across the southeast. The last of the species tested in this study, RC (family *Cupressaceae*) is a coniferous species native to all of east and central North America, primarily east of the Rocky Mountains growing to between 12.2–15.2 m (40 and 50 ft) tall, and reaching spreads of between 2.4–6.1 m (8 and 20 ft) (5). Specific cultivars of RC are excellent landscape plants, but the species, found native to traditional hardwood forests, are thought to be somewhat invasive (11). All of these species are currently viewed as either 'trash trees' or low-value pulpwood trees to the forest industry, indicating they could have the potential to become economical and viable amendments in standard greenhouse substrates.

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

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

Existing studies have evaluated the growth of woody ornamentals in nursery substrates amended with cedar and hardwoods, but limited research has been conducted on using these substrates with greenhouse-grown crops. The objective of this study was to determine if growers could substitute one of three low-value forest tree species for perlite and up to 25% peat in their standard peat/perlite greenhouse substrates without reducing the quality of three annual crops. Positive results from this study could have the potential to meet the substrate demands created by peat shortages and worker safety problems associated with perlite use.

Materials and Methods

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

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

Three bedding plant species were used in this study, which was initiated on February 25, 2009, (Exp. 1) and May 8, 2009, (Exp. 2) at the Paterson Greenhouse Complex at Auburn University. 'Dreams Sky Blue' petunia (*Petunia ×hybrida* Juss. 'Dreams Sky Blue'), 'Cooler Peppermint' vinca [*Catharanthus roseus* (L.) G.Don 'Cooler Peppermint'], and 'Super Elfin Salmon' impatiens (*Impatiens walleriana* Hook.f. 'Super Elfin Salmon') were planted into 1.21 liter (1.28 qt) containers with two plugs (from a 288 plug flat) per pot in both experiments. Plants were placed on greenhouse benches and watered by hand as needed. The experimental design was a randomized complete block design with 8 single pot replications per treatment. Each species was treated as its own experiment. Data were analyzed using Tukey's Honestly

Significant Difference test ($p \leq 0.05$) in a statistical software package (SAS® Institute version 9.1.3, Cary, NC).

Physical properties [substrate air space (AS), water holding capacity (WHC), total porosity (TP)] were determined using the North Carolina State University porometer method (n = 3) (10). Bulk densities (BD) were determined from the same samples used to determine physical properties, and were obtained from 347.5 cm^3 (21.2 in^3) samples dried in a 105C (221F) forced air oven for 48 hours (n = 3). Particle size distribution (PSD) analysis was determined by passing a 100 g sample [dried in a 76.7C (170F) forced air oven] through a series of sieves (n = 3). Sieves were shaken for three minutes with a Ro-Tap sieve shaker (Ro-Tap RX-29, W.S. Tyler, Mentor, OH). Pour-through leachates were obtained from 'Super Elfin Salmon' impatiens at 1, 15, 30 and 45 days after planting (DAP) in order to determine substrate pH and electrical conductivity (EC) (n = 4) (22). Substrate shrinkage was evaluated on each species at termination (46 DAP for Exp. 1; 47 DAP for Exp. 2) by measuring distance (in cm) from the top of the pot to the top of the substrate (n = 8). Flower number was evaluated at termination, where only open blooms and blooms showing color were counted towards the total number on each plant (n = 8). Growth indices [(height + width1 + width2) / 3] (cm) were also measured at termination (n = 8). Plant dry weights (PDW) (shoots only) were determined after samples were dried at 76.7C (170F) for 72 hours (n = 4). Root growth was assessed at study termination on a scale from 1–10, where 1 was assigned to plants with less than 10% root ball coverage, and 10 was assigned to plants with between 90–100% root ball coverage (n = 8). Tissue nutrient content was determined using 25–30 recently matured leaves of 'Dreams Sky Blue' petunia in each experiment (n = 4). Leaf nitrogen (N) was determined by conducting combustion analysis using a 1500 N analyzer (Carlo Erba, Milan, Italy). Selected remaining macronutrients, as well as micronutrients [phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu) and boron (B)] were quantified by microwave digestion with inductively coupled plasma-emission spectrometry (Thermo Jarrel Ash, Offenbach, Germany). Experiments were terminated on April 12, 2009, (Exp. 1) and June 24, 2009 (Exp. 2).

Results and Discussion

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

Table 1. Physical properties[z] of nine substrates containing peat, perlite, *WholeTree*, hickory, sweetgum, and redcedar[y].

Substrate	Air space[x]		Substrate water holding capacity[w]		Total porosity[v]		Bulk density ($g \cdot cm^{-3}$)[u]	
	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1	Exp. 2
75:25 Peat:Perlite	11.8ab[t]	6.8c	72.2e	82.0abc	83.9c	88.8de	0.15abc	0.15ab
75:25 Peat:*Wholetree*	11.8ab	6.5c	74.9de	83.3ab	86.7bc	89.8cd	0.14bc	0.13d
75:25 Peat:Sweetgum	10.8ab	5.9c	81.0ab	84.7a	91.9a	90.5bcd	0.13c	0.13d
75:25 Peat:Hickory	10.5ab	8.8bc	78.1abcd	79.6bc	88.7b	88.4de	0.16a	0.14bcd
75:25 Peat:Redcedar	10.2b	8.6bc	81.6a	83.9a	91.9a	92.6ab	0.15ab	0.13d
50:50 Peat:*Wholetree*	15.0ab	12.3ab	77.0abcde	74.9d	92.0a	87.2e	0.15ab	0.13d
50:50 Peat:Sweetgum	12.8ab	9.3bc	80.8abc	82.2ab	93.5a	91.5abc	0.14bc	0.14bcd
50:50 Peat:Hickory	16.8ab	11.3ab	75.7cde	80.9abc	92.5a	92.1abc	0.14bc	0.16a
50:50 Peat:Redcedar	17.1a	15.4a	76.0bcde	78.1cd	93.0a	93.5a	0.14bc	0.15abc
Optimal range for greenhouse substrates[s]	10–20%		50–65%		60–75%		N/A	
Recommended range for nursery crops[r]	10–30%		45–65%		50–85%		0.19–0.70	

[z]Analysis performed using the North Carolina State University porometer (http://www.ncsu.edu/project/hortsublab/diagnostic/porometer/).

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

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

[w]Substrate water holding capacity is (wet weight – oven dry weight) / volume of the sample.

[v]Total porosity is substrate water holding capacity + air space.

[u]Bulk density after forced-air drying at 105.0C (221.0F) for 48 hrs; 1 $g \cdot cm^{-3}$ = 62.43 $lb \cdot ft^{-3}$.

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

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

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

Particle size distribution (PSD). Analysis of PSD in Exp. 1 showed that there were no differences across any treatment for the distribution of particles left on the 9.50 and 6.35 mm screens (Table 2). In smaller screen sizes, many differences occurred. Therefore, in order to better interpret the data in both experiments, the authors grouped the screens into three distinct categories: coarse (3.35–9.50 mm), medium (1.00–2.36 mm) and fine (0.00–0.50 mm). In Exp. 1, coarse particles for all treatments ranged from 6.5 to 11.1%. Coarse particles are responsible for aeration in a substrate. The 50:50 P:WT treatment (11.1%) had more coarse particles than any other treatment, although five other treatments had statistically similar values, including 75:25 P:WT (8.6%), 75:25 P:H (8.3%), 75:25 P:RC (8.7%), 50:50 P:SG (8.9%), and 50:50 P:H (9.8%). Medium particles were greatest in the 50:50 P:SG (50.0%) and 50:50 P:RC (50.7) treatments, although both were similar to the other two 50:50 (v:v) treatments. The GS had the least medium particles of those tested (34.7%). The GS had more fine particles (0.00–0.50 mm) (57.5%) than any other treatment, although several other substrates did have similar values [75:25 P:WT (51.5%), 75:25 P:SG (54.7%), and 75:25 P:H (52.1%)]. This is logical, since the GS also had more particles in the pan (3.1%) than any other substrate tested. Fine particles are necessary in a container substrate to maintain adequate water holding properties.

In Exp. 2, the 50:50 P:RC treatment had the most coarse particles of any treatment (21.7%), however both the 50:50 P:SG (16.8%) and the 50:50 P:H (18.1%) treatments had similar values (Table 3). The 75:25 P:H treatment had the least coarse particles of any substrate tested (5.4%). Medium

Table 2. Particle size distribution[z] analysis of nine substrates containing peat, perlite, *WholeTree*, sweetgum, hickory, and redcedar[y] (Experiment 1)[x].

U.S. standard sieve no.	sieve opening (mm)[w]	Substrates								
		75:25 Peat: Perlite	75:25 Peat: *WholeTree*	75:25 Peat: Sweetgum	75:25 Peat: Hickory	75:25 Peat: Redcedar	50:50 Peat: *WholeTree*	50:50 Peat: Sweetgum	50:50 Peat: Hickory	50:50 Peat: Redcedar
3/8	9.50	0.0[v,ns]	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0
1/4	6.35	0.1[ns]	0.1	0.3	0.3	0.5	0.0	0.3	0.5	0.3
6	3.35	7.7bc	8.5abc	6.1c	7.9bc	7.9bc	11.1a	8.6abc	9.3ab	7.6bc
8	2.36	12.3bcd	12.1cd	10.7d	11.1cd	11.9cd	16.6a	15.6a	14.1abc	15.3ab
10	2.00	4.4cd	4.3d	4.2d	4.6cd	5.4bc	5.7b	5.9b	5.7b	7.1a
14	1.40	9.1d	11.5c	11.2cd	11.5c	13.3bc	13.9ab	15.5ab	15.1ab	15.8a
18	1.00	8.9e	9.4de	10.8bcd	9.7cde	11.8ab	11.2abcd	12.9a	11.3abc	12.5ab
35	0.50	16.3f	19.1cde	22.8a	20.1bc	21.2b	18.8cde	19.7bcd	18.1e	18.4de
60	0.25	16.4ab	17.5ab	18.3a	17.6ab	14.5bc	12.4c	11.7c	12.6c	12.0c
140	0.11	15.7a	11.0b	9.8bcd	10.3bc	7.1cde	6.0de	5.1e	7.1cde	6.5cde
270	0.05	6.1a	2.8bc	2.7bc	2.9b	1.8bc	1.6bc	1.3c	2.5bc	1.8bc
pan	0.00	3.1a	1.1b	1.1b	1.1b	0.7bcd	0.5cd	0.5d	1.2b	1.0bc
Texture[u]										
Coarse		7.8bc	8.6abc	6.5c	8.3abc	8.7abc	11.1a	8.9abc	9.8ab	7.9bc
Medium		34.7d	37.3cd	36.9cd	37.0cd	42.3bc	47.5ab	50.0a	46.2ab	50.7a
Fine		57.5a	51.5ab	54.7a	52.1ab	45.3bc	39.3c	38.3c	42.5c	39.7c

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

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

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

[w]1 mm = 0.0394 in.

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

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

[ns]Means in row not significantly different.

Table 3. Particle size distribution[z] analysis of nine substrates containing peat, perlite, *WholeTree*, sweetgum, hickory, and redcedar[y] (Experiment 2)[x].

		Substrates								
U.S. standard sieve no.	sieve opening (mm)[w]	75:25 Peat: Perlite	75:25 Peat: *WholeTree*	75:25 Peat: Sweetgum	75:25 Peat: Hickory	75:25 Peat: Redcedar	50:50 Peat: *WholeTree*	50:50 Peat: Sweetgum	50:50 Peat: Hickory	50:50 Peat: Redcedar
3/8	9.50	0.5d[v]	1.2cd	4.1abc	0.6d	4.3ab	1.1cd	3.4abcd	1.5bcd	6.4a
1/4	6.35	0.4d	1.0cd	2.2bc	0.3d	3.2ab	2.5bc	3.4ab	3.0b	4.9a
6	3.35	9.7b	7.3c	6.9c	4.5d	6.4cd	15.0a	10.0b	13.6a	10.4b
8	2.36	9.3c	9.6c	8.3c	8.3c	8.3c	17.6a	13.1b	17.1a	14.4b
10	2.00	4.1c	4.2c	3.5c	4.0c	3.9c	7.2a	5.4b	7.8a	7.1a
14	1.40	10.3d	8.9e	9.5de	9.4de	9.8de	13.2b	11.8c	15.2a	14.6a
18	1.00	12.1ab	9.9c	11.3b	9.2c	9.4c	11.2b	12.5a	12.4ab	11:6ab
35	0.50	22.5a	21.6ab	22.9ab	19.1c	18.2cd	16.2de	19.7bc	15.3e	15.5e
60	0.25	15.2bc	19.8a	18.3ab	20.5a	18.0ab	9.0d	12.5c	7.9d	9.1d
140	0.11	8.6c	11.6b	9.2c	15.7a	13.2b	4.1d	5.5d	3.8d	4.1d
270	0.05	3.4a	2.8b	2.3cd	3.9a	3.4a	1.1d	1.3d	1.1d	1.1d
pan	0.00	2.9a	1.0bc	0.8cd	1.2bc	1.3b	0.5d	0.5d	0.5d	0.5d
Texture[u]										
Coarse		10.6cd	9.4cd	13.2bc	5.4d	13.9bc	18.5ab	16.8ab	18.1ab	21.7a
Medium		35.8d	32.6de	32.6de	30.9e	31.4e	49.2ab	42.9c	52.5a	47.8b
Fine		52.7b	56.8ab	53.4ab	60.4a	54.2ab	30.8d	39.5c	28.6d	30.3d

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

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

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

[w]1 mm = 0.0394 in.

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

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

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

pH and EC. The recommended range for pH of *Impatiens walleriana* is between 5.5 and 6.0 (17). In Exp. 1, all treatments were below that range at 1 DAP (Table 4). At 14 DAP, the pH of all treatments had climbed to within the ideal range, except for the GS (5.4). Throughout the rest of Exp. 1, treatments remained consistent, and by 45 DAP, only 50:50 P:SG (6.1) and 50:50 P:H (6.1) were slightly over the recommended range. These two were the only treatments not similar to the GS (5.5) by study termination. In general, treatments containing RC tended to have similar pH values to the GS treatment, except at 1 DAP, where 75:25 P:RC (5.1) and 50:50 P:RC (5.2) both exhibited higher pH values than the GS (4.8).

In Experiment 2, at 14, 30, and 45 DAP, 50:50 P:H had higher pH levels (6.2, 6.7, 6.4, respectively) than the GS (5.6, 6.2, 5.9, respectively). The pH values for 50:50 P:SG tended to be higher than those for the GS throughout Exp. 2, except at 14 DAP, where the values were similar. Substrate pH values for the 75:25 P:RC treatment were similar to those of the GS at all testing dates in Exp. 2. However, higher percentages of RC in the substrate (50%) tended to raise pH values to levels higher than in the GS. Evidence of this can be seen at 30 and 45 DAP where pH values for 50:50 P:RC treatments (6.5 and 6.3, respectively) were higher than those for the GS control (6.2 and 5.9, respectively). Treatments containing WT had similar pH values to the GS at each testing date in Exp. 2. For the most part, pH values were slightly higher in Exp. 2 than in Exp. 1, although the general trends between substrates were consistent across both experiments.

The recommended range for substrate EC levels of *Impatiens walleriana* is between 1.25 and 2.0 mS·cm^{-1} (17). At both 1 and 14 DAP (Exp. 1), EC levels were much lower for all treatments compared to the GS (1.8 and 1.6 mS·cm^{-1}, respectively) (Table 4). By 30 DAP however, the EC of all treatments were similar to the GS (0.6 mS·cm^{-1}). However, EC values for 50:50 P:H (0.7 mS·cm^{-1}) was higher than the EC values for the following treatments: 75:25 P:WT, 75:25 P:SG, 75:25 P:RC, and 50:50 P:WT (all of which had a mean EC of 0.4 mS·cm^{-1}). In Exp. 2, substrate EC levels for all treatments were similar to the GS (1.2 mS·cm^{-1}) at 1 DAP except for the 50:50 P:RC treatment (0.7 mS·cm^{-1}). At 14 DAP, the only treatments dissimilar to the GS (2.4 mS·cm^{-1}) were the 50:50 blends of P:SG (1.0 mS·cm^{-1}) and P:H (0.7 mS·cm^{-1}). All other treatments, including all 75:25 blends of P:WT (1.3 mS·cm^{-1}), P:RC (1.7 mS·cm^{-1}), P:SG (2.2 mS·cm^{-1}), and P:H (2.0 mS·cm^{-1}), as well as the 50:50 blends of both P:WT (1.4 mS·cm^{-1}) and P:RC (1.4 mS·cm^{-1}) were similar to the GS (2.4 mS·cm^{-1}). There were no differences among any substrate EC levels at 30 DAP for Exp. 2, and by study termination (45 DAP), no differences were observed among any treatments for either experiment.

Table 4. Effect of nine substrates containing peat, perlite, *WholeTree* substrate, sweetgum, hickory, and redcedar on pH and electrical conductivity (EC) in impatiens[z].

	Exp. 1		Exp. 2		Exp. 1		Exp. 2	
Substrate	pH	EC[y] (mS·cm^{-1})[x]	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})	pH	EC (mS·cm^{-1})
	1 DAP[w]				14 DAP			
75:25 Peat:Perlite	4.8cd[v]	1.8a	5.2bc	1.2a	5.4b	1.6a	5.6b	2.4a
75:25 Peat:*Wholetree*	5.0bcd	1.0b	5.2bc	1.1ab	5.7ab	0.6cde	5.7b	1.3abc
75:25 Peat:Sweetgum	5.2ab	0.8b	5.3abc	1.0ab	5.7ab	0.5e	5.7b	2.2ab
75:25 Peat:Hickory	5.1bcd	1.2b	4.9c	1.2a	5.6ab	1.0bcd	5.7b	2.0abc
75:25 Peat:Redcedar	5.1ab	0.8b	5.4ab	1.1ab	5.6ab	0.8bcde	5.7b	1.7abc
50:50 Peat:*Wholetree*	5.1bcd	0.9b	5.5ab	0.8ab	5.8ab	0.4e	5.9ab	1.4abc
50:50 Peat:Sweetgum	4.8d	1.1b	5.7a	0.9ab	5.8ab	0.6de	6.0ab	1.0bc
50:50 Peat:Hickory	5.4a	0.7b	4.9c	1.1ab	5.9a	1.1b	6.2a	0.7c
50:50 Peat:Redcedar	5.2ab	1.1b	5.6ab	0.7b	5.8ab	1.1bc	5.9ab	1.4abc
	30 DAP				45 DAP			
75:25 Peat:Perlite	5.5b	0.6ab	6.2d	0.9[ns]	5.5b	0.2[ns]	5.9b	0.4[ns]
75:25 Peat:*Wholetree*	5.7ab	0.4b	6.2d	0.6	5.9ab	0.3	6.1ab	0.4
75:25 Peat:Sweetgum	5.7ab	0.4b	6.3cd	0.9	5.6ab	0.2	6.1ab	0.5
75:25 Peat:Hickory	5.6ab	0.4ab	6.4bcd	0.9	5.9ab	0.2	6.3a	0.3
75:25 Peat:Redcedar	5.8ab	0.4b	6.3cd	1.0	5.6ab	0.3	6.1ab	0.3
50:50 Peat:*Wholetree*	5.9ab	0.4b	6.4bcd	0.5	5.8ab	0.3	6.2ab	0.3
50:50 Peat:Sweetgum	6.0a	0.5ab	6.6ab	0.9	6.1a	0.3	6.3a	0.5
50:50 Peat:Hickory	5.9ab	0.7a	6.7a	0.7	6.1a	0.3	6.4a	0.5
50:50 Peat:Redcedar	5.9ab	0.5ab	6.5abc	0.6	6.0ab	0.3	6.3a	0.4

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

[y]EC = electrical conductivity.

[x]1 mS·cm^{-1} = 1 mmho·cm^{-1}.

[w]DAP = days after planting.

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

[ns]Means not significantly different.

Shrinkage. In Exp. 1 with petunia, only the 75:25 P:SG (2.4 cm) and 50:50 P:RC (2.4 cm) treatments had shrinkage greater than in the GS (1.8 cm); (Table 5). With impatiens, all treatments were similar to the GS (2.3 cm), and the only difference among treatments was between 75:25 P:H (2.8 cm) and 50:50 P:WT (2.0 cm). With respect to vinca grown in Exp. 1, shrinkage among all treatments was similar to the GS (1.3 cm), except for the 75:25 P:H treatment (2.0 cm). Shrinkage tended to be less in Exp. 2. This could be due to the fact that Exp. 2 was initiated 81 days after the trees were harvested, giving the substrate components time to slightly decompose. For petunia, there were no differences among all treatments with respect to shrinkage. For impatiens, the only treatment differing from the GS (1.3 cm) was the 75:25 P:RC (1.9 cm) treatment. With vinca, all treatments had similar shrinkage values to the GS (0.8 cm).

Flower number. In Exp. 1, the only treatment to have similar petunia flower number to the GS was the 75:25 P:WT treatment (Table 6). In evaluating impatiens flower number, four treatments had similar flower counts to that seen in the GS (59.1), including 75:25 P:WT (50.5), 75:25 P:SG (39.1), 75:25 P:RC (41.8), and 50:50 P:WT (41.8). For vinca, the only treatments similar to the GS were 75:25 P:WT and 75:25 P:RC. All substrate treatments containing SG or H had less flowers than those containing 25% WT or RC, or the GS. In Exp. 2, petunia flower number for all treatments were similar to the GS, except for the 50:50 (v:v) P:H treatment. With impatiens, treatments with RC and WT were similar to the GS (both v:v ratios of each), while treatments with H and SG had less flowers. Only two treatments (75:25 P:RC and 50:50 P:RC) were similar to the GS with respect to flower number in vinca. Other treatments, including those with WT, H and SG had fewer flowers than the GS in Exp. 2. Preliminary studies evaluating WT showed similarities to the current study. In a study by Fain et al., (8), flower number of lantana and petunia generally decreased as the volume of WT increased in the substrate.

Growth indices. Petunia growth indices from Exp. 1 indicated that only the 75:25 P:WT and 75:25 P:RC treatments were similar to the GS (Table 7). For both impatiens and vinca, plants in three treatments were as large as those in the GS (19.7 and 21.0, respectively); 75:25 P:WT (19.2 and 19.4, respectively), 75:25 P:RC (17.1 and 19.8, respectively), and 50:50 P:WT (17.9 and 18.5, respectively). All other substrate treatments exhibited less growth than plants grown in the GS. Results were similar with few exceptions in Exp. 2. Petunias in the following treatments were similar in size to those in the GS (26.7): 75:25 P:WT (26.1), 75:25 P:H (24.9), 75:25 P:RC (26.1), 50:50 P:WT (26.4), and 50:50 P:RC (26.3). Both substrate treatments containing SG [75:25 P:SG (23.2) and 50:50 P:SG (22.2)], as well as 50:50 P:H (18.1) had less growth than that exhibited in the GS. With impatiens, the only 75:25 (v:v) treatment not similar to the GS (22.4) was 75:25 P:H (18.5). When the volume of the alternative was increased from 25 to 50%, only treatments containing WT and RC remained similar in growth to the GS. Vinca growth

Table 5. Effect of substrate on shrinkage[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals.

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

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

[y]DAP = days after planting.

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

Table 6. Effect of substrate on flower number[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals.

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

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

[y]DAP = days after planting.

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

Table 7. Effect of substrate on growth indices[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals.

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

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

[y]DAP = days after planting.

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

in the GS (25.6) for Exp. 2 was equaled by three treatments [75:25 P:WT (24.0), 75:25 P:RC (25.6) and 50:50 P:RC (25.1)]. Treatments containing SG and H did not perform well. Overall, growth was numerically greater for all treatments in Exp. 2 compared to Exp. 1. The authors attributed this to the fact that the alternative wood substrates had aged approximately 80 days prior to initiating Exp. 2, while the age at initiation of Exp. 1 was only 8 days.

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

Table 8. Effect of substrate on dry weights[z] at termination (46 DAP[y] for Experiment 1 and 47 DAP for Experiment 2) for three greenhouse annuals.

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

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

[y]DAP = days after planting.

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

Plant dry weight. Petunia PDW (Exp. 1) was greater in the GS substrate mix (10.4 g) than in any other substrate (Table 8). When comparing treatments with the same v:v ratios, plants grown in those containing RC and WT generally had higher PDW than ones grown in treatments containing SG and H for both experiments. For instance, 75:25 P:WT (7.7 g) and 75:25 P:RC (7.6 g) had greater PDW in Exp. 1 than petunias in 75:25 P:SG (3.8 g) or 75:25 P:H (4.6 g). With impatiens in Exp. 1, the only treatment to have a similar PDW to the GS (4.6 g) was the 75:25 P:WT treatment (3.5 g). For vinca in Exp. 1, plants grown in the GS had the highest PDW (7.7 g). In Exp. 2, Petunia PDW in 75:25 P:RC (14.4 g), P:WT (13.4 g), 50:50 P:RC (13.3 g) and P:WT (12.3 g) were similar to GS PDW (13.2 g). The 75:25 P:H (10.3 g) treatment was the only treatment containing H or SG to be similar to the GS. For impatiens and vinca in Exp. 2, substrate treatments containing RC were the only treatments similar to the GS. PDW of plants in treatments containing H and SG had the least PDW. In general, PDW was greater in Exp. 2 than respective treatments in Exp. 1. Again, this could be attributed to the substrate aging between experiments. Also, Exp. 1 was initiated in February 2008, while Exp. 2 was initiated in May 2008. The warmer temperatures and longer daylengths may have positively affected growth, and subsequently, PDW.

Root growth. Petunias, in all treatments, had similar root growth ratings to those grown in the GS in Exp. 1 (5.0) (Table 9). For impatiens in Exp. 1, all but two treatments exhibited similar, or greater, root growth to plants grown in the GS (4.1); plants grown in 50:50 P:WT (7.0) had more root growth than the GS, while plants grown in 50:50 P:SG (1.4) had less. There were no differences across any treatment with respect to root growth for vinca in Exp. 1. Root ratings were similar in Exp. 2, where all treatments were similar to the GS (7.4) with petunia. With impatiens and vinca, all treat-

Table 9. Effect of nine substrates containing peat, perlite, *WholeTree* substrate, sweetgum, hickory and redcedar on root growth[z] of three annual species.

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

[z]Root growth assessed at study termination (45 days after planting) on 1–10 scale (1 = less than 10% root ball coverage, 5 = 50% root ball coverage, and 10 = 100% root ball coverage).

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

[ns]Means not significantly different.

Table 10. Tissue nutrient content of *Petunia* × *hybrida* 'Dreams Sky Blue' grown in nine substrates containing peat, perlite, *WholeTree* substrate, sweetgum, hickory, and redcedar.

Substrate	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm[y])	Cu (ppm)	B (ppm)	Fe (ppm)	Na (ppm)	Al (ppm)	Zn (ppm)
	Tissue nutrient content[z] for Exp. 1											
75:25 Peat:Perlite	2.99a[x]	0.22abc	1.59d	0.61[ns]	1.11abc	138a	12[ns]	24a	308.50a	5695a	31[ns]	20[ns]
75:25 Peat:*Wholetree*	2.16b	0.21abc	2.56cd	0.60	1.10abc	104ab	11	19a	113.75b	3166b	23	21
75:25 Peat:Sweetgum	2.30ab	0.25a	3.72bc	0.66	1.19a	114ab	15	22a	133.00b	3588b	22	24
75:25 Peat:Hickory	1.58bc	0.18bc	4.37ab	0.69	1.08abc	131ab	16	21a	156.75ab	2688b	25	22
75:25 Peat:Redcedar	2.14bc	0.23abc	2.10d	0.65	1.09abc	84ab	16	22a	102.50b	3864b	21	19
50:50 Peat:*Wholetree*	2.25ab	0.26a	3.70bc	0.60	1.08abc	130ab	12	14b	111.25b	2532b	25	26
50:50 Peat:Sweetgum	1.63bc	0.24ab	5.40a	0.70	1.15ab	129ab	9	22a	70.00b	3250b	21	18
50:50 Peat:Hickory	1.38c	0.17c	4.72ab	0.63	0.95bc	91ab	12	12b	51.00b	2062b	23	17
50:50 Peat:Redcedar	2.33ab	0.24ab	2.21d	0.62	0.88c	76b	19	13b	95.00b	2984b	19	28
	Tissue nutrient content for Exp. 2											
75:25 Peat:Perlite	2.82a	0.25a	0.89f	1.05b	1.24ab	93cd	25[ns]	24ab	468.50a	11311a	67[ns]	44b
75:25 Peat:*Wholetree*	2.16bc	0.19ab	1.12ef	1.13ab	1.25ab	105abc	15	23ab	250.75ab	10025ab	40	42b
75:25 Peat:Sweetgum	1.82cd	0.17ab	1.64def	1.30ab	1.22ab	139ab	31	23ab	232.75ab	7510cd	46	50ab
75:25 Peat:Hickory	1.92bcd	0.17ab	1.80cde	1.15ab	1.20ab	150a	22	32a	164.25b	7774cd	39	50ab
75:25 Peat:Redcedar	2.44ab	0.24a	1.08ef	1.40ab	1.29a	101bc	21	27ab	340.00ab	9216bc	33	44b
50:50 Peat:*Wholetree*	2.08bcd	0.22ab	2.45bc	1.10ab	1.10ab	64cd	17	11c	152.25b	7307cd	38	46ab
50:50 Peat:Sweetgum	1.87cd	0.21ab	2.61b	1.66a	1.27a	106abc	17	30a	259.33ab	6925d	31	57ab
50:50 Peat:Hickory	1.57d	0.15b	4.28a	1.44ab	1.27a	92cd	44	18bc	124.25b	6744d	75	82a
50:50 Peat:Redcedar	2.35abc	0.23ab	1.95bcd	1.16ab	0.99b	51d	21	9c	166.00b	7617cd	120	45b
Sufficiency range[w]	3.85–7.60	0.47–0.93	3.13–6.65	1.20–2.81	0.36–1.37	44–177	3–19	18–43	84–168	3067–10896	50–92	33–85

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

[y]1 ppm = 1 mg·kg^{-1}.

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

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

[ns]Means not significantly different.

ments containing 25% of the alternative substrate material were observed to have similar root ratings to the GS (6.4 for impatiens; 7.1 for vinca). The only two treatments in both plant species to have dissimilar root ratings to the GS were 50:50 P:SG (1.9 for impatiens; 4.4 for vinca) and 50:50 P:H (1.5 for impatiens; 3.9 for vinca).

Tissue nutrient content. Tissue N levels of petunia in both Exp. 1 (1.38 to 2.99%) and Exp. 2 (1.57 to 2.82%) were all below the sufficiency range of 3.85 to 7.60% (18) (Table 10). In Exp. 1, percentage N was highest in the GS (2.99%), and least in any substrate treatment containing H [75:25 P:H (1.58%) and 50:50 P:H (1.38%)]. The only treatments with similar percentage N values to the GS in Exp. 1 were 75:25 P:SG (2.30%), 50:50 P:WT (2.25%) and 50:50 P:RC (2.33%), while in Exp. 2, only treatments with RC [75:25 P:RC (2.44%) and 50:50 P:RC (2.35%)] were similar to the GS (2.82%). Values for P were also less than the recommended range (0.47–0.93%) for all treatments in both experiments. However, P levels in all treatments were similar to the GS (0.22% for Exp. 1, 0.25% for Exp. 2) with respect to P in both experiments with only one exception in Exp. 2 [50:50 P:H (0.15%)]. In Exp. 1 and 2, all treatments had equal or higher K levels than the GS (1.59% in Exp. 1, 0.89% in Exp. 2). There were no differences concerning Ca content in Exp. 1, although the range of values for Ca (0.60 to 0.70%) was less than the recommended range (1.20 to 2.81%). Ca levels were higher in Exp. 2, and all levels were similar to the GS (1.05%), except for 50:50 P:SG (1.66%). All Mg levels were within the recommended range of 0.36 to 1.37%, and all treatments were similar to the GS (1.11%). Similar results were obtained with Mg in Exp. 2. All Mn levels were within the recommended range (44 to 177 ppm) for both experiments. While some of the Cu levels were slightly above the recommended range of 3 to 19 ppm in Exp. 2, there were no differences across any treatments for Cu in either experiment. For the most part, B values were within the recommended range (18 to 43 ppm) for all treatments in both experiments. The B levels for 50:50 P:WT (14 ppm in Exp. 1 and 11 ppm in Exp. 2) and 50:50 P:RC (13 ppm in Exp. 1 and 9 ppm in Exp. 2) were the only two treatments less than the recommended range. The only treatment in Exp. 1 with an Fe level similar to the GS (309 ppm) was the 75:25 P:H (157 ppm) treatment, and the only treatments outside the recommended range (84 to 168 ppm) were the GS, 50:50 P:SG (70 ppm), and 50:50 P:H (51 ppm). Results for Fe content in Exp. 2 were higher than in Exp. 1. Fe levels were different in four treatments compared to the GS (469 ppm), including 75:25 P:H (164 ppm), 50:50 P:WT (152 ppm), 50:50 P:H (124 ppm), and 50:50 P:RC (166 ppm). Coincidentally, these four treatments were also the only four within the recommended range for Fe. The GS had the highest Na value (5695 ppm) in Exp. 1. The Na levels in Exp. 2 were slightly higher, but were within the recommended range (3067 to 10896 ppm) with the exception of the GS (11311 ppm). Al and Zn values in Exp. 1 (19 to 31 ppm for Al; 17 to 28 ppm for Zn) were less than the recommended sufficiency ranges (50 to 92 ppm for Al; 33 to 85 ppm for Zn), but there were no differences across treatments for either element.

Although Al levels were higher in Exp. 2 (31 to 120 ppm), there were still no differences among treatments. Zn levels were also higher in Exp. 2 (42 to 82 ppm), but they were all within the recommended range.

In general, these data show that while physical properties of the substrates evaluated were within optimal ranges, there were minor differences among them, particularly with respect to PSD. The percentage of coarse particles, which are responsible for aeration in a substrate, varied less across substrates than the percentages of medium and fine particles, which are particles necessary for maintaining adequate substrate water holding capacity. Similarly, plant growth was also different across substrate treatments. Throughout the study, treatments with RC as an amendment tended to be comparable to the traditional GS. Plants in treatments with RC also performed equal to or better than plants in WT. Plants grown with SG and H as amendments differed significantly from the GS with respect to lower flower number, smaller growth indices, and less PDW. SG and H are not recommended as amendments for annual plant production with current greenhouse practices. Additional studies are in place to determine if different fertility regimes could improve the growth and flowering of plants in these alternative substrates. While results from this study concerning using RC as an amendment in the GH production of three annual crops were promising, additional trials with a greater number of plant species would be necessary before advising growers to make a switch in their own production practices.

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