Distilled Eastern Redcedar (*Juniperus virginiana* L.) as an Alternative Substrate in the Production of Greenhouse-Grown Annuals[1]

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Abstract

Peat moss is the main component used in soilless greenhouse substrates and is thus in high demand commercially. Due to both perceived 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. One example of these wood-based substrates is eastern redcedar (*Juniperus virginiana* L.). The objectives of these experiments were to evaluate post-distilled, milled eastern redcedar shavings, in varying volumetric concentrations, as a substrate component, and to compare its effectiveness to a grower's standard peat-lite mix. *Petunia ×hybrida* Vilm. 'Celebrity Blue' and *Impatiens walleriana* Hook.f. 'Extreme Violet' grown in substrates containing up to 40% eastern redcedar product had equal or greater growth index than in the standard peat-lite mix, although bloom count was reduced in one experiment. Therefore, growers could amend their substrates with up to 40% eastern redcedar shavings and see little to no change in marketable plant growth for these two annual species.

Index words: peat moss, perlite, peat-lite, greenhouse substrate.

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

Significance to the Horticulture Industry

Greenhouse substrates have been primarily peat based ever since the debut of Cornell peat-lite mixes in the 1960s (Boodley and Sheldrake 1982). 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 a financial strain for growers in an increasingly harsh economic time. Distilled eastern redcedar shavings that have been milled through a 1.27 cm (0.5 in) screen, could be a potential alternative/amendment for peat moss in greenhouse substrates. This cedar is a residual biomass leftover from the extraction of cedar oil that is produced by CedarSafe®, a company located in Huntsville, AL. Due to the research results from these trials, this biomass is currently being marketed as a potential proportional replacement to peat moss and perlite in standard greenhouse mixes. Growers with access to this operation, or others similar to it, could potentially incorporate this product into their business model and possibly 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 emerged as important components in soilless greenhouse substrates in the 1960s, and are still recognized as the basis for greenhouse substrates today. The reason for the long reign of PM and perlite can be attributed to their superior capability to produce marketable plants through the creation of optimal air space and water holding capacity, as 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 increasingly becoming scarce, leading to increased protection of remaining bogs. Extraction of PM requires clearing of all surface vegetation and site drainage. These methods, evaluated extensively in the United Kingdom in 2008, 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. PM 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 perlite. In recent years, research regarding alternative substrates has steadily increased with an emphasis on sourcing locally and regionally available 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 softwood and hardwood fiber-based alternative substrates (Boyer et al. 2008, Fain et al. 2008a, Fain et al. 2008b, Murphy et al. 2011, 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.) were ground to pass through a hammer mill fitted with a 0.48 cm (0.19 in) screen. 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 (fertigated). Fertilizer was

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applied in varying rates of a 20N–4.4P–16.6K (20-10-20) soluble fertilizer ranging from 50 to 400 mg·L^{-1} nitrogen (N). About 100 mg·L^{-1} N more fertilizer was required for PTS than PL to obtain similar growth in both experiments. Electrical conductivity (EC) values were higher for PL substrates than PTS substrates. This research showed 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). In a study by Fain et al. (2008a), WT was processed to pass a 0.48, 0.64, or 0.95 cm (0.19, 0.25, or 0.37 in) screen. The resulting three WT substrates were used alone or mixed with 20 or 50% (by vol) PM and compared to an industry standard mix of 8:1:1 (by vol) PM:vermiculite:perlite. 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 across all substrates for marigold. Petunias grown in the industry standard 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:PM substrate had less growth than plants in any 1:1 WT:PM or industry standard substrate. At 28 DAP, petunias grown in the industry standard substrate were also larger than those grown in any 4:1 WT:PM substrate; however, all plants were considered marketable. 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).

Additional research by Fain et al. (Fain et al. 2008b) evaluated WT substrates along with starter fertilizer (SF) 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 in combination with 20 or 50% (by vol) PM, and compared with an industry standard mix of 8:1:1 PM:vermiculite:perlite (by vol). A 7N–1.3P–8.3K (7-3-10) 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}). In general, petunia shoot dry weight (SDW) was highest 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. 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 (Fain et al. 2008b).

Clean Chip Residual (CCR) is a by-product of thinning pine plantations, and is 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 ageratum (*Ageratum houstonianum* Mill. 'Blue Hawaii'), salvia (*Salvia ×superba* L. 'Vista Purple'), and impatiens (*Impatiens walleriana* Hook.f. 'Coral' or 'White'). CCR, ground to two different particle sizes, was used alone, or in combination with 10 or 20% PM (by vol). These treatments were compared to control treatments containing pine bark (PB), and PB blends (10 and 20% PM, by vol). There were no differences in growth indices (GI) or SDW of ageratum. Salvia had the highest GI in substrates containing PB:PM and the largest impatiens were observed in PB-based substrates at one location. The GI of ageratum at another location 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 demonstrated 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 redcedar (C) as an alternative substrate component for PM has risen. In many parts of the United States, C is considered a weed species that will establish on unmanaged land and out-compete native grasses. Griffin et al. (2009) conducted a study where C was evaluated as a substrate in the production of woody plants. There were no visible signs of nutrient deficiencies, substrate shrinkage, or allelopathy associated with C. Therefore, C 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% C and observe little to no difference in plant growth of petunia, vinca or impatiens. Starr et al. (2011) showed that C chips could be incorporated into a substrate for container-grown rudbeckia (*Rudbeckia fulgida* var. *fulgida* L.). Chips milled through a 0.5 cm (0.2 in) screen performed the best when compared to a PB substrate. More recently, Edwards et al. 2014 evaluated processed C (milled to three different screen sizes) as a substrate amendment (at 25 or 50% by vol) in the production of four annual species (petunia, vinca, begonia and celosia). While growth of all annual species grown in 25% C was similar to, or larger than, that of those grown in the grower's standard, bloom count was negatively affected. In addition to the replacement of PM, the physical nature of C tends to add substrate porosity normally achieved with the addition of perlite. Therefore, we believe a reduction or elimination in the need for perlite might also be realized with the use of C as a substrate component.

The cedar used in these experiments was obtained from CedarSafe®, a company located in Huntsville, AL. CedarSafe® primarily exports cedar oil for use in the perfume industry and as a closet lining. Eastern redcedar logs 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 (0.5 in) screen. 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 evaluate the shoot growth, bloom count, and root growth, of two common annual species in substrates incorporated with distilled cedar in increasing percentages directly proportional to a peat-lite mix. All the treatments were compared to a standard greenhouse substrate mix 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 (the first initiated February 11, 2011; the second initiated April 15, 2011). In both experiments, debarked eastern redcedar logs were shaved, milled through a 1.27 cm (0.5 in) screen, and then processed through a steam distillation process where a percentage of oil was extracted (details proprietary to CedarSafe®). These post-distilled milled cedar shavings (ERC) were then used alone or in volumetric combination with an industry standard peat-lite (PL) base mix, consisting of 80% PM (Professional Grade, Berger Saint-Modesto, QC Canada) and 20% P (Coarse Premium Grade, Sun Gro Horticulture Distribution Inc., Bellevue, WA). Six treatments were evaluated: 100% PL, 20:80 ERC:PL, 40:60 ERC:PL, 60:40 ERC:PL, 80:20 ERC:PL, and 100% ERC. Substrate treatments were amended at mixing with: 2.26 kg·m^{-3} (5 lbs·yd^{-3}) lime (added only to PL base); 0.91 kg·m^{-3} (2 lbs·yd^{-3}) starter nutrient charge (7N-1.3P-8.3K, or 7-3-10, Greencare Fertilizers Inc., Kankakee, IL), 0.45 kg·m^{-3} (1 lb·yd^{-3}) Micromax (The Scott's Company LLC, Marysville, OH), 0.45 kg·m^{-3} (1 lb·yd^{-3}) gypsum (added only to 100% ERC), and 2.72 kg·m^{-3} (6 lbs·yd^{-3}) slow-release fertilizer (13N-2.6P-13.3K, or 13-6-16, Harrell's LLC, Lakeland, FL). A wetting agent, Aqua-Gro L (Aquatrols Corporation, Paulsboro, NJ), was added at 118.3 mL·m^{-3} (4 oz·yd^{-3}). Containers, 1.2 L (0.32 gal) (06.00AZ COEX, Dillen Products, Middlefield, OH), were filled with the substrates and planted with two plugs [200 cell flat] of either 'Extreme Violet' impatiens or 'Celebrity Blue' petunia. 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. Each species was treated as its own experiment. Data were analyzed using Tukey's Studentized Range Test ($P \leq 0.05$) (SAS Institute version 9.1, Cary, NC). Experiment 1 (Expt 1) was terminated on March 25, 2011 (42 DAP), and Experiment 2 (Expt 2) was terminated on July 29, 2011 (35 DAP).

Physical properties, including initial substrate airspace (AS), container capacity (CC), and total porosity (TP) were determined using the North Carolina State University porometer method (n = 3) (Fonteno and Hardin 1995). Bulk density (BD) (g·cm^{-3}) was determined from 347.5 cm^3 (21.2 in^3) samples dried in a 105 C (221 F) forced air oven for 48 hours (n = 3). Particle size distribution (PSD) was analyzed by passing three 100 g air-dried samples of each treatment through a series of sieves (n = 3). Sieves were shaken for three minutes with a Ro-Tap (Ro-Tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations·min^{-1}, 159 taps·min^{-1}). Initial substrate pH and electrical conductivity (EC) (Accumet Excel XL50, Fisher Scientific, Pittsburgh, PA) were evaluated through collected leachates using the pour-through method on petunia only (n = 4) (Wright 1986). Subsequent pH and EC analyses were conducted at 28 and 35 days after planting (DAP) (Expt 2), or 28 and 42 DAP (Expt 1). At 35 (Expt 2) or 42 DAP (Expt 1), each plant's height and perpendicular widths (cm) were recorded, and the mean was used to determine growth index (GI) [(height + width1 + width2) / 3] (n = 12). Bloom count (BC) for each plant was also recorded (flowers and buds showing color) at study termination (42 DAP for Expt 1 and 35 DAP for Expt 2) (n = 12). Termination data also included a visual root rating (RR), where roots were visually inspected and rated on a scale of 0 (no visible roots) to 5 (roots visible over the entire substrate surface) (n = 8). Following collection of all termination data, shoots were removed at substrate surface, oven dried at 70 C (158 F) and weighed to determine shoot dry weight (SDW) (n = 8).

Results and Discussion

Physical properties. The substrates in these experiments were evaluated with the AS, CC, and TP recommendations (AS, 10–20%; CC, 50–65%; TP, 60–75%) from Jenkins and Jarrell (1989). Treatments containing higher amounts of ERC had higher AS (up to 32.1% AS in Expt 1 and 35.9% AS in Expt 2), and lower CC (down to 50.2% in Expt 1 and 50.1% in Expt 2) (Table 1). These findings are consistent with research by Starr et al. (2011), who also reported that substrates containing ERC tended to have a higher AS and lower CC when compared to an industry standard substrate. In both experiments, AS increased as percentages of ERC increased, with the exception of 20% ERC (4.7% AS in Expt 1; 4.4% AS in Expt 2). This could be due to the small amount and size of ERC particles filling the pore space of the 80% PL and forming a substrate with a lower percentage of available AS. Expt 1 AS percentages for 60% ERC (15.9%) and 80% ERC (20.0%) and Expt 2 AS percentages for 40% ERC (12.7%) and 60% ERC (20.3%), were all within the recommended range of 10 to 20%. The CC for both experiments tended to decrease with increasing percentages of ERC. 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 anywhere between 60 and 100% ERC had CC percentages that were within the recommended range of 50 to 65%. All other substrates had CC percentages that were higher than the recommended range. All of the substrates for both experiments possessed TP values that were higher than the recommended range of 60 to 75%. The TP of all treatments in a study conducted by Murphy et al. (2011), were also higher than the recommended range. However, all TP means were statistically similar in Expt 1, and all ERC-amended substrates in Expt 2 were statistically similar to the 100% PL substrate, although there were some minor differences between ERC-amended substrates. For Expt 1, BD tended to increase with increasing percentages of ERC, up to 60% ERC in Expt 1 (0.18 g·cm^{-3}), and 20% ERC in Expt 2 (0.15 g·cm^{-3}), at which point additional percentages of ERC had no effect on BD (Table 1). The BD of all treatments in both experiments were lower than the recommended range for nursery crops of 0.19 to 0.24 g·cm^{-3} (Yeager et al. 2013). The BD of eastern redcedar substrates for Murphy et al. (2011) were also lower than the recommended range set by Yeager et al. (2013).

Particle size distribution. For ease of interpretation, the authors have chosen to group the spread of PSD across three distinct categories: coarse particles (3.35–9.50 mm), medium particles (1.00–2.36 mm), and fine particles (0.00–0.50 mm) (Table 2). In Expt 1, substrates containing higher percentages of ERC (higher than 60% ERC) possessed larger amounts of coarse and medium particles; however, they contained lower amounts of fine particles (Table 2). In Expt 2, all substrates

Table 1. Physical properties of six substrates with varying volumetric contents of peat-lite and cedar[z].

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

[z]Analysis performed using the NCSU porometer method. Fonteno, et al., 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer.

[y]Air space = volume of water drained from the sample / volume of the sample.

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

[w]Total porosity = container capacity / air space.

[v]Bulk density after drying [105°C (221°F) forced air oven for 48 hours]; (g·cm-3 = 62.4274 lb·ft-3).

[u]Peat-lite base mix consists of 80% peat moss (Professional Grade, Berger Saint-Modesto, QC Canada) and 20% perlite (Coarse Premium Grade, Sun Gro Horticulture Distribution Inc. Bellevue, WA).

[t]ERC — Distilled eastern redcedar shavings milled through 1.27 cm (0.5 in) screen.

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

[ns]Means not significantly different.

possessed similar amounts of coarse particles. Nevertheless, the substrates containing higher percentages of ERC (more than 40% ERC) had greater amounts of medium particles when compared to substrates with greater PL content (more than 40% PL). As was seen in Expt 1, substrates containing lower amounts of ERC in Expt 2 possessed higher amounts of fine particles.

pH and EC. The recommended range for pH of *Petunia ×hybrida* is between 5.5 and 6.0 (Kessler 1998). Initial pH

Table 2. Particle size distribution analysis[z] of six substrates containing PL[y] and ERC[x], expressed as a percent by volume.

U.S. standard sieve no.	sieve opening (mm)[w]	Substrates											
		Experiment 1						Experiment 2					
		100% PL	20:80 ERC:PL	40:60 ERC:PL	60:40 ERC:PL	80:20 ERC:PL	100% ERC	100% PL	20:80 ERC:PL	40:60 ERC:PL	60:40 ERC:PL	80:20 ERC:PL	100% ERC
1/4	6.35	0.0c[v]	0.5abc	0.4bc	0.6abc	0.9ab	1.3a	0.0[ns]	0.0	0.0	0.2	0.3	0.0
6	3.35	6.1c	6.4c	7.4bc	8.5ab	9.9a	9.9a	12.2[ns]	12.0	9.4	8.0	7.7	9.3
8	2.36	8.4d	9.6cd	10.9bc	12.0ab	13.5a	14.0a	9.5c	11.3bc	12.4bc	12.9b	14.4ab	16.3a
10	2.00	3.7d	4.7d	6.0c	6.6bc	7.6ab	8.1a	3.5e	4.8d	6.0c	7.9b	9.0a	9.3a
14	1.40	9.2f	11.7e	14.2d	16.9c	18.4b	19.6a	7.8d	13.5c	15.3c	19.2b	21.5a	22.9a
18	1.00	9.7d	10.7c	13.3b	14.1b	15.4a	15.9a	7.8d	12.5c	12.7c	14.2b	15.7a	15.6a
35	0.50	24.9a	22.9b	23.3ab	20.6c	19.0cd	17.8d	18.5b	23.7a	18.6b	17.1bc	16.2bc	15.3c
60	0.25	22.7a	20.0b	15.4c	13.3c	10.0d	8.8d	24.1a	14.5b	15.9b	12.5bc	9.5cd	6.8d
140	0.11	11.8a	10.2a	6.9b	5.7bc	3.9cd	3.5d	14.1a	5.9bc	8.0b	6.7bc	4.3c	3.2c
270	0.05	2.6a	2.3a	1.5b	1.3bc	0.9cd	0.8d	2.0a	1.3ab	1.3ab	0.9b	1.1b	1.0b
pan	0.00	0.9a	0.9a	0.6b	0.5b	0.4bc	0.3c	0.5[ns]	0.6	0.2	0.2	0.5	0.4
Texture[u]													
Coarse		6.1d	6.9cd	7.9bc	9.1b	10.8a	11.3a	12.0[ns]	12.0	9.4	8.2	8.1	9.3
Medium		31.0e	36.7d	44.4c	49.5b	54.8a	57.5a	28.7d	42.0c	46.5c	54.2a	60.5a	64.1a
Fine		62.9a	56.4b	47.7c	41.4d	34.4e	31.2e	59.1a	46.0b	44.1b	37.5cd	31.5cd	26.7d

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

[y]PL = peat-lite. Peat-lite base mix consists of 80% peat moss (Professional Grade, Berger Saint-Modesto, QC, Canada) and 20% perlite (Coarse Premium Grade, Sun Gro Horticulture Distribution Inc., Bellevue, WA).

[x]ERC — Distilled eastern redcedar shavings milled through 1.27 cm (0.5 in) screen.

[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 Honest 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. Effects of six substrates on pH and EC[z] of *Petunia ×hybrida* Vilm. 'Celebrity Blue' in both experiments[y].

	Experiment 1					
	0 DAP[x]		28 DAP		42 DAP	
Substrate	pH	EC ($mS \cdot cm^{-1}$)[w]	pH	EC (mS·cm-1)	pH	EC ($mS \cdot cm^{-1}$)
100% Peat-lite	4.38ab[u]	2.24ab	5.72ab	0.62b	5.48b	0.35[ns]
20:80 ERC:Peat-lite[v]	4.19abc	2.37a	5.58b	1.33ab	5.27b	0.74
40:60 ERC:Peat-lite	4.15bc	2.56a	5.74ab	0.90ab	5.45b	0.54
60:40 ERC:Peat-lite	4.10c	2.39a	5.81ab	1.22ab	5.44b	0.54
80:20 ERC:Peat-lite	4.24abc	1.66b	5.81ab	1.40a	5.61ab	0.40
100% ERC	4.44a	1.62b	6.09a	1.14ab	6.07a	0.35

	Experiment 1					
	0 DAP		28 DAP		35 DAP	
Substrate	pH	EC ($mS \cdot cm^{-1}$)	pH	EC (mS·cm-1)	pH	EC ($mS \cdot cm^{-1}$)
100% Peat-lite	4.98ab	2.27[ns]	5.27b	1.13[ns]	5.11bc	0.96a
20:80 ERC:Peat-lite	4.99ab	2.55	5.04b	1.27	4.86c	0.82ab
40:60 ERC:Peat-lite	4.83ab	2.40	5.40b	1.06	5.08bc	0.77ab
60:40 ERC:Peat-lite	4.65b	2.29	5.40b	0.71	5.23b	0.48ab
80:20 ERC:Peat-lite	4.73ab	2.03	5.53ab	1.74	5.28b	0.48ab
100% ERC	5.10a	1.98	5.98a	0.49	5.87a	0.43b

[z]EC = electrical conductivity.

[y]pH and EC of solution determined using pour-through method.

[x]DAP = days after planting.

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

[v]ERC — Distilled eastern redcedar shavings milled through 1.27 cm (0.5 in) screen.

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

[ns]Means in column not significantly different.

measurements (at 0 DAP) for both experiments were below that range (4.10–4.44 in Expt 1; 4.65–5.10 in Expt 2) (Table 3). Additionally, increasing amounts of ERC tended to have no effect on pH initially, as pH in the 100% PL substrate was statistically similar to the 100% ERC substrate for both experiments. By 14 DAP, pH in Expt 1 had increased an average of 14%, although all values (4.78–4.89) were still less than the recommended range. On average, values for pH in Expt 2 only increased approximately 5.3% from 0 DAP to 14 DAP, and only the 100% ERC (5.84) substrate was within the recommended range at 14 DAP. The 100% ERC substrate stayed within the recommended range for the remainder of Expt 2. By 28 DAP in Expt 1, pH values had risen to within the recommended range, and even slightly above the range for the 100% ERC substrate (6.09). At study termination, pH values across both experiments tended to be slightly higher in substrates with high percentages of ERC, although the authors consider all pH values to be acceptable, and a non-contributing factor to any differences in plant growth.

The recommended range for substrate EC following planting of *Petunia ×hybrida* is between 1.0 and 1.5 $mS \cdot cm^{-1}$ (Kessler 1998). The initial EC values for substrates in Expt 1 were between 1.62 (100% ERC) and 2.56 $mS \cdot cm^{-1}$ (40:60 ERC:PL). Values for all substrates were statistically similar to the 100% PL substrate (2.24 $mS \cdot cm^{-1}$) at 0 DAP in Expt 1. By 28 DAP in Expt 1, EC values had lowered, but were mostly within the recommended range of 1.0 to 1.5 $mS \cdot cm^{-1}$ with the exceptions of 100% PL at 0.62 $mS \cdot cm^{-1}$ and 40:60 ERC:PL at 0.90 $mS \cdot cm^{-1}$. By study termination in Expt 1 (42 DAP), there were no statistical differences among any treatments. In Expt 2, no differences were noted between any substrates at 0 DAP, and values ranged between 1.98 (100% ERC) and 2.55 (20:80 ERC:PL). In Expt 2, final EC values were mostly similar, with only the 100% PL substrate (0.96 $mS \cdot cm^{-1}$) and the 100% ERC substrate (0.43 $mS \cdot cm^{-1}$) differing from one another.

Growth indices. In Expt 1, petunia grown using substrates containing 20% ERC had 10% higher GI (31.1) than the 100% PL (28.4) (Table 4). Furthermore, plants grown using the 100% ERC substrate had 35% lower GI (20.2) than the 20% ERC substrate (31.3). In addition, GI was similar for the 40% ERC (29.5) and 60% ERC (26.9) substrates compared to the 100% PL control (28.4). For impatiens in Expt 1, there was no difference between 20 and 40% ERC (26.0, 25.0) substrates when compared to the 100% PL (26.5) substrate for GI. The GI for impatiens grown in the 60% ERC (21.9) substrate were only slightly lower (12%) than the 40% ERC (25.0) substrate. Starr et al. (2010) observed similar results, in that plants grown in substrates containing up to 40% eastern redcedar had GI comparable to the control treatment. Murphy et al. (2011) had observed comparable GI to the control (75:25 PM:P) in substrates containing up to 50% eastern redcedar in the authors' first experiment. In their second experiment, substrates containing 25% eastern redcedar were similar to the control. The GI for petunia in Expt 2 indicated that there was no difference found between the 20% ERC (35.4) substrate, the 40% ERC substrate (33.6), and the 100% PL control (35.8). However, there was a 22% decrease in GI when comparing the 20% ERC (35.4) and

Table 4. Effect of six substrates on growth index[z], bloom count[y], root rating[x], and shoot dry weight[w] of two greenhouse grown annuals[v].

	Petunia ×hybrida							
	Growth index		Bloom count		Root rating		Shoot dry weight	
Substrate	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
100% Peat-lite	28.4b[t]	35.8a	32.9a	60.1b	4.4a	4.1a	12.1ab	12.2ab
20:80 ERC:Peat-lite[u]	31.3a	35.4a	30.6ab	69.7a	4.5a	4.1a	13.4a	12.9a
40:60 ERC:Peat-lite	29.5ab	33.6ab	25.4bc	63.6ab	4.4a	3.8a	11.5ab	10.6b
60:40 ERC:Peat-lite	26.9bc	30.9bc	23.2c	49.5c	4.4a	2.6b	9.6bc	8.3c
80:20 ERC:Peat-lite	24.6c	29.2cd	20.4c	42.0cd	3.5a	2.8b	7.2c	7.1cd
100% ERC	20.2d	27.6d	13.7d	36.9d	1.6b	1.3c	3.9d	5.7d

	Impatiens walleriana							
	Growth index		Bloom count		Root rating		Shoot dry weight	
Substrate	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
100% Peat-lite	26.5a	28.3a	60.8a	68.3a	4.5a	4.5[ns]	10.6a	13.3a
20:80 ERC:Peat-lite[v]	26.0a	28.6a	46.7b	68.0a	4.4a	4.9	8.6b	12.9a
40:60 ERC:Peat-lite	25.0a	28.0a	46.4b	63.9a	4.1a	5.0	7.3c	11.8a
60:40 ERC:Peat-lite	21.9b	26.9a	35.1c	49.0b	4.4a	5.0	5.4d	9.2b
80:20 ERC:Peat-lite	18.8c	24.1b	22.9d	41.7b	3.5b	5.0	3.3e	6.5c
100% ERC	16.9c	22.1c	19.6d	28.8c	2.5c	5.0	2.6e	4.6d

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

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

[x]Root growth assessed on 1–5 scale (1 = less than 20% root ball coverage; 5 = between 80–100% root ball coverage); (n = 8).

[w]Dry weights (g) determined by drying the above-soil portion of the plant in a 76.7 C (170.0 F) forced air oven for 72 hours; (n = 8).

[v]Data for Expt. 1 taken at 42 days after planting; Data for Expt. 2 taken at 35 days after planting.

[u]ERC — Distilled eastern redcedar shavings milled through 1.27 cm (0.5 in) screen.

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

[ns]Means in column not significantly different.

100% ERC (27.6) substrates. Impatiens in Expt 2 grown in up to 60% ERC were similar in size to those grown in the 100% PL standard (28.3).

Bloom count. Petunia BC was similar when comparing the 100% PL control (32.9) with the 20% ERC (30.6) substrate (Table 4). However, BC was reduced 22 to 58% with 40 to 100% ERC in Expt 1 (40% ERC, 25.4; 60% ERC, 23.2; 80% ERC, 20.4; and 100% ERC, 13.7) when compared to the 100% PL control (32.9). Impatiens BC was similar for the 20% ERC (46.7) and 40% ERC (46.4) treatments in Expt 1. However, they had 24% less blooms than the 100% PL standard (60.8). All other treatments displayed a 42 to 60% reduction in BC compared to the 100% PL standard. Petunia BC in Expt 2 indicated that the 20% ERC substrate (69.7) had 16% higher BC than the 100% PL control (60.1). Petunia BC for 20% ERC (69.7) and 40% ERC (63.6) in Expt 2 were similar; however, there was a 22% decrease from 40% ERC (63.6) to 60% ERC (49.5).

Root rating. The RR for petunia in Expt 1 were similar among all treatments with the exception of the 100% ERC substrate (1.6), where a 53% decrease in RR from the 80% ERC substrate (3.5) was observed (Table 4). Impatiens RR in Expt 1 were similar to the 100% PL control (4.5) in substrates containing 20 to 60% ERC (20% ERC, 4.4; 40% ERC, 4.1; 60% ERC, 4.4). Murphy et al. (2011) observed that root growth was comparable to the control treatment in up to 50% eastern redcedar substrates for the three annual species tested (petunia, vinca, impatiens). Petunia RR in Expt 2 were similar and highest in substrates containing 60% or higher amounts of PL (60% PL, 3.8; 80% PL, 4.1; 100% PL, 4.1). The 100% ERC substrate (1.3) had the lowest RR for petunia in Expt 2. Results for impatiens in Expt 2 were slightly different, in that all substrates were similar.

Shoot dry weight. Petunia SDW for Expt 1 were similar when comparing 20 and 40% ERC to the 100% PL treatment (Table 4). Impatiens SDW were highly variable amongst treatments. Substrates containing 20% ERC had 19% lower SDW than the control. The SDW for plants grown in 40% ERC were 15% lower than 20% ERC substrates. The values decreased with an increasing rate of ERC. For petunia, plants grown in 20% ERC had 6% higher SDW than the control. There was a 64% decrease in SDW when comparing plants in the 20% ERC and 100% ERC substrates.

For both experiments, petunias and impatiens grown in substrates containing 20% and 40% ERC were generally of equal, if not greater, size and quality than those grown in the standard peat-lite mix. Post-distilled milled eastern redcedar shavings provided by CedarSafe® would be an acceptable alternative component for greenhouse substrates replacing portions of PM and perlite.

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