Evaluation of Eastern Redcedar Substrate in the Production of Four Annual Species[1]

Lucy E. Edwards, Adam F. Newby, Charles H. Gilliam, Glenn B. Fain, Jeff L. Sibley and Anna Marie Murphy[2]

Abstract

Peat moss and perlite have been major components in greenhouse substrates for over 50 years; however, shortages could occur due to restrictions from environmental concerns, fuel cost, and weather conditions. Due to these factors, research continues to seek available materials as alternative substrate components. These studies evaluated processed eastern redcedar (*Juniperus virginiana* L.) as an alternative substrate in the greenhouse production of four annual species: petunia (*Petunia ×hybrida* Juss.), annual vinca [*Catharantus roseus* (L.) G. Don], wax begonia (*Begonia semperflorens-cultorum* Hort.), and plumed cockscomb (*Celosia argentea* L.). Three screen sizes of hammer-milled eastern redcedar (ERC) were used including 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.5 in). Plants were grown in peat moss amended with either 25 or 50% ERC (combinations of three screen sizes) and compared to a standard 80:20 peat:perlite mix. Plant growth was similar for petunia and vinca in 50% ERC (1.27 cm screen size) compared to those grown in 80:20 peat:perlite. Plants grown in 25% ERC were similar to plants grown in 80:20 peat:perlite mix for all species in all screen sizes. Root growth was similar to or greater for plants in substrates with 25% ERC when compared to the standard peat:perlite treatment. Amending peat with up to 25% eastern redcedar is an acceptable practice for the four annual species used in this study.

Index words: greenhouse, alternative substrates, perlite, container-grown.

Species used in this study: petunia (*Petunia ×hybrida* Juss. 'Dreams Pink', 'Dreams Rose'); annual vinca (*Catharanthus roseus* L. G. Don 'Cooler Hot Rose', 'Pacifica Blush'); wax begonia (*Begonia semperflorens-cultorum* Hort. 'Senator Rose', 'Senator Scarlet'); plumed cockscomb (*Celosia argentea* L. 'Kimono Red').

Significance to the Horticulture Industry

Potential shortages of peat moss (peat) for horticultural use have led to the evaluation of alternative substrates in greenhouse plant production. Concerns have also developed regarding perlite manufacturing and handling due to its propensity as an eye and lung irritant. Ideally, a perlite alternative substrate component would possess similar physical qualities, but without the dust. Our data show annuals grown in peat amended with 25% eastern redcedar (ERC) hammer-milled at 0.6, 1.0, and 1.3 cm (0.25, 0.38, and 0.5 in) screen sizes produced plants that were similar to those grown in a peat plus perlite substrate.

Introduction

Peat and perlite comprise most substrates in greenhouse annual production due to their ideal characteristics of water and nutrient retention, ease of handling, and light weight. Increased demand for peat has resulted in economic and environmental concerns, which have in turn, led to peat bog preservation efforts. Expected shortages have also been noted in previous years due to severe weather conditions (Short, P. 2012. President, Canadian Sphagnum Peat Moss Association. St. Albert, AB, Canada. Personal Communication. March 26, 2012). Perlite manufacturing and handling concerns have developed due to its dust, which is considered to be an eye and lung irritant (Polatli et al. 2001). These and other factors have led to an increased need for locally-available materials as alternative substrate components. Many alternative substrates composed of various plant materials have been evaluated in recent years (Boyer et al. 2008, Broussard et al. 1999, Fain et al. 2008, Griffin 2009, Murphy et al. 2011, Vandiver et al. 2011, Wright et al. 2006). Research evaluating high wood fiber substrates has shown positive potential with minimal adjustments made to traditional greenhouse fertilization and irrigation practices. Research has shown that substrate with 25% fresh cut eastern redcedar (ERC) (*Juniperus virginiana* L.) with a screen size of 0.6 cm (0.25 in) produced annual species (petunia, vinca, and impatiens (*Impatiens wallerana* Hook.f.) that were similar to those grown in a commercial standard substrate (75:25 peat:perlite) (Murphy et al. 2011).

Although ERC is found native in traditional hardwood forests, it has become a weed species throughout the Great Plains, Midwest, and Southern United States (Griffin 2009). Results in 1975 showed that two azalea species exhibited best growth from pine (*Pinus* spp.) shavings and second best growth from ERC shavings (Self 1975). Research has identified ERC chips (ground to 2.0 cm) as a viable amendment incorporated into a pine bark:sand substrate mixture for seedling growth of Chinese pistache (*Pistacia chinensis* Bunge) and Carolina buckhorn (*Frangula caroliniana* Walter) (Griffin 2009). Plants grown in 5, 20, and 40% ERC had similar plant height and shoot dry weight compared to plants grown in a 100% pine bark substrate. Starr et al. (2010a) evaluated silver maple (*Acer saccharinum* L.) seed propagation in varying ERC:sand:pine bark percentages. Substrates containing up to 20% ERC produced similar plant caliper, root dry weight, and shoot dry weight compared to plants grown in pine bark. In 2010, bald cypress [*Taxodium distichum* (L.) Rich.] growth was evaluated in pine bark:sand substrates amended with ERC (Starr et al. 2010b). Plant height between treatments were similar, but dry weights were lower in plants grown in 80% ERC due to higher porosity, lower container capacity, and higher air space. Starr et al. (2011) evaluated the effects of particle size on orange coneflower (*Rudbeckia fulgida* Alton) growth. Treatments consisted of five substrates using pine bark and hammer-milled ERC passed through 0.5, 1.0, 1,3, or 1.9 cm (0.19, 0.38, 0.50, 0.75 in) screen sizes. As particle size increased, shoot dry weight decreased, although plant size was similar among all ERC substrates except the 1.3 cm (0.50 in) screen size.

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[2]Graduate Research Assistant, Assistant Professor, Professor, Associate Professor, Professor, and Research Associate, respectively, Department of Horticulture, Auburn University, AL 36849

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ERC was a suitable substrate amendment for all four screen sizes evaluated; plants performed best in the 0.5 cm (0.19 in) screen size.

While existing studies have evaluated the growth of woody ornamentals in varying sizes of E, limited research has been done evaluating various screen sizes of ERC as an amendment to peat in greenhouse production of summer annuals. The objective of this study was to evaluate three screen sizes of ERC as an amendment to peat in the greenhouse production of four summer annual species.

Materials and Methods

ERC used in these studies was harvested from the Auburn Piedmont Research Station, Camp Hill, AL, on May 11, 2012. Trees were de-limbed at the time of cutting, using only the main tree trunk. Logs were chipped through a Vermeer BC1400XL (Vermeer Co., Pella, IA) chipper on May 15, 2012. ERC chips were processed through a swinging hammer-mill (Williams General Purpose Mill, Model 1518, Williams Patent Crusher & Pulverizer Co., St. Louis, MO) on May 16, 2012. Three screen sizes were used: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in).

Nine substrates were evaluated in this study including a growers standard of 80:20 (v:v) peat:perlite. Eight substrate treatments consisted of peat mixed with either 25 or 50% ERC by volume at screen sizes of 0.64, 0.95, or 1.27 cm (0.25, 0.38, or 0.50 in), or a 1:1:1 (v:v:v) mix of ERC from the three screen sizes. All substrates were amended with 2.7 kg·m^{-3} (4.0 lb·yd^{-3}) 18.0N-2.64P-9.96K (18-6-12) Polyon controlled-release fertilizer (3–4 month; Harrell's Fertilizer Inc., Lakeland, FL), 3.0 kg·m^{-3} (5.0 lb·yd^{-3}) dolomitic limestone, and 0.9 kg·m^{-3} (1.5 lb·yd^{-3}) Micromax (The Scotts Company LLC, Marysville, OH).

Four annual species were evaluated in a study initiated on June 27, 2012 (Experiment 1). Petunia [*Petunia ×hybrida* Juss. 'Dreams Pink'], annual vinca [*Catharanthus roseus* (L.) G. Don 'Cooler Hot Rose'], wax begonia [*Begonia semperflorens-cultorum* Hort. 'Senator Rose'], and plumed cockscomb (*Celosia argentea* L. 'Kimono Red') were planted into 1.4 L (1.5 qt) containers with two plugs (200 plug flat) per pot. Experiment 2, initiated on August 16, 2012, evaluated 'Dreams Rose' petunia, 'Pacifica Blush' annual vinca, and 'Senator Scarlet' wax begonia planted into 1.4 L (1.5 qt) containers with two plugs per pot (200 plug flat). Both studies were conducted at the Paterson Greenhouse Complex at Auburn University, AL. 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 Honest Significant Difference Test ($p \leq 0.05$) using SAS® Institute version 9.2 (Cary, NC). Physical properties [substrate air space (AS), water holding capacity (WHC), and total porosity (TP)] were determined using the North Carolina State University porometer method (n = 3) (Fonteno et al. 1995). 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 at 105C (221F) in a forced air oven for 48 hours (n = 3). Particle size distribution (PSD) was determined by passing 100 g sample [dried at 76.7C (170F) in a forced air oven for 120 hours] 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 petunia in order to determine substrate pH and electrical conductivity (EC) (n = 4) at 1, 14, 28, and 35 days after potting (DAP) for Experiments 1 and 2 and additionally at 45 DAP for Experiment 2. Irrigation water pH was measured 7 and 14 DAP for both experiments and ranged from 6.7 to 7.3. Experiment 1 was terminated 35 DAP, and Experiment 2 was terminated 45 DAP. Growth indices [(height + widest width + perpendicular width) ÷ 3; cm] were measured at termination (n = 8). Bloom count (BC) was counted at termination; only open blooms were counted towards BC total number (n = 8). Root growth ratings were assigned at study termination on a scale from 1 to 5, where 1 was assigned to plants with less than 20% visible root ball coverage, 2 to plants with 20–40%, 3 to plants with 40–60%, 4 to plants with 60–80%, and 5 was assigned to plants with 80–100% visible root ball coverage (n = 8).

Results and Discussion

Physical properties. Data herein are compared to established greenhouse crops optimal substrate physical property ranges for AS, TP, WHC, and BD (Jenkins and Jarrell 1989). In Experiment 1, substrate AS was lower than the optimal range (10 to 20%) for most treatments; observed values ranged from 5.1% (80:20 peat:perlite) to 13.4% (50% ERC from a mix of screen sizes) (Table 1). Only three substrates had AS within the recommended range: those containing 50% ERC from screen sizes of 0.95 cm (10.2%), 1.27 cm (10.7%) and a mixed screen sizes (13.4%). AS in Experiment 2 ranged from 3.9% (80:20 peat:perlite) to 11.6 % (50% ERC at 0.64 cm). Substrates containing 50% ERC from a 0.64 cm screen size and with mixed screen sizes had AS values within the optimal range (11.6 and 10.4%, respectively).

The WHC values of all treatments, including the peat:perlite standard were higher than the greenhouse crop WHC optimal range (Table 1). In Experiment 1, WHC ranged from 71.9% (50% ERC with mixed screen sizes) to 83.0% (80:20 peat:perlite). All four treatments containing 25% ERC had similar WHC values to the peat:perlite standard, while all four treatments containing 50% ERC had lower WHC values than the peat:perlite standard and ranged from 71.9% (50% ERC from mixed screen sizes) to 76.6% (50% ERC from a 0.64 cm screen size). Substrate WHC in Experiment 2 ranged from 72.3% (50% ERC from a 0.64 cm screen size) to 80.9% (25% ERC from mixed screen sizes). Substrate containing 50% ERC at a 0.64 cm screen size had a significantly lower WHC value than the peat:perlite standard, while WHC of all other substrates containing ERC were similar to the peat:perlite standard.

All substrates in both experiments had greater TP values than the recommended range of 60 to 75% (Table 1). In Experiment 1, all ERC substrates had similar TP values compared to 80:20 peat:perlite (88.2%). In Experiment 2, both ERC substrates from a 0.64 cm screen size were similar in TP to the 80:20 peat:perlite standard; all other treatments had higher TP values.

BD values for all treatments were understandably less than the recommended range for nursery substrates (0.19 to 0.70 g·cm^{-3}; Yeager et al. 2007) (Table 1). Substrate BD's in Experiment 1 were similar to 80:20 peat:perlite (0.116 g·cm^{-3}) among substrates containing 25% ERC with 0.95 cm, 1.27 cm, and a mixed screen sizes. All other substrates containing ERC had higher BD values. In Experiment 2, substrates containing 25% ERC at screen sizes of 0.64 and 0.95 cm had lower BD values than that for the 80:20 peat:perlite treat-

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Table 1. Physical properties[z] of nine substrates containing peat, perlite, and eastern redcedar.

Substrate[y]		Air space (% vol)[x]		Water holding capacity (% vol)[w]		Total porosity (% vol)[v]		Bulk density ($g \cdot cm^{-3}$)[u]	
% Redcedar	Screen size (cm)	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
25	0.64	5.4b[t]	7.9abc	81.9a	77.6a	87.4ab	85.5ab	0.1ab	0.1e
25	0.95	8.6ab	7.4abc	79.8ab	80.4a	88.4ab	87.8a	0.1abc	0.1e
25	1.27	8.4ab	8.3abc	81.3a	78.2a	89.7a	86.5a	0.1abc	0.1bc
25	mix[s]	7.8ab	5.8bc	82.3a	80.9a	90.1a	86.6a	0.1bc	0.1de
50	0.64	8.2ab	11.6a	76.6bc	72.3b	84.8ab	83.9ab	0.1a	0.2a
50	0.95	10.2ab	9.8ab	73.5cd	77.0a	83.7b	86.7a	0.1a	0.1b
50	1.27	10.7ab	9.5ab	74.5cd	77.7a	85.2ab	87.2a	0.1a	0.1bc
50	mix	13.4a	10.4ab	71.9d	76.8a	85.3ab	87.2a	0.1a	0.1de
80:20 Peat:Perlite		5.1b	3.9c	83.1a	77.5a	88.2ab	81.5b	0.1c	0.1cd
Recommended range for greenhouse substrates[r]		10–20%		50–65%		60–75%		N/A	
Recommended range for nursery crops[q]		10–30%		45–65%		50–85%		0.19–0.70	

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

[y]Substrates consisted of peat moss mixed with 25 or 50% eastern redcedar processed through three different screen sizes: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in). A grower's standard of 80:20 (v:v) peat:perlite was also included.

[x]Air space = volume of water drained from the sample ÷ volume of the sample.

[w]Water holding capacity = (wet weight – oven weight) ÷ volume of the sample.

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

[u]Bulk density after forced-air dyring at 105.0C (221.0F) for 48 hours; 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 Honest Significant Difference Test at $\alpha = 0.05$ (n = 3).

[s]Cedar Mix = an 1:1:1 (v:v:v) mix of each screen size.

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

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

ment (0.137 $g \cdot cm^{-3}$), while substrates containing 50% ERC at screen sizes of 0.64 and 0.95 cm had BD values higher than that of the peat:perlite treatment. All other substrates were similar in BD to the commercial standard.

Particle size distribution (PSD). PSD values were the same in Experiment 1 among all treatments for the distribution of particles left on the largest screen [9.50 mm (0.37 in)] and ranged from 0.3 to 1.4% (data not shown). Many differences occurred in the smaller screen sizes. Therefore, screen sizes were grouped into three categories: coarse [> 3.35 mm (> 0.13 in)], medium [> 1.00 to 3.35 mm (> 0.04 to 0.13 in)], and fine [0 to 1.00 mm (0 to 0.04 in)]. Coarse particles for all treatments ranged from 6.9 to 18.0% (Table 2). The 80:20 peat:perlite treatment, with 18.0% coarse particles, had a higher percentage of coarse particles than in all other

Table 2. Texture of nine substrates containing peat, perlite and eastern redcedar according to particle size distribution analysis[z].

Substrate[y]		Experiment 1			Experiment 2		
% Redcedar	Screen size (cm)	Coarse[x]	Medium	Fine	Coarse	Medium	Fine
25	0.64	12.1[w]bc[v]	33.1cde	54.8ab	10.2bcd	36.7d	53.1a
25	0.95	10.7bcd	37.5c	51.7b	12.3bc	37.8d	49.9ab
25	1.27	13.3b	35.0cd	51.7b	14.1b	39.1cd	46.8ab
25	mix[u]	8.6cd	31.5de	60.0a	11.8bcd	35.3d	53.0a
50	0.64	6.9d	43.2b	49.9bc	8.9cd	42.1c	49.0ab
50	0.95	7.1d	48.9a	44.0cd	11.0bcd	52.6a	36.5c
50	1.27	11.3bc	51.3a	37.4d	18.0a	54.7a	27.3d
50	mix	8.3cd	48.6a	43.1d	8.1d	47.4b	44.4b
80:20 Peat:Perlite		18.0a	29.2e	52.8b	18.4a	31.3e	50.3ab

[z]Particle size distribution determined before the addition of incoporated amendments by passing a 100g dry sample [76.7°C (170°F) forced air oven for 120 hours] 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]Substrates consisted of peat moss mixed with 25 or 50% eastern redcedar processed through three different screen sizes: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in). A grower's standard of 80:20 (v:v) peat:perlite was also included.

[x]Coarse = > 3.35 mm; Medium = 1.00 to < 3.35 mm; Fine = 0.00 to < 1.00mm.

[w]Percent weight of sample collected on each screen.

[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 = 3).

[u]Cedar Mix = a 1:1:1 (v:v:v) mix of each screen size.

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treatments. The peat:perlite standard also had the lowest percentage of medium size particles (29.2%). Substrates containing 25% ERC at a 0.64 cm and the mixed screen sizes had a similar percentage of medium size particles compared to the standard. Percentage of medium sized particles were highest for three treatments: 50% ERC from a 0.95 cm screen size (48.9%), 1.27 cm screen size (51.3%), and from mixed screen sizes (48.6%). The substrate containing 25% ERC from mixed screen sizes had the highest percentage of fine particle size (60.0%) and was the only substrate with a significantly higher percentage than the commercial standard. Treatments with similar percentages of fine particles to 80:20 peat:perlite (52.8%) included 25% ERC substrates from a 0.64 cm (54.8%), 0.95 cm (51.7%), and 1.27 cm screen sizes (51.7%) and the 50% ERC from a 0.64 cm screen size (49.9%).

In Experiment 2, PSD values were similar among all treatments for particles left in the 9.50 mm (0.37 in) screen size and ranged from 0.2 to 1.9% (data not shown). Total coarse particles ranged from 8.1% (50% ERC from mixed screen sizes) to 18.4% (80:20 peat:perlite). The 80:20 peat:perlite standard and 50% ERC from the 1.27 cm screen size treatment had similar percentages of coarse particles (18.4 and 18.0%, respectively), and both substrates had significantly higher percentages of coarse particles than all other substrates. Percentage of medium size particles was highest for 50% ERC from a 0.95 cm screen size (52.6%) and 1.27 cm screen size (54.7%) and least for 80:20 peat:perlite (31.3%). Percent fine particles in substrates containing 25% ERC ranged from 46.8% (1.27 cm screen size) to 53.1% (0.64 cm screen size), and all were similar in percent fine particles compared to the 80:20 peat:perlite (50.3%). The only two substrates with significantly lower percentages of fine particles than the 80:20 peat:perlite were 50% ERC substrates from a 0.95 cm screen size (36.5%) and from a 1.27 cm screen size (27.3%).

Percentage of coarse particle s in 80:20 peat:perlite was among the highest measured, while percentage of medium particles was among the lowest measured in both experiments (Table 2). The greater divide between coarse and medium sized particles resulted in very low AS values. Smaller particles were most likely nestled into spaces created by larger particles, thus decreasing pore size.

pH and EC. Optimal pH range for *Petunia ×hybrida* is between 5.40 and 5.80 (Cavins et al. 2005). In Experiment 1, at 1 DAP, pH values among all substrates were similar; all pH values (4.47 to 4.84) were below the optimum range (Table 3). At 14 DAP, pH values for all treatments had increased and were similar to the peat:perlite standard (5.98); those within the optimum range include 25% ERC substrates from the 0.64 cm (5.66) and 1.27 cm screen sizes (5.74). By 28 DAP, pH ranged from 5.89 (25% ERC from a mixed screen size) to 6.54 (50% ERC from a mixed screen size). The pH values of all treatments were higher than the recommended pH range at 28 DAP. All substrates containing 50% ERC had higher pH values than the peat:perlite standard. When Experiment 1 was terminated 35 DAP, pH values of all treatments were above the recommended range. All 25% ERC substrates had similar pH values to that for peat:perlite, while all 50% ERC substrates had higher pH values than that for peat:perlite.

In Experiment 2, all treatments had lower pH values 1 DAP than the recommended range (5.40 to 5.80; Table 3). Substrates with 50% ERC had similar to or higher pH values than peat:perlite (4.84), while all 25% ERC substrate pH values were less than the peat:perlite standard. At 14 and 28 DAP, all 50% ERC substrates had similar pH values to peat:perlite (5.68) and were in the recommended range for petunias. All 25% ERC substrates were below the recommended range 14 DAP, while only 25% ERC from a 0.64 cm screen size was within the recommended pH range 28 DAP. At 35 DAP, peat:perlite and all 50% ERC substrate pH values were above the recommended pH range, while all 25% ERC substrates except those from a 0.64 cm screen size were within the recommended range. When Experiment 2 was terminated 45 DAP, all 25% ERC substrates were within the recommended pH range, while all other substrates had higher than recommended values.

The recommended substrate EC range for *Petunia ×hybrida* is between 2.0 and 3.5 $mS \cdot cm^{-1}$ (Cavins et al. 2005). Initially, in Experiment 1, EC values were similar ranging from 2.88 (50% ERC from mixed screen size) to 4.98 (25% ERC from mixed screen size); only 50% ERC substrates from the 0.95 cm and mixed screen sizes were within the recommended range (Table 3). EC values at 14 DAP were similar to peat:perlite (3.31 $mS \cdot cm^{-1}$); only 25% ERC substrates with 1.27 cm and mixed screen sizes were higher than recommended EC values. By 28 DAP, EC values of all substrates had dropped below the optimum range. All ERC substrate EC values were similar to that of the peat:perlite standard (1.06 $mS \cdot cm^{-1}$). EC values for all treatments were similar and lower than optimal 35 DAP and ranged from 0.31 (25% ERC with 0.95 cm screen size) to 0.59 (peat:perlite). In Experiment 2, EC values were similar among all treatments for the duration of the experiment. At 1 DAP, only 50% ERC substrates from the 0.95 and 1.27 cm screen sizes were within the recommended range. By 14 DAP, the peat:perlite standard, all 50% ERC substrates, and the 25% ERC from the mixed screen size were within the recommended EC range. At 28, 35, and 45 DAP, all EC values were lower than the recommended range for all substrates.

Growth indices (GI). In Experiment 1, GI of petunia, vinca, and celosia grown in 25% ERC substrates were similar in size to plants grown in peat:perlite (Table 4). GI values for each of these species were lower among plants grown in 50% ERC compared to those grown in peat:perlite. Begonia grown in 25% ERC were larger [1.27 cm screen size (19.1) and mixed screen sizes (22.1)] or equivalent in size (0.64 and 0.95 cm screen sizes) to those grown in peat:perlite (15.6). All begonia grown in 50% ERC had similar or lower GI values than those grown in peat:perlite. In Experiment 2, five ERC substrates produced similar petunia growth as growth in peat:perlite. Substrates containing 25% ERC from a mixed screen size, 50% ERC from a 0.95 cm screen size, and 50% ERC from a 1.27 cm screen size (GI values of 21.6, 22.6, and 22.3, respectively) produced smaller plants than the peat:perlite standard (GI value of 27.0). Vinca growth was comparable for all substrates except 50% ERC from a 0.95 and 1.27 cm screen size which were both smaller than vinca grown in peat:perlite. All Experiment 2 substrates produced similar begonia growth indices to peat:perlite except 50% ERC from a 0.64 cm screen size.

Bloom count. In Experiment 1, the only substrate to produce a similar number of petunia blooms per plant compared to peat:perlite was 25% ERC from a 1.27 cm screen size

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Table 3. Effect of nine substrates containing peat, perlite, and eastern redcedar on pH and electrical conductivity (EC) measurements[z] in petunias.

Substrate[y]		pH								
		1 DAP[x]		14 DAP		28 DAP		35 DAP		45 DAP
% Redcedar	Screen size (cm)	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 2
25	0.64	4.73[ns]	4.30c[w]	5.66b	5.06b	6.07de	5.50ab	6.61bc	5.90abc	5.70cd
25	0.95	4.71	4.42c	5.83ab	4.93b	6.18bcde	4.97c	6.76abc	5.57c	5.75cd
25	1.27	4.73	4.40c	5.74ab	5.15b	6.14cde	5.10bc	6.59bc	5.59c	5.80bcd
25	mix[v]	4.47	4.32c	5.81ab	5.30ab	5.89e	5.30abc	6.46c	5.62bc	5.54d
50	0.64	4.59	5.07a	5.97ab	5.65a	6.44abc	5.62a	6.98a	6.01abc	6.25ab
50	0.95	4.71	4.96ab	6.11a	5.61a	6.49ab	5.60a	6.96a	6.00abc	6.38a
50	1.27	4.84	4.86ab	6.06ab	5.60a	6.39abcd	5.62a	6.91ab	6.09ab	6.48a
50	mix	4.84	4.77b	6.10a	5.58a	6.54a	5.74a	6.92ab	6.19a	6.29a
80:20 Peat:Perlite		4.82	4.84b	5.98ab	5.68a	6.10de	5.64a	6.44c	6.07ab	6.05abc
		EC (mS·cm^{-1})								
Substrate		1 DAP		14 DAP		28 DAP		35 DAP		45 DAP
% Redcedar	Screen size (cm)	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 2
25	0.64	4.02[ns]	4.27[ns]	3.77ab	3.94	0.57ab	0.38[ns]	0.43[ns]	0.36[ns]	0.51[ns]
25	0.95	3.87	3.69	3.38ab	4.44	0.97ab	1.03	0.31	0.45	0.48
25	1.27	4.70	4.02	5.03a	3.64	1.01ab	0.76	0.47	0.33	0.32
25	mix	4.98	4.56	4.15ab	2.65	1.48a	0.89	0.50	0.45	0.43
50	0.64	4.08	3.57	2.71b	3.38	0.83ab	0.78	0.35	0.46	0.50
50	0.95	3.39	3.29	3.15ab	2.88	0.59ab	0.89	0.32	0.41	0.43
50	1.27	4.68	3.41	2.80b	3.32	0.64ab	1.05	0.37	0.60	0.48
50	mix	2.88	3.80	2.10b	3.00	0.53b	0.64	0.37	0.34	0.40
80:20 Peat:Perlite		4.10	4.89	3.31ab	2.88	1.06ab	0.56	0.59	0.32	0.65

[z]pH and EC of solution determined using pour-through nutrient extraction procedure on petunia.

[y]Substrates consisted of peat moss mixed with 25 or 50% eastern redcedar processed through three different screen sizes: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in). A grower's standard of 80:20 (v:v) peat:perlite was also included.

[x]DAP = days after potting

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

[v]Cedar Mix = an 1:1:1 (v:v:v) mix of each screen size.

[ns]Means not significantly different.

Table 4. Effect of nine substrates containing peat, perlite, and cedar on growth indices of four greenhouse annual crops at experiment termination (35 DAP[z] for Exp. 1 and 45 DAP for Exp. 2).

Substrate[y]		Petunia		Vinca		Begonia		Celosia
% Redcedar	Screen size (cm)	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1[x]
25	0.64	29.8[w]a[v]	24.4abc	22.0abc	24.2abc	16.5bcd	23.8ab	17.5abc
25	0.95	28.8a	25.0abc	22.9ab	24.4abc	18.4bc	22.5abc	17.9abc
25	1.27	30.3a	25.5ab	22.6ab	24.9ab	19.1ab	24.3a	18.6a
25	mix[u]	27.8ab	21.6c	23.6ab	24.1abc	22.1a	21.4abc	18.5a
50	0.64	21.0c	23.8abc	21.0bcd	23.6abc	12.0f	16.5d	11.6d
50	0.95	23.4c	22.6bc	21.3bcd	23.1bc	13.6def	19.3bcd	13.3d
50	1.27	24.0bc	22.3bc	19.5cd	22.0c	15.3de	18.4cd	13.7cd
50	mix	21.2c	23.9abc	19.1d	23.8abc	12.3ef	19.4bcd	14.1bcd
80:20 Peat:Perlite		29.1a	27.0a	24.0a	25.9a	15.6cd	22.0abc	20.5a

[z]DAP = days after potting.

[y]Substrates consisted of peat moss mixed with 25 or 50% eastern redcedar processed through three different screen sizes: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in). A grower's standard of 80:20 (v:v) peat:perlite was also included.

[x]Celosia was not evaluated in Experiment 2.

[w]Growth index = [(height + widest width + perpendicular width) ÷ 3].

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

[u]Cedar Mix = an 1:1:1 (v:v:v) mix of each screen size.

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(Table 5). Petunias grown in 25% ERC had more blooms than those in 50% ERC substrates. In Experiment 2, only petunia grown in 25% ERC from a 0.95 cm screen size had a similar number of blooms as those grown in peat:perlite. All plants in the other treatments had fewer blooms than those growing in the commercial standard. Vinca in Experiment 1 grown in peat:perlite had more blooms per plant than all other treatments. Bloom count ranged from 2.9 to 3.9 blooms among plants grown in 25% ERC, while bloom count ranged from 0.6 to 2.2 blooms for those grown in 50% ERC. Results were similar in Experiment 2; all ERC substrates produced fewer blooms than peat:perlite (22.0). In Experiment 1, begonia plants grown in peat:perlite had the highest number of blooms. Number of blooms per begonia grown in 25% ERC ranged from 9.4 to 16.6, while those grown in 50% ERC ranged from 4.4 to 10 blooms per plant. In Experiment 2, all begonia grown in 25% ERC had similar number of blooms (6.3 to 9.9) as those grown in peat:perlite (10.0), while all begonia grown in 50% ERC substrates had fewer blooms (1.1 to 2.5) than those grown in peat:perlite. In Experiment 1, celosia grown in peat:perlite had more blooms than all other plants. Celosia grown in 50% ERC from a 0.64 cm screen size and mixed screen sizes had fewer blooms than celosia grown in any of the 25% ERC substrates. In general, bloom count tended to be lower among plants grown in 50% ERC substrates.

Root growth ratings. In Experiments 1 and 2, root growth ratings of petunia grown in ERC substrates were all similar to those grown in peat:perlite (Table 6). Vinca plants grown in 25% ERC in Experiments 1 and 2 had similar roots growth ratings to those grown in peat:perlite. In Experiment 1, vinca grown in 50% ERC had significantly lower root growth ratings than those grown in peat:perlite with the exception of plants grown in 50% ERC from a 1.27 cm screen size. In Experiment 2, vinca grown in 50% ERC from the 0.64 and 0.95 cm screen sizes had root growth ratings similar to those of peat:perlite, while those grown in 50% ERC from a 1.27 cm screen size and with a mix of screen sizes had lower root growth ratings. All begonia grown in 25% ERC had similar root growth ratings in Experiment 1 compared to plants grown in peat:perlite (5.0). Only one treatment among 50% ERC substrates (1.27 cm screen size) had similar root growth ratings compared to peat:perlite, while plants grown in the other 50% ERC substrates had lower ratings than those grown in peat:perlite. Begonia in Experiment 2 grown in ERC substrates had similar root growth ratings compared to plants grown in peat:perlite. Celosia grown in 25% ERC substrates had similar root growth ratings compared to peat:perlite (5.0) in Experiment 1, while plants grown in 50% ERC substrates had significantly lower root growth ratings.

In general, plants growth in ERC were similar to or greater than plants grown in 80:20 peat:perlite for all species in treatments containing 25% ERC at all screen sizes. Plants grown in 50% ERC were smaller than those grown in peat:perlite with a few exceptions. However, plants grown in ERC-amended substrates tended to have fewer blooms compared to those grown in peat:perlite with the exception of begonia grown in 25% ERC substrates in Experiment 2. Root growth ratings for all plants grown in 25% ERC-amended substrates were similar to those grown in peat:perlite for both experiments, however vinca, begonia, and celosia grown in 50% ERC tended to have lower root growth ratings. These results agree with the results reported by Murphy et al. (2011), where petunia and vinca were grown in substrates consisting of peat mixed with either 25 or 50% ERC at a 0.64 cm screen size and compared to a standard substrate consisting of 75:25 peat:perlite. In one experiment conducted by Murphy et al., petunia and vinca grown in 25% ERC were similar in size to those grown in 25% perlite. However, petunia grown in 50% ERC were smaller than those in grown in 25% perlite. Petunia grown in either ERC mix had fewer blooms than those grown in 25% perlite, while vinca grown in 50% ERC had fewer blooms than those grown in 25% perlite.

This work demonstrates that peat amended with 25% ERC at 0.64 cm, 0.95 cm, 1.27 cm, and mixed screen sizes will produce plants of the four greenhouse annuals used in this study comparable to ones grown in the standard peat peat:perlite mix. Such combinations will help address potential shortages of peat in the future.

Table 5. Effect of nine substrates containing peat, perlite, and eastern redcedar on number of blooms per plant of four greenhouse annual crops at experiment termination (35 DAP[z] for Exp. 1 and 45 DAP for Exp. 2).

Substrate[y]		Petunia		Vinca		Begonia		Celosia
% Redcedar	Screen size (cm)	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1[x]
25	0.64	13.4b[w]	16.0bc	2.9bc	13.7bc	10.4bcd	6.8abc	39.9b
25	0.95	13.1b	18.6ab	3.9b	14.7b	16.6b	7.1abc	39.7b
25	1.27	16.1ab	16.0bc	3.8b	12.6bc	15.4bc	9.9ab	41.2b
25	mix[v]	13.6b	14.4bc	3.9b	12.6bc	9.4bcd	6.3abc	39.9b
50	0.64	5.3c	15.9bc	0.6c	9.9bc	6.4cd	2.4c	18.3c
50	0.95	8.3c	14.0bc	0.8c	7.5c	6.6cd	1.5c	24.3bc
50	1.27	8.0c	13.1c	2.2bc	9.3bc	10.0bcd	2.5bc	26.1bc
50	mix	5.4c	13.0c	0.9c	9.5bc	4.4d	1.1c	20.1c
80:20 Peat:Perlite		19.0a	22.3a	8.1a	22.0a	26.3a	10.0a	60.6a

[z]DAP = days after potting.

[y]Substrates consisted of peat moss mixed with 25 or 50% eastern redcedar processed through three different screen sizes: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in). A grower's standard of 80:20 (v:v) peat:perlite was also included.

[x]Celosia was not evaluated in Experiment 2.

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

[v]Cedar Mix = an 1:1:1 (v:v:v) mix of each screen size.

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Table 6. Effect of nine substrates containing peat, perlite, and eastern redcedar on root growth ratings of four greenhouse annual crops at experiment termination (35 DAP[z] for Exp. 1 and 45 DAP for Exp. 2).

Substrate[y]		Petunia		Vinca		Begonia		Celosia
% Redcedar	Screen size (cm)	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1[x]
25	0.64	4.0ab[v]	4.6ab	4.0ab	4.7a	3.5abc	5.0a	4.1ab
25	0.95	4.1ab	4.3ab	5.0a	4.7a	3.8ab	4.9a	4.0ab
25	1.27	4.5a	4.6ab	4.6a	4.3ab	4.3a	4.9a	4.8a
25	mix[u]	3.1b	4.0b	4.5a	4.3ab	3.1abcd	4.6a	3.2abc
50	0.64	3.1b	5.0a	2.8b	4.1ab	1.5cd	3.5b	1.1d
50	0.95	3.5ab	4.9ab	3.1b	4.1ab	1.8bcd	4.5a	2.8bcd
50	1.27	4.0ab	5.0a	4.0ab	3.8b	3.1abcd	4.5a	1.3cd
50	mix	3.0b	4.8ab	2.8b	3.8b	1.3d	4.5a	2.3cd
80:20 Peat:Perlite		4.0ab	4.5ab	5.0a	4.8a	5.0a	4.1ab	5.0a

[z]DAP = days after potting.

[y]Substrates consisted of peat moss mixed with 25 or 50% eastern redcedar processed through three different screen sizes: 0.64, 0.95, and 1.27 cm (0.25, 0.38, and 0.50 in). A grower's standard of 80:20 (v:v) peat:perlite was also included.

[x]Celosia was not evaluated in Experiment 2.

[w]Root growth ratings assessed on a 1–5 scale (1 = less than 20% root ball coverage; 3 = 50% root ball coverage; 5 = 100% root ball coverage).

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

[u]Cedar Mix = an 1:1:1 (v:v:v) mix of each screen size.

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