Production and Landscape Establishment of Nursery Crops in Eastern Redcedar-Amended Substrates[1]

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Abstract

Substrate material used for the purpose of growing ornamental plants in the Great Plains is generally shipped a significant distance, primarily from the Southeastern United States. Eastern redcedar (*Juniperus virginiana*; ERC) chips have been identified as a possible alternative to pine bark (PB) for nursery substrates. Landscape establishment of *Ulmus parvifolia* 'Emer II' (elm), *Rosa* 'Radtkopink' (rose), *Ilex glabra* 'Compacta' (holly), *Miscanthus sinensis* 'Little Kitten' (maiden grass), *Gaillardia ×grandiflora* (blanket flower), *Sedum* 'Autumn Fire' (sedum), *Hosta* 'Sum and Substance' (hosta), and *Hemerocallis* 'Charles Johnston' (daylily) plants were grown in three substrate mixes. Substrate mixes were composed of 80:20 PB:sand (PBS), 40:40:20 PB:ERC:sand (PBERCS) or 80:20 ERC:sand (ERCS) (by vol). The study was split into production and landscape phases. During the production phase, pH and EC were among the parameters measured. For both phases of the study, growth index (GI), SPAD, caliper and shoot- and root dry weight were measured. At the end of the production phase, differences in growth were observed in elm, holly, and maiden grass where substrates containing PB or a mixture of PB:ERC resulted in greater growth over a primarily ERC-based substrate. Sedum also exhibited growth differences, with plants growing larger in ERCS as a production substrate. At the conclusion of the landscape establishment phase, there were no observed differences in growth for tested species with the exception of holly and hosta which grew best if produced in PBS and/or PBERCS prior to transplanting based on shoot- and root dry weights as well as GI on most evaluation dates. The majority of species in this study overcame any growth shortages present at the end of production within the first growing season in the landscape. Therefore, ERC is a viable substrate option for producing and planting many nursery crops, though it is advisable for each nursery to evaluate their particular crops for production in alternative substrates.

Index words: media, sustainable, local, *Juniperus virginiana* L.

Species used in this study: 'Allee®' lacebark elm (*Ulmus parvifolia* Jacq. 'Emer II'), Double Pink Knockout® rose (*Rosa* L. 'Radtkopink'), inkberry holly (*Ilex glabra* A. Gray 'Compacta'), 'Little Kitten' maiden grass (*Miscanthus sinensis* Andersson 'Little Kitten'), blanket flower (*Gaillardia ×grandiflora* hort.), 'Autumn Fire' sedum (*Sedum spectabile* 'Autumn Fire'), 'Sum and Substance' hosta (*Hosta* Tratt. 'Sum and Substance'), and 'Charles Johnston' daylily (*Hemerocallis* L. 'Charles Johnston').

Significance to the Horticulture Industry

Pine bark (PB) availability has become inconsistent due to factors such as increased shipping costs and demand from other industries. Increasing the options for local, sustainable substrate alternatives across the United States is important. A local and sustainable alternative to PB in the Great Plains region of the U.S. is eastern redcedar (ERC) chips. Eastern redcedar is a native tree in the Great Plains and has become known as a 'weedy species' due to a lack of natural controls. Using ERC as a substrate, nursery growers can reduce substrate costs and increase local sustainability. In this study, ERC as a substrate component was evaluated for effects on eight plant species during production and after being planted into the landscape. At the conclusion of the study, most species that were first grown in 80:20 ERC:sand (ERCS) grew similarly to plants grown in 80:20 PB:sand (PBS) or 40:40:20 PB:ERC:sand (PBERCS) after field planting for one year. These results indicate that nursery growers should consider using ERC as a substrate component if it is available in their region.

[1]Received for publication November 8, 2013; in revised form June 9, 2014. This research was supported by the United States Department of Agriculture – Agriculture Research Service – Floriculture and Nursery Research Initiative, James L. Whitten Building 1400 Independence Ave., S.W. Washington, DC 20250. Contribution no. 14-164-J from the Kansas Agricultural Experiment Station.

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Introduction

Pine bark (PB) has been used for many years as a substrate component for nursery crop production. Since the 1970s, PB has become the industry standard in many regions of the U.S. for growing plants in containers, however Penick (1980) noted that by the year 2020 PB could become a desired resource by two main industries: horticulture and fuel. Due to increased shipping costs and demand from other industries (Lu et al. 2006), PB is becoming more difficult to locate and purchase, particularly in the Great Plains region of the U.S. (Boyer et al. 2012a; Murphy et al. 2010). The need to find alternatives is important in the Great Plains region where no native pine stands are available for harvest necessitating that PB supplies be shipped long distances, raising costs for growers. These issues have accelerated the need to find alternative substrates for nursery crop production.

Several studies have evaluated wood-based substrate component alternatives for PB such as clean chip residual from pine (primarily loblolly pine, *Pinus taeda* L.; CCR) and pine tree substrates (Boyer et al. 2012b; Jackson et al. 2008; Murphy et al. 2010). In a study by Murphy et al. (Murphy et al. 2010) CCR and whole tree from pine (primarily loblolly pine; WT) substrates were evaluated as alternatives to PB for woody nursery crops. The authors reported no difference in growth for six ornamental taxa when PB was amended with up to 75% alternative wood-based substrate.

Eastern redcedar (*Juniperus virginiana* L., ERC) is abundant throughout the Great Plains region, where it is considered a weedy tree species. Eastern redcedar has become a native invasive species because of the lack of natural controls such as livestock grazing and wildfires (Difei and Hiziroglu 2010; Star et al. 2012; Stritzke and Rolins 1984). It has been estimated that 762 acres per day in Oklahoma are lost to ERC invasion, with an economic loss of $447 million by 2013 (Drake and Todd 2002). With this rapid encroachment of ERC into fields and grasslands, a small tree cutting industry has developed to help reduce the spread of ERC (Griffin 2009). Once harvested, ERC is allowed to dry for six months to one year before grinding into a size appropriate for landscape mulch. Eastern redcedar chips produced from the grinding process have the potential to be used as an alternative substrate (Star et al. 2012). However, not all ERC trees are processed; most are cut and left in the field because the demand is too small to justify grinding [Don Queal, Queal Enterprises (timber services), personal communication, 2012. Pratt, KS].

A study conducted by Griffin (2009) suggested that ERC chips could be used as an alternative substrate. Eastern redcedar was mixed with PB and 20% sand at six different ratios 0, 5, 10, 20, 40, and 80% (by vol). Seedlings of Chinese pistache (*Pistacia chinensis* Bunge) and Indian-cherry [*Frangula caroliniana* (Walter) A. Gray] were planted and after 20 weeks, growth data were collected. Plants grown in 10 and 80% ERC had less shoot growth than plants grown in other treatments. The author did not speculate on the reason for reduced growth in 10% ERC. In this study two fertilization rates were evaluated (low and high). The high fertilization treatment resulted in improved root growth in 40 and 80% ERC substrates. Research with ERC continued in a study by Starr et al. (2013) where 100% ERC and 100% hedge-apple (*Maclura pomifera* (Raf.) C.K. Schneid) substrates were evaluated as alternatives to PB when growing black-eyed susan (*Rudbeckia fulgida* Aiton var. *fulgida* Cronquist), 'Graziella' maiden grass (*Miscanthus sinensis* Andersson 'Graziella'), 'Arapaho' crapemyrtle (*Lagerstroemia* L. ×'Arapaho'), baldcypress (*Taxodium distichum* (L.) Rich.), and redbud (*Cercis canadensis* L.). In this study, shoot dry weight and plant growth indices decreased as ERC particle size increased. This result was attributed to low container capacity (water-holding capacity) (CC) and high air space (AS). The authors noted that all plants grown in ERC were marketable, except for crapemyrtle.

Three low-value tree species including sweetgum (*Liquidambar styraciflua* L.), hickory (*Carya sp.* Nutt.), and ERC were evaluated along with WT as potential amendments to a standard peat/perlite mix (Murphy et al. 2011). Three bedding plant species including 'Dreams Sky Blue' petunia (*Petunia ×hybrida* Juss. 'Dreams Sky Blue'), 'Cooler Peppermint' vinca [*Cathanranthus roseus* (L.) G. Don.'Cooler Peppermint'], and 'Super Elfin Salmon' impatiens (*Impatiens walleriana* Hook.f. 'Super Elfin Salmon') were planted into substrate mixes of 75:25 and 50:50 (v:v) peat mixed with either sweetgum, hickory, or ERC chips. At the conclusion of the study, plants grown in ERC-amended substrates grew as large as those in the standard peat/perlite mix. Eastern redcedar-based substrates also performed better than substrates amended with WT. The authors did not recommend using sweetgum or hickory as amendments in annual plant production due to reduced plant growth, flower count and plant dry weights.

Most recently, a study by Edwards et al. (2013) evaluated 10 woody ornamental plant species for tolerance and production growth in a range of ERC-based substrates [100% PB, 95:5, 90:10, 80:20, 60:40, 20:80 (all ratios PB:ERC by vol), and 100% ERC]. At the conclusion of this study, 7 of the 10 species had growth indices (GI) [(height + width + perpendicular width) ÷ 3] similar to the 100% PB treatment. Species exhibiting less growth when grown in ERC-based substrates were those that preferred a low-pH growing media: 'Premier' blueberry [*Vaccinium ashei* Reade. 'Premier' and 'Formosa' azalea (*Rhododendron indicum* L. 'Formosa']. This study concluded that ERC substrates are suitable for a wide range of woody ornamental plant species currently in commercial production in the U.S., though not preferable for acid-loving species.

Marble et al. (2012) compared landscape establishment of three woody ornamental species that were grown in 6:1 (v:v) CCR:sand and WT:sand to plants grown in PB over two growing seasons. At the conclusion of production in these substrates, there were no differences in plant size between substrate treatments prior to planting into the landscape. Regardless of production substrate, all three species grew similarly once in the landscape. It has not been determined whether growing plants in ERC has an impact on their growth in the landscape. The purpose of this study was to evaluate the effects of ERC substrates on the growth of nursery crops (trees, shrubs, and herbaceous perennials) in containers and then observe their growth after planting into the landscape.

Materials and Methods

Production study. Eastern redcedar chips were obtained from Queal Enterprises (Pratt, KS) and processed through a hammer mill (C. S. Bell Co., Tiffin, OH, Model 30HMBL) with a 3.18 mm (⅜ in) screen on May 19, 2011. On June 2, 2011, three substrate treatments consisting of 80:20 PB:sand (PBS), 40:40:20 PB:ERC:sand (PBERCS), and 80:20 ERC:sand (ERCS) (by vol) were mixed. Each substrate blend was preplant incorporated with 8.9 $kg \cdot m^{-3}$ (15 $lb \cdot yd^{-3}$) 18N-6P-12K Osmocote® (The Scotts Co. Maryville, OH) controlled-release fertilizer (9 month) and 0.9 $kg \cdot m^{-3}$ (1.5 $lb \cdot yd^{-3}$) Micromax® (The Scotts Co. Maryville, OH). Particle size distribution analysis was conducted with a Ro-Tap sieve shaker (W.S. Tyler, Mentor, OH) by passing 250 g (0.55 lb) of dried substrate through 12.5, 9.5, 6.3, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, 0.11, and 0.05 mm sieves. Particles that passed through the 0.05 mm sieve were collected in the pan. Substrate physical properties were determined with methods set forth by Fonteno and Harden (2003) for the North Carolina State University porometer.

Eight species were evaluated in this study: elm (24 count RootMaker®, RootMaker Products Co., Huntsville, AL; Cedar Valley Nurseries, Ada, OK), rose (32 count cell pack; Spring Meadow Nursery, Grand Haven, MI), holly (32 count cell pack; Spring Meadow Nursery), maiden grass (72 count cell pack, Emerald Coast Growers, Pensacola, FL), blanket flower (72 count cell pack, Emerald Coast Growers), sedum (50 count cell pack; Emerald Coast Growers), hosta (bare-root stock; DeVroomen Bulb Co., Russell, IL) and daylily (bare-root stock; DeVroomen Bulb Co.). On June 2, 2011, all plants except elm (June 9, 2011) were potted and placed on a container pad at the Kansas State University John C. Pair Horticulture Center (JCPHC; Haysville, KS) in a randomized complete block design with 14 replications except for hosta and daylily (8 reps) and sedum (10 reps). All plants were planted into 11.4 L (#3) containers (Classic C1200, Nursery Supply Inc., Chambersburg, PA) except sedum, daylily and hosta, which were planted into 3.8 L (#1) containers (Classic C400, Nursery Supply Inc., Chambersburg, PA). Hosta plants were placed in a shade structure and irrigated with 200 ml of water per day by hand. Plants on the container pad were irrigated twice daily by overhead sprinklers with a total of 2.54 cm (1 in) of water per day.

Substrate pH and electrical conductivity (EC) were collected using the pour through method (Wright 1986) on a monthly basis. Leachate was measured with a pH/conductivity meter (XL20 Fisher Scientific, Pittsburgh, PA) at 7, 28, 75, 96, and 120 days after potting (DAP). Growth indices (GI) [(height + width + perpendicular width) ÷ 3] and stem diameter of woody plants [measured at 10.16 cm (4 in) above soil surface] were recorded at 120 DAP. There was one exception for measuring plant growth, daylily, for which fan count was recorded rather than GI. Since elm was potted later, GI and stem diameter were measured at potting and 113 DAP. Leaf greenness was measured at 71 DAP using a SPAD-502 Chlorophyll Meter (Konica Minolta, Ramsey, NJ) by taking the average leaf greenness of four recently mature leaves on elm, rose, holly, and blanket flower. On October 5, 2011 (125 DAP) 4 reps from each species were removed from the production area and moved from the research station to main campus in Manhattan, KS, where they were destructively harvested on October 12, 2011 (132 DAP), except hosta and daylily, which had fewer reps in production and were not harvested in this stage. Plants were cut at the substrate surface to separate roots from shoots. Substrate was removed from roots with a high-pressure water stream. Shoots and roots were dried in a forced-air oven (Grieve SC-350 Electric Shelf Oven, Round Lake, IL) at 71C (160F) until dry weight stabilized (13 d). Hosta and daylily plants (herbaceous perennials) were overwintered in a poly house and, at planting on April 9, 2012, had not emerged to full size (thus, no growth data were recorded). Additionally, since there were fewer reps of these plants available due to liner supply for the landscape establishment phase of the study, no destructive harvest data were taken.

All data were analyzed using SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) and means were separated by using Waller-Duncan Multiple Range Test ($\alpha = 0.05$).

Landscape establishment study. On October 5, 2011, the remaining 10 reps (three substrate treatments and 2 single-plant subsamples per treatment) of the same five species (elm, rose, holly, maiden grass, and blanket flower) were planted into a Canadian-Waldeck fine sandy loam soil with a pH of 5.9 located at the JCPHC. Plants were transplanted into six rows with 1.5 m (5.0 ft) in-row spacing and 3.1 m (10 ft) between-row spacing. All plants were planted by hand and were watered immediately after planting. Each plant was fertilized after planting with 14.2 g (0.5 oz) of N from urea 46N-0P-0K per plant. Soil moisture was maintained by drip irrigation [Netafim Typhoon series 0.95 LPM·100 m^{-1} (0.25 GPM·100 ft^{-1}); Tel Aviv, Israel). Irrigation occurred weekly for 6 hr to achieve 18.0 L·m^{-1} (4.75 gal·3.2 ft^{-1}) of water when rainfall was insufficient. Weed control was achieved using oryzalin (United Phosphorous Inc., Trenton, NJ) applied after planting at a rate of 9.45 L·ha^{-1} (4 qt·A^{-1}) with hand hoeing occurring thereafter. Italian ryegrass (*Lolium multiflorum* Guss.; Tillage RootMax™, Cover Crop Solutions, Robesonia, PA) was used as a cover crop between rows. Sedum, hosta and daylily were overwintered in a poly-covered hoop house at JCPHC. On April 9, 2012 six reps of daylily and 10 reps of sedum were planted into the same field at the JCPHC. On the same date 8 reps of hosta were planted into a shade structure located at the JCPHC (also Canadian-Waldeck fine sandy loam soil). Holly, blanket flower, and sedum sustained deer damage prior to planting in the landscape; therefore these plants were arranged in a randomized complete block design, blocking for the amount of deer damage. Deer damage was too extensive for plant survival of blanket flower in the field; therefore data were not collected for this species.

During the landscape establishment phase, GI were measured at 230, 292, and 329 days after planting into the landscape (DAPL). Leaf greenness was measured at 329 DAPL using a SPAD-502 Chlorophyll Meter by taking the average leaf greenness of four recently mature leaves. On September 5, 2012, plants were harvested by undercutting with a U-blade (mounted on a Bobcat 671975, 0.91 m (36 in) Digger, on a skid-steer (Bobcat S185, Bobcat Co. West Fargo, ND). Elm also required the additional use of a tree spade [Bobcat TS34T (truncated spade set to 0.86 m (34 in) diameter)]. Plants were cut at the soil interface to separate roots from shoots. Roots were washed of soil with a high-pressure water stream. Shoots and roots were dried in a forced-air oven (Grieve SC-350 Electric Shelf Oven, Round Lake, IL) at 71C (160F) until dry weight stabilized (7d).

At the conclusion of the study, relative growth rate was calculated [(GI at harvesting – GI at field planting) ÷ harvest GI] × 100. All data were analyzed using SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) and means were separated by using Waller-Duncan Multiple Range Test ($\alpha = 0.05$).

Results and Discussion

Production physical properties. Only the ERCS substrate had greater air space (AS) than the recommended range (Yeager et al. 2007; Table 1). Container capacity of PBS was within the recommended range, while both ERCS and PBERCS mixes were below the recommended range. Total porosity (TP) of all three substrates were similar and within the recommended range. The PBS substrate had greater bulk density (BD) than the ERCS and the PBERCS mixes, but all three substrates were within the recommended range. The PBS and PBERCS treatments had similar fine particle sizes, while ERCS had equal coarse particles to PBS, but less medium and fine particles than the other treatments (Table 2). Based one previous work (Star et al. 2013) these properties were not surprising. The greater proportion of coarse particles in ERCS results in a substrate that holds less water and has greater air space, necessitating more detailed irrigation management (increasing frequency based on plant need or increasing volume applied to crop based on environmental conditions). Selection of species for production that prefer substrates which do not retain a significant amount of water in the root zone after irrigation events is another way of using substrates such as ERCS in nursery crop production.

Production EC and pH. Electrical conductivity was similar among substrates at all three measurement dates (Table 3). At 7 DAP pH was lowest in PBS (5.6), followed by the PBERCS mix (6.5) and ERCS (7.6). Substrate pH at 75 and 120 DAP was not different among treatments. It is interesting to note that a trend existed of pH dropping between 7 and 75 DAP and then rising again by 120 DAP. This can be attributed to the high alkalinity (240 ppm $CaCO_3$) of irrigation water at the JCPHC.

Table 1. Physical properties of pine bark (PB)- and eastern redcedar (ERC)-based substrates[z].

	Air space[y]	Container capacity[x]	Total porosity[w]	Bulk density[v]
		(% vol)		(g·cm^{-3})
80:20 PB:sand	13.7b[u]	53.4a	67.1a	0.44a
40:40:20 PB:ERC:sand	28.1a	43.1b	71.1a	0.40b
80:20 ERC:sand	34.1a	33.2c	67.3a	0.38c
Recommended ranges	10–30[t]	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]Air space is volume of water drained from sample ÷ volume of sample.

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

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

[v]Bulk density after forced-air drying at 105C for 24 h; 1 g·cm^{-3} = 62.4274 lb·ft^{-3}.

[u]Mean separation within column using Waller-Duncan Multiple Range test ($\alpha = 0.05$).

[t]Recommended ranges as reported by Yeager et al. 2007. Best Management Practices Guide for Producing Container-Grown Plants.

Crop growth in containers. Shoot and root dry weights were significantly smaller when elm was grown in ERCS compared to PBS and PBERCS substrates (Table 4). Growth index of plants grown in both PBERCS and ERCS were similar to the control treatment (PBS). Since plants grown in ERCS had up to half the shoot and root dry weight of plants grown in other treatments even though the plants grew as tall and wide as those in other treatments, they were not as densely populated with branches, leaves and roots, resulting in greater shoot and root dry weights for plants grown in PBS and PBERCS substrates. However, there were no significant differences in SPAD measurements among substrates indicating that appropriate amounts of nutrients, particularly nitrogen, were available to the crop during production, regardless of substrate. Caliper was greater for plants grown in PBERCS (9.0 cm) than in those grown in PBS or ERCS at 113 DAP. These results suggest that plants produced in PBERCS are similar in growth to the industry standard substrate (PBS).

Rose shoot dry weight, root dry weight and GI were unaffected by substrates (Table 4). There were minor differences in SPAD readings at 71 DAP, but these did not appear to effect overall plant growth adversely.

Holly grown in PBS and PBERCS had greater GI than plants growing in ERCS (Table 4). In addition, plants grown in ERCS exhibited greater leaf greenness (SPAD) when compared to plants in PBS. Plants growing in PBERCS had similar SPAD readings to the others. Shoot dry weight of holly grown in PBS was greater than plants grown in ERCS. However, growth in PBERCS was similar to that seen in the other substrates, whereas, root dry weight was unaffected by substrates.

Table 2. Particle size analysis of pine bark (PB)- and eastern redcedar (ERC)-based substrates[z].

		Substrate fraction weight (g)		
U.S standard sieve no.	Sieve opening (mm)[y]	80:20 PB:sand	40:40:20 PB:ERC:sand	80:20 ERC:sand
½	12.5	0.1a[x]	0.0a	0.0a
⅜	9.5	2.1a	0.5a	0.8a
¼	6.4	10.8a	3.1b	3.1b
6	3.4	26.1a	18.8b	27.3a
8	2.4	13.6b	15.4b	29.0a
10	2.0	5.3b	6.8b	16.4a
14	1.4	11.4b	12.6b	32.6a
18	1.0	13.1b	13.8b	25.5a
35	0.5	47.7a	49.9a	48.7a
60	0.3	87.0a	90.5a	46.1b
140	0.1	28.5a	35.3a	18.2b
270	0.1	0.1ab	1.9a	0.7b
pan	0.0	0.0b	0.3a	0.1b
Texture[w]				
Coarse		39.0a	22.3b	31.2a
Medium		43.4b	48.6a	25.9c
Fine		163.8a	177.8a	113.7b

[z]250 g (0.55 lb) of substratre used for analysis.

[y]1 mm = 0.0394 in.

[x]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly difference based on Waller-Duncan Multiple Range test ($\alpha = 0.05$).

[w]Coarse = 3.35–12.50 mm; Medium = 1.00–2.36 mm; Fine = 0.00–0.50 mm

Table 3. **Substrate pH and electrical conductivity (EC) in pine bark- and redcedar-based substrates for container-grown rose (*Rosa* 'Radtkopink').**

	Rose					
	7 DAP[z]		75 DAP		120 DAP	
	pH	EC[y]	pH	EC	pH	EC
80:20 PB:sand	5.6c[x]	1.1a	5.5a	2.2a	5.8a	1.0a
40:40:20 PB:ERC:sand	6.5b	1.0a	6.0a	3.1a	6.9a	0.8a
80:20 ERC:sand	7.6a	1.1a	6.1a	2.4a	7.3a	0.9a

[z]DAP=days after potting.

[y]EC measured as 1mS·cm^{-1} = 1 mmho·cm^{-1}.

[x]Mean separation within column using Waller-Duncan Multiple Range test ($\alpha = 0.05$).

Recommended ranges for pH 4.5 to 6.5 and EC 0.5 to 1.0.

Growth index and shoot dry weight of maiden grass grown in PBS was greater than that of plants grown in ERCS (Table 4). Plants growing in PBERCS had a similar GI as those growing in the other substrates. Root dry weight was unaffected by substrate. Growth index, SPAD, shoot, and root dry weights for blanket flower were unaffected by substrate (data not shown). Data were recorded prior to deer damage. Growth index of sedum grown in PBERCS was greater than sedum grown in PBS. Shoot and root dry weight not collected due to deer damage.

Landscape establishment. At the end of the study, there were no differences among substrates for GI of elm, rose, maiden grass, or sedum at 230, 292, or 329 DAPL (data not shown). There were also no differences in SPAD for elm or rose as well as caliper of elm. The number of daylily fans was not different among treatments. Additionally, shoot and root dry weights of elm, rose, maiden grass, sedum and daylily did not demonstrate differences at study termination (data not shown). Percent growth was calculated for elm, rose, holly, maiden grass, sedum and hosta in order to determine if there were differences among growth rates for plants produced in the three substrate treatments. No differences in these growth rates (among species) was measured and they grew significantly during the field-establishment phase of the study: elm increased an average of 42%, rose increased 36%, maiden grass increased 46% and sedum increased 40% (no GI was measured for daylily — only fan counts; data for percent growth rate not shown).

The only plant growth differences measured in the landscape establishment phase of the study were for holly and hosta. Growth index of holly at 230, 292 and 329 DAPL for plants grown in PBS and PBERCS were similar to each other and both treatments resulted in greater growth than plants grown in ERCS (Table 5). For shoot dry weight at termination, holly plants grown in ERCS were similar to

Table 4. **Effect of pine bark (PB)- and eastern redcedar (ERC)- substrates on growth of *Ulmus parvifolia* 'Emer II' (elm), *Rosa* 'Radtkopink' (rose), *Ilex glabra* 'Compacta' (holly), *Miscanthus sinensis* 'Little Kitten' (maiden grass) and *Sedum spectabile* 'Autumn Fire' (sedum), in a nursery production setting.**

	Elm			Rose		Holly		Maiden Grass		Sedum
	Shoot dry wt. (g)[z]	Root dry wt. (g)[y]	71 DAP[x] SPAD[w]	Shoot dry wt. (g)	Root dry wt. (g)	Shoot dry wt. (g)	Root dry wt. (g)	Shoot dry wt. (g)	Root dry wt. (g)	120 DAP GI
80:20 PB:sand	109.8a[v]	109.9a	50.1a	72.1a	14.8a	60.6a[u]	23.9a	194.8a	81.8a	30.0b
40:40:20 PB:ERC:sand	93.3a	96.5a	48.1a	83.3a	25.3a	46.3ab	18.3a	129.1ab	52.5a	33.3a
80:20 ERC:sand	55.6b	67.8b	51.0a	74.5a	23.1a	33.8b	15.5a	69.3b	55.2a	32.2ab
	113 DAP GI[u]	113 DAP Caliper[t]		120 DAP GI	71 DAP SPAD	120 DAP GI	71 DAP SPAD	120 DAP GI		
80:20 PB:sand	83.5ab	8.1b		52.6a	45.2ab	37.7a	49.5b	106.8a		
40:40:20 PB:ERC:sand	88.8a	9.0a		58.2a	39.0b	36.5a	50.3ab	100.7ab		
80:20 ERC:sand	80.5b	7.5b		50.3a	48.4a	30.1b	57.8a	89.6b		

[z]Shoots harvested at container surface and oven dried at 71C until weight stablized (1 g = 0.0035 oz).

[y]Roots barerooted and oven dried at 71C until weight stablized.

[x]DAP= Days after potting.

[w]SPAD = Soil Plant Analysis Development: A lightweight, handheld meter for measuring the chlorophyll content of leaves without causing damage to plants. An indirect measurement of nutrition status of plants, particularly nitrogen. SPAD value = index value displayed by Konica Minolta chlorophyll meters and having a correlation to chlorophyll density. Range: –9.9 to 199.9 SPAD units.

[v]Mean separation within column using Waller-Duncan Multiple Range test ($\alpha = 0.05$).

[u]Growth index (GI) = (height + width + perpendicular width ÷ 3).

[t]Caliper measured 4 in (10.16 cm) above container surface.

Table 5. **Effect of pine bark (PB)- and eastern redcedar (ERC)-based substrates on growth and landscape establishment of *Ilex glabra* 'Compacta' (holly) and *Hosta* 'Sum and Substance'.**

	Holly			Hosta		
	Growth index[z]			Growth index		
	230 DAPL[y]	292 DAPL	329 DAPL	230 DAPL	292 DAPL	329 DAPL
80:20 PB:sand	43.2a[x]	51.1a	57.5a	43.0a	37.3a	33.1a
40:40:20 PB:ERC:sand	43.5a	50.1a	56.4a	36.8b	30.5b	26.7ab
80:20 ERC:sand	35.7b	42.2b	47.4b	28.3c	24.3b	25.1b
	Shoot dry wt.[w] (g)	Root dry wt.[v] (g)	SPAD[u]	Shoot dry wt. (g)	Root dry wt. (g)	
80:20 PB:sand	253.1a	139.1a	49.5a	25.5a	65.1a	
40:40:20 PB:ERC:sand	217.9ab	144.3a	49.0a	19.0ab	42.0b	
80:20 ERC:sand	168.8b	118.0a	48.7a	11.6b	24.1b	

[z]Growth index (GI) = (height + width + perpendicular width ÷ 3).

[y]DAPL = Days after planting into the landscape.

[x]Mean separation within column using Waller-Duncan Multiple Range test ($\alpha = 0.05$).

[w]Shoots harvested at container surface and oven dried at 71C until weight stablized (1 g = 0.0035 oz).

[v]Roots barerooted and oven dried at 71C until weight stablized.

[u]SPAD = Soil Plant Analysis Development: A lightweight, handheld meter for measuring the chlorophyll content of leaves without causing damage to plants. An indirect measurement of nutrition status of plants, particularly nitrogen. SPAD value = index value displayed by Konica Minolta chlorophyll meters and having a correlation to chlorophyll density. Range: –9.9 to 199.9 SPAD units.

those grown in PBERCS, but had less shoot dry weight than plants grown in PBS. However, root dry weight and SPAD were unaffected by substrate, indicating that root growth was vigorous in each of the three substrates. Plant growth was not different among substrates and holly plants grew an average of 24% over the course of the landscape establishment study (data not shown). Growth indices for hosta were different among substrates at 230, 292, and 329 DAPL (Table 5). By 329 DAPL plants grown in PBS had greater GI and shoot dry weight than plants grown in ERCS, though plants grown in PBERCS were similar to both other treatments. Root dry weight of hosta grown in PBS was greater than the treatments containing ERC. Hosta had a negative percent growth (–33%) due to extreme weather conditions of 30 days of 37.8C (+100F) and extensive damage by blister beetles (*Epicauta pennsylvanica* DeGeer) (personal observation), but still showed no significant differences among substrates (data not shown).

In summary, crop growth varied when produced in these alternative substrates. For three out of the six species (50%) for which growth data were recorded during production, there were no or few differences (rose, blanket flower and sedum). Another two species demonstrated reduced growth in ERCS, but were similar to PBERCS (holly and maiden grass). Growth of one species was significantly reduced when grown in ERCS (elm). These differences may be attributed to root/shoot architecture (ability to deflect or direct water from overhead irrigation) and preference for water use during production. Growth index and shoot dry weight data suggest plants grown in substrates amended with ERC may require a different irrigation schedule than plants grown in PB. In general, combining PB with ERC in equal amounts did not have a detrimental effect on most crops evaluated and can be recommended for nursery crop production in regions where it is readily available. Caution should be taken when considering producing plants in a primarily ERC substrate such as ERCS. Some species will grow to an acceptable size for retail sale while others will require additional inputs (water), negating substrate cost savings. However, if control of substrate supply or decreased shipping weight is desired (bulk density is less in ERC-based substrates), it may be advantageous to evaluate various species at each nursery for potential production in ERC.

Previous studies with pine-based alternative substrates have mentioned high microbial activity as a potential problem with wood-based substrates as high microbial activity ties up nitrogen, preventing crops from taking up the nutrient and preventing ideal crop growth. Jackson et al. (2008) and Boyer et al. (2012b) identified this as a potential problem with wood-based substrates and recommended higher levels of fertilization for crop production in those substrates. However, ERC is a species known for it's natural decay-resistant properties (Difei and Hiziroglu 2010), particularly in the heartwood portion of the stem. It has often been used as fence posts in the Great Plains. A study by Starr et al. (2012) evaluated growth of three tree species (baldcypress, Chinese pistache, and silver maple (*Acer saccharinum* L.) in ERC-based substrates with both a low (4.5 $kg \cdot m^{-3}$ (7.5 $lb \cdot yd^{-3}$) or a high fertilizer rate 8.9 $kg \cdot m^{-3}$ (15 $lb \cdot yd^{-3}$) and found that plants responded similarly to both fertilizer rates, suggesting that the limiting factor for plant growth is substrate physical properties rather than fertilization. This is a potential advantage for ERC over other wood-based alternative substrates currently available for nursery crop production.

Fortunately, most differences in crop growth measured during the production cycle were eliminated after one year in the landscape (71% of species tested). This may be due to the ability of plant roots to use water stored in the surrounding soil, rather than rely on the substrate in the container for water retention. This could explain why species demonstrating reduced growth during production in ERCS (elm and maiden grass) were able to catch up to plants grown in PB-based substrates over the course of the growing season. For those in which differences remained after one year (holly and hosta), growth differences can be explained with environmental conditions. In the case of holly, plants with reduced growth during production could not catch-up to the largest-sized plants of that species, though their percent growth rate was the same among substrate treatments. Hosta plants were exposed to a variety of stressful conditions including pests and heat. This species appears to have a preference for pine bark as the primary substrate component during production, likely due to greater container capacity. Results observed in this study are similar to a study by Marble et al. (2012). The authors studied the performance of 'Acoma' crapemyrtle (*Lagerstroemia indica ×faurei* 'Acoma'), 'D.D. Blanchard' magnolia (*Magnolia grandiflora* L. 'D.D. Blanchard'), and shumard oak (*Quercus shumardii* Buckley) that were container-grown in WT, CCR, and PB then planted into the landscape. The authors noted that all species performed similarly regardless of the container substrate. These data suggest that ERC is an acceptable amendment at up to 40% for PB-based substrates. Most plants in this study were marketable and grew well in the landscape regardless of the substrate in which they were produced. Nursery growers in the Great Plains should consider supplementing their crop production substrates with ERC in order to reduce costs, manage substrate supply and increase sustainability efforts.

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