Evaluation of Eastern Red Cedar as a Substrate Component for Container Plant Production

by

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Abstract

Peat moss, perlite and pine bark, being readily available and relatively inexpensive, have been the most popular substrate components of greenhouse and container nursery production for the past forty to fifty years. Increasing demand for peat has resulted in economic and environmental concerns; while shortages have also been noted in previous years due to severe weather conditions. Perlite manufacturing and handling concerns have developed from its dust, considered to be an eye and lung irritant. Increasing energy cost has led to the use of pine bark as an alternative resource of clean fuels. This increasing demand for pine bark coincides with the slowly declining timber industry. These, and other factors have led to an increased need for locally available materials as alternative substrate components. Research evaluating high wood fiber substrates to grow plants has been shown to have positive potential when minimal adjustments are made to greenhouse fertilization and irrigation practices. In previous studies, plants grown in up to 50% fresh cut eastern red cedar had little to no difference when compared to plants in a grower's standard. In multiple studies, eastern red cedar was evaluated as a potential substrate in greenhouse annual production. Red cedar is a coniferous species native to east and central North America, primarily east of the Rocky Mountains growing between 12.2-15.2 m (40-50 ft) tall, and reaching spreads of 2.4-6.1 m (8-20 ft). It has become known as a "weed species", indicating cedar may have potential to be an economical and viable amendment in standard greenhouse substrates. In the first study, processed eastern red cedar (*Juniperus virginiana*) (RC) was evaluated as an alternative substrate in the greenhouse production of four annual species (petunia, vinca, begonia, and celosia). Three screen sizes of RC were used including 0.6cm (0.25in), 1.0cm (0.375in), and 1.3cm (0.50in). Plants were grown in either 25% or 50% RC mixed with a peat moss:perlite substrate. Plant growth was similar for two of the four species grown in 50% cedar at 1/4 in. screen size; all screen sizes were similar to the control treatment of peat moss and perlite grown in 25% RC for all species. The next study evaluated locally grown RC as a potential alternative to pine bark in the nursery production of 10 ornamental species. Plant growth for 7 of the species grown in 100% RC performed as well as plants grown in the pine bark control treatment. Species that have lower pH requirements did not perform as well in substrates amended with high percentages of cedar. Premier blueberry did not grow well in cedar above 40%. Formosa azalea and Sargents juniper growth was comparable to pine bark in up to 80% cedar. This data concludes that cedar has potential as an amendment to pine bark in nursery production. In the last study snapdragons grown in up to 75% RC with a 2.37 $kg{\cdot}m^{-3}$ fertilizer rate were comparable to those grown in 2.37 $kg{\cdot}m^{-3}$ (4.0lbs$\cdot$$yd^{-3}$) 100% peat substrate. Pansies grown in up to 50% RC with 2.37 $kg{\cdot}m^{-3}$ (4.0lbs$\cdot$$yd^{-3}$) of fertilizer were similar to those grown in 2.37 $kg{\cdot}m^{-3}$ (4.0lbs$\cdot$$yd^{-3}$) 100% peat moss. Petunia growth was similar for all substrates with up to 100% RC when amended with 1.19 $kg{\cdot}m^{-3}$ (2.0lbs$\cdot$$yd^{-3}$) of fertilizer. In conclusion, data shows eastern red cedar has potential as an alternative to peat moss amended up to 50% with the addition of fertilizer. These studies have shown that eastern red cedar is a source of locally available substrate that is economical and sustainable.

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CHAPTER I

Introduction and Literature Review

Nursery and greenhouse container plant production has changed dramatically over the past forty to fifty years with many innovations including automated irrigation, slow and controlled released fertilizers, plastic pots, and the breakthrough of pine bark as a substrate for container grown nursery plants (33). Economic growth after World War II brought pine bark into the horticultural industry as a landscaping mulch, along with evaluation as a substrate component for container grown plant production. By the mid- to late-seventies, pine bark had become the 'standard' growing substrate, comprising 75 to 100% of container substrates (8, 24, 26).

Pine bark (PB) and peat moss (PM) serve as current industry substrate standards due to many inherit qualities. Besides being readily available, PB and PM contain crucial physical characteristics needed in container plant production. Recommended physical characteristics of nursery container substrates are as follows: air space 10 to 30%; total porosity 50 to 85%; container capacity 45 to 65%; and bulk density between 0.19 and 0.70 $g \cdot cm^{-3}$ (40). Greenhouse container substrates differ due to their ability to readily hold water. Air space should be between 10 and 20%; container capacity between 50 to 65%; and total porosity between 60 and 75% for greenhouse crops (20).

Today's increasing energy cost has resulted in the use of bark as an alternative resource of clean fuels. Increasing demand for bark coincides with the slowly declining timber industry. Without a decrease of energy costs in sight, bark shortages could occur. Energy cost has preference over the horticultural industry; therefore, alternative substrates for growing plants are needed (5, 16, 17, 23).

Potential shortages of PM for horticultural use have resulted in the evaluation of alternative substrates in greenhouse production. Peat moss, with perlite, comprise most greenhouse substrates due to their combined physical characteristics and ideal characteristics of nutrient retention, ease of handling, low bulk density, and adequacy for growing multiple species. Increasing demand for PM has resulted in economic and environmental concerns. Such concerns have led to peat bog preservation efforts. Expected PM shortages have also been noted in recent years due to severe weather conditions (28). Perlite manufacturing and handling concerns have developed from its dust, which is considered to be an eye and lung irritant (6). These and other factors have led to an increased need for locally available materials as alternative substrate components.

Research has been conducted evaluating alternative substrates using organic and inorganic components since the 1970's. Organic and non-organic components outside wood based alternatives have consisted of expanded polystyrene (7), pecan shells (35), scrubber waste (32), parboiled rice hulls (9, 11, 21), and coconut coir dust (10). Other components have also been evaluated including: polyphenolic foam, hydrophilic gels, perlite, vermiculite, polystyrene foam, rockwool, and calcined clays (17).

Some of the latest evaluations of alternative substrates involve non-wood fiber components such as miscanthus straw and processed corncob. Altland and Locke (1) examined Miscanthus (*Miscanthus ×giganteus*) straw (MS) as an alternative growing media for Hibisccus 'Luna Red' (*Hisbiscus moscheutos* 'Luna Red') creating five substrates composed of sphagnum peat moss, municipal solid waste compost, with percentages of both pine bark and MS. Amending with sphagnum peat moss and compost were necessary for moderation of MS physical properties and substrate pH. Results exhibited suitable plant production as long as 20% of the substrate remained pine bark. Substrates with 20 to 60% MS had comparable pH, plant quality, foliar color, and size to those without MS.

Processed corncob as an alternative to perlite in greenhouse production of *Impatiens walleriana* 'Dazzler Cranberry' and *Petunia* ×*hybrida* 'Dream Rose' was evaluated by Weldon et al. (36). Substrates were composed of PB:PM amended with either corncob or perlite. Growth of impatiens and petunia in substrates containing the corncob was equal to or greater than those grown in substrates amended with perlite.

In addition, earlier research was conducted evaluating pine wood and hardwood bark as an amendment to PB substrate mixes (5, 18, 19, 22, 38, 39). Laiche and Nash (22) examined the use of PB amended with wood (PBW) and whole tree chips (WTC) as an organic component to produce woody ornamentals in containers. Significant amounts of organic matter in the fractions of PB and PBW resulted in a higher water holding capacity than the WTC. A trend developed between the three media's suitability as an alternative substrate, ranking: pine bark, pine bark with wood, and pine chips. While substrates with a high wood content may be used, they were inferior to PB; attributed to the leaching of nutrients, low moisture retention rate, and low water holding capacity. Results suggest if the pine chips were chipped smaller than 0.5 in. leaching would decrease, while the retention rate and water holding capacity would increase.

Broussard et al. (5) evaluated the growth of container grown woody ornamentals with varying percentages of PB and hardwood bark (0, 25, 75, and 100%). Results exhibited no significant differences in visual quality, shoot dry weight, or growth index for Burford Holly (*Ilex cornuta* 'Burfordii'), Compacta Holly (*Ilex crenata* 'Compacta'), Dwarf Gardenia (*Gardenia radicans*), or Indian Hawthorn (*Rhaphiolepis indica*). Overall, the 100% hardwood bark may have reduced growth of some species, such as Japanese Yew and 'Mary Nell' Holly, but combinations with less than 25% hardwood bark could be used successfully as a container substrate.

Wright and Browder (38) evaluated the possibility of growing greenhouse and nursery crops in a substrate composed of chipped pine logs (CPL). However, due to the difference in chemical and physical properties compared to PB, CPL required different management practices, including additional irrigation and nutrient applications.

Comparison of ground pine chips to PB as a substrate for the production of two plantings of several woody species was conducted by Wright et al. (39). Treatments consisted of either ground pine chips amended with 5% calcined clay or PB amended with dolomitic limestone. Only four species had higher shoot dry weights in PB compared to the ground pine chips in the first planting and six species in the second planting. Reduced growth in the pine chips was thought to be due to reduced nutrient availability compared to PB. Pine chips appear to be suitable for woody ornamental container production with adjustments to fertility.

Pine tree substrate (PTS) is another whole tree substrate produced by grinding coarse loblolly pine (*Pinus taeda*) chips through a hammer-mill; producing a substrate size suitable for specific substrate requirements for a wide variety of plant species and sizes. PTS has shown promise as an alternative substrate to PM and PB (18). The amending of coarsely ground PTS with finer particles or with other materials (PM, sand, or PB) results in a substrate with comparable physical properties (container capacity and plant growth) to PM:perlite or 100% PB (19).

Recently whole tree softwoods (12, 13, 14), low-value hardwoods (25, 37), and eastern red cedar (*Juniperus virginiana*) (15, 25, 29, 30, 31) have been processed for examination as alternative substrates. Clean Chip Residual (CCR), composed of 50% wood, 40% bark, and 10% needles, is a by-product developed from in-field harvesting of pine trees. (2, 3, 4). Boyer et al. (2) experimented with container grown loropetalum (*Loropetalum chinensis*) using a substrate composed of CCR. Results showed loropetalum having similar to or greater growth in CCR compared to PB. Data indicated CCR is comparable to PB as a container grown substrate for woody nursery crops.

Boyer et al. (3) continued evaluating CCR at two locations: the Paterson Greenhouse Complex in Auburn, AL and the USDA-ARS Southern Horticultural Laboratory, Poplarville, MS. Nine perennial species were examined including: *Buddleia davidii* 'Pink Delight', *Gaura linheimeri* 'Siskiyou Pink', *Coreopsis grandiflora* 'Early Sunrise' (Poplarville only), *Coreopsis rosea* 'Sweet Dreams' (Auburn only), *Verbena canadensis* 'Homestead Purple', *Scabiosa columbaria* 'Butterfly Blue', *Dianthus gratianopolitanus* 'Firewitch', *Rosemarinus officinalis* 'Irene', and *Salvia guaranitica* 'Black and Blue' (Poplarville only). Two particle sizes 1.9cm (0.75in) and 1.3cm (0.50in) screen-size of CCR were amended with PM then compared to PB and PB:PM. Substrates of 100% CCR or 100% PB had higher air space and lower water holding capacity than PB:PM, resulting in less water available for the plant. Additional PM lowered the airspace and increased the water holding capacity. Plants evaluated at Poplarville, MS had little growth difference for 6 of 8 species and 3 of 7 species at Auburn, AL. The remaining 4 species at Auburn were only slightly smaller when grown in 100% CCR.

In another study, Boyer et al. (4) examined the growth of five woody plants grown in both CCR and PB substrates. The data showed the species tested, *Buddleia davidii* 'Black Knight', *Lagerstroemia indica* 'Hopi', and *Rhododendron*×'Fashion', were similar to or greater in CCR compared to PB when looking at growth indices, leaf chlorophyll count, and inflorescence number, indicating that CCR is a viable alternative for PB. Overall, the treatments had similar root-ball coverage. Throughout the experiments, CCR was shown to be a viable alternative substrate for producers.

Researchers have also investigated the use of whole pine trees being chipped and incorporated into the substrate mixture. *WholeTree* (WT) is composed of approximately 80% wood, 15% bark, and 5% needles. It differs from CCR because it consists of the entire pine tree harvested from pine plantations at the thinning stage, leading to a higher wood percentage (12, 13, 14). As with CCR, several studies have been conducted evaluating WT as an alternative substrate.

Fain et al. (12) examined container production of annual vinca (*Catharanthus roseus*) using substrates of processed WT, using loblolly pine (*Pinus taeda*), slash pine (*Pinus elliottii*), and longleaf pine (*Pinus palustrus*) species, compared to PB. Pine bark had 50% less air space with 32% greater water holding capacity than WT. Shoot dry weights were 15% greater for plants grown in 100% PB compared to those grown in WT substrates. No difference was reported in growth indices. Plant tissue micronutrient content was similar and within sufficient ranges for the species. Root growth was also similar among treatments.

A second study by Fain et al. (13), evaluated WT substrate and fertilizer rates in the production of greenhouse-grown Petunia (*Petunia*×*hybrida* Vilm.) and Marigold (*Tagetes* *patula* L.). *WholeTree* substrate was used alone or combined with either 20% or 50% PM, then compared to a industry standard peat-lite mix. A starter fertilizer (SF) of 7N-1.3P-8.3K was added to each substrate at 0.0, 1.19, 2.37, 3.56 kg·m^{-3}. Petunia dry weight was greatest for any substrate containing PM with a SF rate of 2.37 kg·m^{-3} or greater, the exception being petunia grown in 100% WT at 3.56 kg·m^{-3} having similar dry weight to all treatments. Marigold dry weight was similar for all treatments with at least 2.37 kg·m^{-3} SF. Overall, WT proved an acceptable alternative for PM with additional starter fertilizer.

In 2010, WT substrate was compared to chipped pine logs (CPL) as a potential greenhouse substrate evaluating the growth of *Catharanthus roseus* L. 'Grape Cooler' and *Impatiens walleriana* Hook.f. 'Dazzler Apricot' (14). Treatments consisted of 1:1 (v:v) WT:PM and 1:1 (v:v) CPL:PM. In Experiment 1, higher container capacity and total porosity occurred with WT:PM than with CPL:PM. Air space and bulk density were similar. Physical properties in Experiment 2 were similar. Shoot dry weight was greater for plants grown in CPL:PM than those grown in WT:PM in Experiment 1, but were similar in Experiment 2. Results concluded that WT and CPL could be used interchangeably as a substrate amendment to PM.

In 1975, Self et al. (27) evaluated the growth of two azalea species in substrates composed of cedar, mahogany, and pine shavings. Results exhibited best growth in pine shavings followed by cedar shavings. Griffin (15) examined eastern red cedar chips, ground to pass a 2.0-cm screen, incorporated at several percentages (0%, 5%, 10%, 20%, 40%, 80%) into a PB:Sand substrate mix, reducing the bark component. Different fertilizer applications were also considered [0.81 kg N·m^{-3} (1.37 lbs·yd^{-3}) control release fertilizer (CRF), 1.6 kg N·m^{-3} (2.70 lbs·yd^{-3}) CRF, 0.4 kg N·m^{-3} (0.67 lbs·yd^{-3}) Urea (46-0-0) or no fertilizer]. Seedling Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) were planted; after 20 weeks the response to the substrates was similar between the species. Plant height in 10% and 80% red cedar was less than plants grown in 0% red cedar. Rates of all other substrate treatments had equal or greater height growth. Shoot weight followed the same trend as growth, plants in both 10% and 80% red cedar weighed less than those growing in 0%. Root weight was greater for plants grown in 0%, 5%, 10%, or 20% when amended with 0.18 kg $N \cdot m^{-3}$. When amended with 1.6 kg $N \cdot m^{-3}$ root weight was greater in 40% and 80% red cedar than in the other treatments. There were no visible signs of nutrient deficiencies, substrate shrinkage, or allelopathy recorded. The author recommends further research to determine the use of eastern red cedar as a substrate amendment (14).

Starr et al. (29) evaluated *Acer saccharinum* propagated from seed in eastern red cedar in substrates composed of 0, 5, 10, 20, 40 or 80% cedar, 20% sand, and the remaining PB. Two fertilization rates were also examined [low=4.5 kg $N \cdot m^{-3}$(7.58 $lbs \cdot yd^{-3}$), high=8.9 kg $N \cdot m^{-3}$(15.0 $lbs \cdot yd^{-3}$)]. Fertilizer had no significant effect on plant height, but did have effect on root dry weight (RDW) and shoot dry weight (SDW). Plants grown in 0% and 20% cedar had similar RDW and SDW. Substrates containing 40% cedar had less RDW and SDW than plants grown in 0% to 20% cedar, while those grown in 80% cedar had significantly less growth. Lack of growth was attributed to physical properties, rather than allelopathic or toxic quality of cedar. Results concluded cedar as a potential replacement for PB with the further development of substrate physical properties.

In 2010, bald cypress (*Taxodium distichum*) was evaluated in PB:sand substrates amended with 0, 5, 10, 20, 40 or 80% eastern red cedar (*Juniperus virginiana*) (30). Results showed cedar as a suitable alternative or amendment for PB in container-grown production of *T. distichum.* Data concluded there was little significant difference in plant height. Dry weight was lower with 80% cedar, which was attributed to the higher porosity, lower container capacity, and higher air space, providing less plant available water during production.

In 2011, Vandiver et al. (34) evaluated post-distilled cedar in the greenhouse production of impatiens (*Impatiens walleriana* 'Xtreme™ Violet') and petunia (*Petunia ×hybrida* 'Celebrity Blue'). A peat-lite base mix (80 peat: 20 perlite) was amended with 20, 40, 60, 80, and 100% cedar. Results showed both petunia and impatiens to have similar growth index, shoot dry weight, and bloom count when amended with up to 40% cedar.

Starr et al. (31) evaluated five substrates using PB and cedar chips passed through 0.5cm (0.1875in), 1cm (0.375in), 1.3cm (0.50in), or 1.9cm (0.75in) screen sizes. As the particle size increased the shoot dry weight decreased, even though plant growth indices were similar and marketable. Cedar chips proved suitable as a container grown substrate component for rudbeckia (*Rudbeckia fulgida*) at all four screen sizes and performed best in 3/16-inch screen size material.

Three possible substrate alternatives were evaluated by Murphy et al. (25) for greenhouse production of petunia, impatiens, and vinca. Substrates consisted of sweetgum, hickory, and eastern red cedar, in addition to WT. Plants grown in sweetgum and hickory did not perform as well when compared to a standard of 75:25 (v:v) PM:perlite in regards to flower number, growth indices, and plant dry weight. Data showed that up to 50% fresh cut eastern red cedar had little to no difference when compared to the standard of PM:perlite.

Research seeking alternative substrates for container grown plant production has proven vital to the nursery industry. Growers want to become more sustainable with the declining economy. In many areas growers are looking for substrates that are locally available in huge quantities. Eastern red cedar has become a "weed species" throughout many parts of the United

States, reducing the amount of available grazing land in the Great Plains and Midwest. A prosperous industry could develop to harvest eastern red cedar as a nursery and greenhouse crop substrate component. While challenging to make a drastic shift from PB or PM to a completely new alternative substrate, some of these substrates can be used to stretch out the existing supplies of PB and PM. In addition, development of alternative substrates would be profitable to forest operators, allowing them to capitalize on low-value forest trees. The objective of this research was to determine additional uses for eastern red cedar in both nursery and greenhouse container plant production.

Literature Cited

1. Altland, J.E. and J.C. Locke. 2011. Use of ground miscanthus straw in container nursery substrates. J. Environ. Hort. 29:114-118.

2. Boyer, C.R., G.B. Fain, C.H. Gilliam, J.L. Sibley, T.V. Gallagher, and H.A. Torbert. 2007. Performance of container-grown loropetalum grown in clean chip residual substrate. Proc. Intl. Plant Prop. Soc. 57:685-691.

3. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2008. Clean chip residual as a substrate for perennial nursery crop production. J. Environ. Hort. 26:239-246.

4. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2009. Production of woody nursery crops in clean chip residual substrate. J. Environ. Hort. 27:56-62.

5. Broussard, C.E. Bush, and A. Owings. 1999. Effects of hardwood and pine bark on growth response of woody ornamentals. Proc. Southern Nurs. Assoc. Res. Conf. 44:57-60.

6. Chung-Li, D.J., P.C. Wang, and Y.L. Guo. 2010. Acute expanded perlite exposure with persistant reactive airway dysfunction syndrome. Industrial Health 48:119-122.

7. Cole, J.C. and D.E. Dunn 2002. Expanded polystyrene as a substitute for perlite in rooting substrate. J. Environ. Hort. 20:7-10.

8. Cotter, D.J. and R.E. Gomez. 1977. Bark as a growing media. HortScience 12:27 (Abstr.).

9. Dueitt, S.D. and S.E. Newman. 1994. Physical analysis of fresh and aged rice hulls used as a peat moss substitute in greenhouse media. Proc. Southern Nurs. Assoc. Res. Conf. 39:81-85.

10. Evans, M.R. and R.H. Stamps. 1996. Growth of bedding plants in sphagnum peat and coir dust-based substrates. J. Environ. Hort. 14:187-190.

11. Evans, M.R and M. Gachukia. 2004. Fresh parboiled rice hulls serve as an alternative to perlite in greenhouse crop substrates. HortScience 39:232-235.

12. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008. WholeTree substrates derived from three species of pine in production of annual vinca. HortTechnology 18:13-17.

13. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008. Wholetree substrate and fertilizer rate in production of greenhouse grown petunia (*Petunia* ×*hybrida* Vilm.) and marigold (*Tagetes patula* L.). HortScience 43:700-705.

14. Gaches, W.G., G.B. Fain, D.J. Eakes, C.H. Gilliam, and J.L. Sibley. 2010. A comparison of WholeTree and chipped pine log substrate components in the production of greenhouse grown annuals. J. Environ. Hort. 28:173-178.

15. Griffin, J. 2009. Eastern red-cedar (*Juniperus virginiana*) as a substrate component for container production of woody plants. HortScience 44:1131 (Abstr.).

16. Haynes, R.W. 2003. An analysis of the timber situation in the United States: 1952-2050. Gen. Tech. Rept. PNW-GTR-560. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

17. Ingram, D.L., R.W. Henley, and T.H. Yeager. 1993. Growth media for container grown ornamental plants. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Bulletin 141. 17pp.

18. Jackson, B.E., R.D. Wright, and J.O. James. 2007. Pine tree substrate: current status. Proc. Southern Nurs. Assoc. Res. Conf. 52:518-522.

19. Jackson, B.E., R.D. Wright, and M.E. Barnes. 2010. Methods of constructing a pine tree substrate from various wood particle sizes, organic amendments, and sand for desired physical properties and plant growth. HortScience 45: 103-112.

20. Jenkins, J.R. and W.M. Jarrell. 1989. Predicting physical and chemical properties of container mixtures. HortScience 24:292-295.

21. Kämpf, A.N. and M. Jung. 1991. The use of carbonized rice hulls as a horticultural substrate. Acta Hort. 294:271-283.

22. Laiche, A.J. and V.E. Nash. 1986. Evaluation of pine bark, pine bark with wood, and pine tree chips as components of a container plant growing media. J. Environ. Hort. 4:22-25.

23. Landis, T. D. and N. Morgan. 2009. Growing media alternatives for forest and native plant nurseries. USDA Forest Service Proceedings RMRS-P-58:26-31.

24. Lu, W., J. L. Sibley, C. H. Gilliam, J. S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

25. Murphy, A. M., C.H. Gilliam, G.B. Fain, H.A. Torbert. T.V. Gallagher, J.L. Sibley, and C.R. Boyer. 2011. Low-value trees as alternative substrates in greenhouse production of three annual species. J. Environ. Hort. 29:152-161.

26. Pokorny, F.A. and S. Delaney. 1976. Preparation of a model pine bark substrate from component particles. Hortscience 11:24 (Abstr.).

27. Self, R. L. 1975. Comparison of cedar, mahogany, and pine shavings in azalea potting mixtures. Proc. Southern Nursery Assoc. Res. Conf. 20:14.

28. Short, P. 2012. President, Canadian Sphagnum Peat Moss Association. St. Albert, AB, Canada. Personal Communication. March 26, 2012.

29. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2010. Growth of containerized *Acer saccharinum* from seed in a cedar-amended substrate. HortScience 45:S234 (Abstr.).

30. Starr, Z.W., C. R. Boyer, and J.J.Griffin. 2010. Growth of containerized *Taxodium distichum* in a cedar-amended substrate. Proc. Southern Nurs. Assoc. Res. Conf. 55:344-346.

31. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2011. Cedar substrate particle size affects growth of container- grown Rudbeckia. Proc. Southern Nurs. Assoc. Res. Conf. 56:236-240.

32. Thomas, C.N. and W.L. Bauerle. 2003. Potential benefits of scrubber waste in nursery crop production. Proc. Southern Nurs. Assoc. Res. Conf. 48:114-116.

33. U. S. Department of Agriculture. 2007. Floriculture and Nursery Crops Yearbook. Market and Trade Economics Division, Economic Research Service, U. S. Dept. of Agr., Washington, D. C.

34. Vandiver, T.V., G.B. Fain, C.H. Gilliam, and J.L. Sibley. 2011. Post-distilled cedar as an alternative substrate in the production of greenhouse grown annuals. Proc. Intl. Plant Prop. Soc. 61:420-424.

35. Wang, T. and F.A. Pokorny. 1989. Pecan shells as an organic component of container potting media. HortScience 24:75-78.

36. Weldon, T.L., G.B. Fain, J.L. Sibley, and C.H. Gilliam. 2010. Processed corncob as an alternative to perlite in the production of greenhouse grown annuals. Proc. Intl. Plant Prop. Soc. 60:531-534.

37. Weldon, T.L., G.B. Fain, J.L. Sibley, and C.H. Gilliam. 2011. Milled *Paulownia tomentosa* as a substrate component in greenhouse annual production. Proc. Intl. Plant Prop. Soc. 61:483-487.

38. Wright, R.D. and J.F. Browder. 2005. Chipped pine logs: a potential substrate for greenhouse and nursery crops. HortScience 40:1513-1515.

39. Wright, R. D., J. F. Browder, and B. E. Jackson. 2006. Ground pine chips as a substrate for container-grown woody nursery crops. J. Environ. Hort. 24:181-184.

40. Yeager, T., T. Bilderback, D. Fare, C. H. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R. D. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, GA.

CHAPTER II

Evaluation of Three Screen Sizes of Eastern Red Cedar in Greenhouse Production of Four Annual Species

Abstract

Peat moss and perlite have been a major component 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 eastern red cedar (*Juniperus virginiana* L.) as an alternative substrate in the greenhouse production of four annual species (Petunia, Vinca, Begonia, and Celosia). Three screen sizes of cedar were used including 0.6cm (0.25in), 1.0cm (0.375in), and 1.3cm (0.5in). Plants were grown in either 25 or 50% cedar mixed with a peat moss:perlite substrate and compared to a standard 80:20 peat moss:perlite. Plant growth was similar for petunia and vinca in 50% cedar 0.25in screen size. Plants grown in 25% cedar were similar to those grown in 80:20 peat moss:perlite for all species in all screen sizes. Root growth was similar to or greater for substrates with 25% cedar when compared to the standard peat:perlite treatment. Overall, data shows positive results for amending peat with up to 25% cedar for all four annual species in these three screen sizes.

Index words: substrate, alternative, greenhouse, container-grown,

Species used in this study: Eastern Red Cedar (*Juniperus virginiana* L.); ‘Dreams Pink’ Petunia (*Petunia ×hybrida* Juss. ‘Dreams Pink’); ‘Cooler Hot Rose’ Vinca [*Catharanthus roseus* L. G.

Don ‘Cooler Hot Rose’]; ‘Senator Rose’ Begonia (*Begonia semperflorens*- cultorum Hort. ‘Senator Rose’); ‘Kimono Red’ Celosia (*Celosia argentea* L. ‘Kimono Red’); ‘Dreams Rose’ Petunia (*Petunia ×hybrida* Juss.‘Dreams Rose’); ‘Pacifica Blush’ Vinca [*Catharantus roseus* (L.) G. Don ‘Pacifica Blush’]; and ‘Senator Scarlet’ Begonia (*Begonia semperflorens*-cultorum Hort. ‘Senator Scarlet’)

Significance to the Industry

Potential shortages of peat moss for horticultural use have led to the evaluation of alternative substrates in greenhouse plant production. It would prove beneficial to growers for the alternative substrates to be locally available. It would also be helpful for alternative substrate components to possess qualities similar to perlite, due to its dusty form. Our data showed annuals grown in 25% cedar at 0.6cm (0.25in), 1.0cm (0.375in), and 1.3cm (0.5in) screen size exhibited little to no difference in growth compared to the control substrate of peat and perlite.

Introduction

Peat moss (PM) 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. Increasing demand for PM has resulted in economic and environmental concerns. Such concerns have led to peat bog preservation efforts. Expected shortages have also been noted in previous years due to severe weather conditions (10). Perlite manufacturing and handling concerns have developed from its dust, considered to be an eye and lung irritant. These, and other factors have led to an increased need for locally available materials as alternative substrate components. Previously evaluated alternative substrates composed of plant material include: Clean Chip Residual, *WholeTree*, Pine Tree Substrate, and low-value trees (1, 2, 3, 4, 6, 15).

Research evaluating high wood fiber substrates have been shown to have positive potential with minimal adjustments made to greenhouse fertilization and irrigation practices. Data has also shown that up to 50% fresh cut eastern red cedar had little to no difference when compared to a grower's standard (8).

Eastern red cedar (*Juniperus virginiana*) has become a "weed species" throughout the Great Plains, Midwest, and Southern United States. Results in 1975 showed that two azalea species exhibited best growth from 'pine shavings followed by cedar shavings' (9). Research has identified eastern red cedar chips as a viable amendment incorporated, at different percentages, into a PB:sand substrate mixture evaluating seedling growth of Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) (6). Response to the substrates was similar for the two species. Plants grown in 5%, 20% and 40% cedar had similar plant height and shoot dry weight to a 100% pine bark standard. Substrates containing 10% and 80% cedar had less plant height and shoot dry weight than the 100% pine bark. Starr et al. (11) evaluated *Acer saccharinum* seed propagation in varying red cedar:sand:pine bark percentages. Results showed substrates containing up to 20% cedar produced similar plant caliper, root dry weight, and shoot dry weight to plants grown in pine bark. In 2010, *Taxodium distichum* was evaluated in pine bark:sand substrates amended with percentages of eastern red cedar (12). Results concluded that there was little significant difference in plant height between the treatments, with dry weight lower at 80% cedar due to higher porosity, lower container capacity, and higher air space. Starr et al. (13) evaluated the growth effects of cedar particle size on *Rudbeckia fulgida*. Treatments consisted of five substrates using PB and cedar chips passed through 0.5cm (0.1875in), 1cm (0.375in), 1.3cm (0.50in), or 1.9cm (0.75in) screen size. As the particle size increased the shoot dry weight decreased, even though plant growth indices were similar and marketable. Cedar chips proved efficient as a container grown substrate for all 4 screen sizes and performed best in 0.5cm (0.1875in) screen size material.

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

Materials and Methods

Cedar was harvested from the Auburn Piedmont Research Station on May 11, 2012. Eastern red cedar trees were de-limbed at the time cutting. Cedar was chipped through a Vermeer BC1400XL (Vermeer Co., Pella, IA) chipper on May 15, 2012. Cedar chips were then processed through a swinging hammer-mill (Williams Patent Crusher & Pulverizer Co., St. Louis, MO) May 16, 2012. Three screen sizes were used: 0.6cm (0.25in), 1.0cm (0.375 in), and 1.3 cm (0.5in).

Nine treatments were evaluated in this study including a growers standard control consisting of 80:20 (v:v) peat (P):perlite (PL). Remaining treatments consisted of either 75:25 (v:v) or 50:50 (v:v) Peat:Cedar (P:C). Cedar treatments were composed of 0.64 cm (1/4 in), 0.95 cm (3/8 in), 1.27 cm (1/2 in), or a 1:1:1 (v:v:v) of the three screen sizes. In summary, the treatments will be referred to throughout the paper as follows: 80:20 P:PL, 75:25 P:C 1/4in., 75:25 P:C 3/8in., 75:25 P:C 1/2in., 75:25 P:C mix, 50:50 P:C 1/4in., 50:50 P:C 3/8in., 50:50 P:C 1/2in., 50:50 P:C mix. All substrates were amended with 4lb·yd^{-3} (2.73 kg·m^{-3}) 18.0N-2.64P-

9.96K (18-6-12) Polyon control release fertilizer (3-4 month) (Harrell's Fertilizer Inc., Lakeland, FL), 5lb·yd^{-3} (3 kg·m^{-3}) dolomitic limestone, and 1.5lb·yd^{-3} (0.9 kg·m^{-3}) Micromax.

Four annual species were evaluated in the study initiated on June 27, 2012 (Exp. 1). petunia (*Petunia ×hybrida* 'Dreams Pink'), vinca (*Catharantus roseus* 'Cooler Hot Rose'), begonia (*Begonia semperflorens* 'Senator Rose'), and celosia (*Celosia argentea* 'Kimono Red') were planted into 1.4 liter (1.5 qt.) containers with two plugs (200 plug flat) per pot in Exp. 1. Three annual species were evaluated in Exp. 2 initiated on August 16, 2012. Experiment 2 evaluated petunia (*Petunia ×hybrida* 'Dreams Rose'), vinca (*Catharantus roseus* 'Pacifica Blush'), and begonia (*Begonia semperflorens* 'Senator Scarlet') planted into 1.4 liter (1.5 qt.) containers with two plugs per pot (200 plug flat). Both studies were conducted at the Paterson Greenhouse Complex at Auburn University. 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 ($p \geq 0.05$) using SAS Institute version 9.2 (Cary, NC). Physical properties [substrate air space (AS), water holding capacity (WHC), total porosity (TP)] were determined using the North Carolina State University porometer method (n=3) (5). 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 105°C (221°F) in a forced air oven for 48 hours (n=3). Particle size distribution (PSD) was determined by passing 100g sample [dried at 76.7°C (170°F) forced air oven] through a series of sieves (n=3). Sieves were shaken for three minutes with a Ro-Tap sieve shaker (Ro-Tap RX-29, W. S. Tyler, Mentor, OH). Pour-through leachates were obtained from petunia (Exp. 1 and 2) at 1, 14, 30, and 45 days after potting (DAP) in order to determine substrate pH and electrical conductivity (EC) (n=4) (14). Flower number (bloom count) was counted at termination, only open blooms were counted towards total number (n=8). Growth indices [(height + width1 + width2)/3] (cm) were measured at termination (n=8). Shoot dry weights (SDW) were determined using shoots only after samples were dried for 72 hours at 76.7°C (170°F) (n=6). Root growth was assessed at study termination on a scale from 1- 5; where 1 was assigned to plants with less than 20% root ball coverage, and 5 was assigned to plants with 80-100% root ball coverage (n=8). Marketability ratings of a plants overall appearance were taken by three individuals, then averaged for a total (n=8). Ratings were determined at termination on a scale from 1 to 5; where 1 = dead, 2 = stunted/chlorosis, 3 = less marketable/stunted, 4 = marketable, and 5 = highly marketable. Foliar color ratings were taken at termination on a scale from 1 to 5; where 1 = dead, 2 = stunted/chlorosis, 3 = stunted/some chlorosis, 4 = green, and 5 = lush green (n=8).

Results and Discussion

Physical properties. Though there is not a set standard on how to best develop greenhouse substrates as for nursery production (16), there are published optimal ranges for AS, TP, WHC, and BD (7). In Exp.1, substrate AS was lower than the optimal range (10 to 20%) for most treatments ranging from 5.1% (80:20 P:PL) to 13.4% (50:50 P:C Mix) (Table 2.1). Only three substrates had AS within the recommended range: 50:50 P:C 3/8in. (10.2%), 1/2in. (10.7%), and mix (13.4%). Air space for Exp. 2 ranged between 3.9% (80:20 P:PL) to 11.6 % (50:50 P:C 1/4in.). Those within the optimal range include: 50:50 P:C 1/4in. (11.6%) and mix (10.4%) treatments. Overall, treatments with 50% cedar tended to have higher AS in both experiments, as a result the WHC was greater than the optimal range in these substrates. The recommended range of WHC is between 50 to 65%; below which substrates drain too quickly. In Exp. 1, WHC ranged from 71.9% (50:50 P:C Mix) to 83.0% (80:20 P:PL). Four treatments were similar to the

P:PL control; 75:25 P:C 1/4in. (81.9%), 3/8in. (79.7%), 1/2in. (81.3%) and mix (82.3%). Though Exp. 2 had greater percentages than the optimal, substrates exhibited little difference in WHC, ranging from 72.3% (50:50 P:C 1/4in.) to 80.9% (75:25 P:C mix). All substrates had greater TP than the recommended range of 60 to 75%. In Exp. 1, TP was least for 50:50 P:C 3/8in. (83.7%) and greatest for 75:25 P:C mix (90.1%). All percentages were similar to the TP of 80:20 P:PL (88.2%). In Exp. 2, those with similar TP values to 80:20 P:PL (81.5%) include: 75:25 P:C 1/4in.(85.5%) and 50:50 P:C 1/4in. (83.9%); all other treatments were greater. Bulk densities were less than the recommended nursery range for substrates (0.19 to 0.70 $g\cdot cm^{-3}$). All substrate BD were similar in Exp. 1 ranging from 0.11 $g\cdot cm^{-3}$ (80:20 P:PL) to 0.13 $g\cdot cm^{-3}$ (50:50 P:C mix). Experiment 2 varied from 0.12 $g\cdot cm^{-3}$ (75:25 P:C 3/8in.) to 0.16 $g\cdot cm^{-3}$ (50:50 P:C 1/4in.), all other treatments were similar to 80:20 P:PL (0.13 $g\cdot cm^{-3}$).

Particle size distribution. Analysis of PSD in Exp. 1 showed that there were no differences among any treatments for the distribution of particles left on the 9.50 mm screen (Table 2.2). Many differences occurred in the smaller screen sizes. Therefore, the screens were grouped into three categories: coarse (> 3.35 mm), medium (>1.00 to 3.35 mm), and fine (0.00 to 1.00 mm). Coarse particles for all treatments ranged from 6.9 to 18.1%, these particles are responsible for aeration in a substrate. The 80:20 P:PL (18.1%) had more coarse particles than all other treatments. Four other substrates, though less than P:PL, had similar values, including 75:25 P:C 1/4in. (12.1%), 3/8in. (10.7%), 1/2in. (13.3%), and 50:50 P:C 1/2in. (11.3%). Medium particles were greatest for three treatments: 50:50 P:C 3/8in. (48.9%), 1/2in. (51.3%), and mix (48.6%). The 80:20 P:PL (29.1%) had the least amount of medium particles. Fine particles were greatest in 75:25 P:C mix (60.0%). Those similar to 80:20 P:PL (52.8%) include: 75:25 P:C 1/4in. (54.8%), 3/8in. (51.7%), 1/2in. (51.7%) and 50:50 P:C 1/4in. (49.9%).

Particle size for Exp. 2 was similar in that there was no difference in substrates for particles left in the 9.50 mm screen size (Table 2.3). Total coarse particles ranged from 8.1% (50:50 P:C mix) to 18.4% (80:20 P:L). Only 50:50 P:C 1/2in. (18.0%) had coarse particles similar to the P:PL (18.4%). Medium PSD was greatest for 50:50 P:C 1/2in. (54.7%) and least for 80:20 P:PL (31.3%); increasing in 50:50 P:C treatments compared to the 75:25 P:C substrates. Substrates containing 25% cedar tended to have a higher fine particle percentage than 50:50 P:C 3/8in. (36.5%), 1/2in. (27.3%), and mix (44.4%) substrate treatments; with 75:25 P:C mix (53.0%) having the greatest.

pH and EC. Optimal pH range for *Petunia*×*hybrida* is between 5.40 and 5.80 (3). In Exp. 1, though there was no difference among substrates, all pH levels (4.47-4.82) were below that optimum range at 1 DAP (Table 2.4). At 14 DAP, all treatments were similar to 80:20 P:PL (5.98), those within the optimum range include 75:25 P:C 1/4in. (5.66) and 1/2in. (5.74). By 30 DAP, treatments were higher than the recommended range, ranging from 5.89 (75:25 P:C mix) to 6.54 (50:50 P:C mix). pH levels continued to increase above the recommended range by 45 DAP. Overall, 75:25 P:C cedar treatments exhibited lower pH levels than the 50:50 P:C treatments, and were similar to the 80:20 P:PL pH levels throughout the experiment. Treatments containing 50:50 P:C had similar or greater pH levels when compared to the 80:20 P:PL control.

In Exp. 2, at 1 DAP all treatments had lower pH (4.30-5.07) than the recommended range (5.40-5.80). Treatments with 50:50 P:C had similar to or greater pH than 80:20 P:PL (4.84); all 75:25 P:C treatment pH levels were less than the P:PL control. At 14 DAP, all 50:50 P:C and 75:25 P:C mix treatment had similar levels to 80:20 P:PL (5.68). At 30 DAP, all treatments were similar to the P:PL (5.54), except 75:25 P:C 3/8in.(4.97) and 1/2in. (5.10). pH values at 45 DAP were similar to 80:20 P:PL (6.05) for all 50:50 P:C and 75:25 P:C treatments, except 75:25 P:C mix (5.53). Overall, 50:50 P:C treatments exhibited a trend similar to Exp. 1 having higher pH levels than the 75:25 P:C treatments.

The recommended range for substrate EC levels for *petunia×hybrida* is between 2.0 and 3.5 $mS{\cdot}cm^{-1}$ (3). Initially, EC levels were similar ranging from 2.88 (50:50 P:C mix) to 4.98 (75:25 P:C mix); all being within or greater than the recommended range. Electrical conductivity levels at 14 DAP continued to be similar to 80:20 P:PL (3.31). By 30 DAP, levels had dropped below the optimum range; but remained similar. There was no significant difference at 45 DAP; levels ranging from 0.31 (75:25 P:C 3/8in.) to 0.59 (80:20 P:PL). In Exp. 2, substrate EC levels were within or higher than the optimal range at 1 and 14 DAP. At 30 and 45 DAP, the EC levels were lower than the recommended range for all treatments. There was no significant difference in EC among substrates for 1, 14, 30, and 45 DAP.

Bloom Count. In Exp.1, the only treatment to produce plants with similar petunia bloom count to those grown in 80:20 P:PL (19.0) was 75:25 P:C 1/2in. (16.1) (Table 2.5). Petunia in 75:25 P:C had greater bloom count than those in 50:50 P:C treatments. In Exp. 2, petunia grown in 75:25 P:C 3/8in. (18.6) and 80:20 P:PL (22.3) had similar bloom count, all other plants were similar with fewer blooms. Vinca bloom count in Exp. 1 was greatest for plants grown in 80:20 P:PL (8.1); all other vinca were similar except in 50:50 P:C 1/4in. (0.6), 3/8in. (0.8), and mix (0.9). For Vinca in Exp. 2, all treatments produced less blooms than 80:20 P:PL (22.0). When evaluating begoniain Exp. 1, plants grown in the control (26.3) had the greatest bloom count, those grown in 50% cedar tended to have less than those in 25% cedar. Begonia bloom count was similar for all plants grown in 75:25 P:C and 80:20 P:PL (10.0); 50:50 P:C treatments had less bloom count in Exp. 2. In Exp. 1, Celosia grown in 75:25 P:C had greater or equal bloom count to those grown in 50:50 P:C; plants in 80:20 P:PL had the greatest bloom count. In general, bloom count tended to decrease with an increase in cedar and cedar size.

Growth indices. For Exp. 1, petunia, vinca and celosia grown in 25% cedar was comparable to those grown in 80:20 P:PL (29.1, 24.0, 20.5 respectively) (Table 2.6). Plant growth for each of these species decreased in 50% cedar. Begonia exhibited its greatest growth in 75:25 P:C mix (22.1) and 1/2in. (19.1). In Exp. 2, five cedar substrates produced similar petunia growth as 80:20 P:PL; those not similar to 80:20 P:PL include: 75:25 P:C mix (21.6); and 50:50 P:C 3/8in. (22.6), 1/2in. (22.3). Vinca growth was comparable for all substrates except 50:50 P:C 3/8in. (23.1) and 1/2in. (22.0). All treatments for begonia produced similar growth to P:PL except 50:50 P:C 1/4in. (16.5).

Shoot dry weight. Petunia SDW exhibited no similarities to 80:20 P:PL (8.1g) for any substrate treatment in Exp. 1; decreasing with an increase in cedar percentage (Table 2.7). In Exp. 2, petunia SDW was similar for plants grown in 80:20 P:PL (13.5g) and 75:25 P:C 3/8in. (10.8g), all other treatments weighed less. In Exp. 1, Vinca SDW was similar to 80:20 P:PL for all 25% cedar treatments. Vinca exhibited similar plant SDW in 50:50 P:C 1/4in. (7.1g) and 3/8in. (6.9g); and 80:20 P:L (8.7g) in Exp. 2. Begonia SDW for Exp. 1 were similar for 75:25 P:C 3/8in. (4.2g), 1/2in. (2.6g) and 80:20 P:PL (5.1g). Shoot dry weights for the begonia in Exp. 2 were all similar to the 80:20 P:PL (4.3g) except 50:50 P:C 1/4in. (1.3g), 3/8in. (1.5g), and 1/2in. (1.4g). Dry weight in Exp. 1, was greatest for celosia grown in 80:20 P:PL (3.1g), with 75:25 P:C 1/2in. (1.7g) having the greatest and 50:50 P:C 1/4in. (0.4 g) having the least for the cedar substrates. In general, treatments containing a higher cedar percentage had less SDW.

Root Growth Ratings. In Exp. 1 and Exp. 2 petunia root ratings were similar to 80:20 P:PL for all treatments (Table 2.8). Vinca had all treatments similar to 80:20 P:PL (5.0) in Exp. 1, except 50:50 P:C 1/4in. (2.8), 3/8in. (3.1), and mix (2.8). Root growth for vinca in Exp. 2 was similar to 80:20 P:PL (4.8) for all treatments except 50:50 1/2in. (3.8) and mix (3.8). In Exp. 1, begonia had all treatments similar to 80:20 P:PL (5.0) except 50:50 P:C 1/4in. (1.5), 3/8in. (1.8), and mix (1.3). All Begonia treatments had similar root ratings to 80:20 P:PL (4.1) in Exp. 2. Root ratings in Exp. 1 for celosia showed all 25% cedar treatments comparable to 80:20 P:PL (5.0); the 50% cedar treatments had less root growth ratings.

Marketability Ratings. In Exp. 1, marketability rationings for all 75:25 P:C treatments and 50:50 P:C 1/2in. were similar to 80:20 P:PL for petunia and vinca (Table 2.9). Petunia that were not qualified as marketable due to stunted growth include 50:50 P:C 1/4in. (3.9) and mix (3.9); all vinca were considered to be marketable. Begonia and celosia exhibited the same marketability ratings in 75:25 P:C 3/8in., 1/2in., and mix as the 80:20 P:PL treatment. Those which were stunted or not marketable for begonia and celosia include 75:25 P:C 1/4in. (3.9, 3.6 respectively) and all 50% cedar treatments. Marketability was similar among treatments for petunia, vinca, and begonia in Exp. 2.

Foliar Color Ratings. Foliar color ratings exhibited no significant difference among substrates for petunia and vinca in Exp. 1 or Exp. 2 (Table 2.10). Begonia foliar color ratings were similar to 80:20 P:PL (5.0) for all treatments except 50:50 P:C 1/4in. (4.0) and mix (4.0); however, they were all similar in Exp. 2. For celosia, all treatments were similar to 80:20 P:PL (5.0) except 50:50 P:C mix (4.0).

Conclusion

In general, the data shows that plant growth in cedar was similar to or greater than those grown in 80:20 P:PL for all species in treatments containing 25% cedar at all screen sizes. Plant growth in 50:50 P:C 1/4in. was similar for two of the four species. Shoot dry weights showed a decrease with an increase in cedar content and size for each annual. Similar or greater root growth was apparent for substrates containing 75:25 P:C compared to the 80:20 P:PL control. Marketability exhibited 75:25 P:C treatments comparable to the 80:20 P:PL for three of the four species. Foliar color ratings showed similarities for all substrates with each species. These results coincide with results reported by Murphy et al. (8) where plant growth was similar to a peat:perlite mix in up to 50% cedar at 1/4in. screen size for petunia, vinca, and impatiens. In conclusion, data shows that peat amended with 75:25 P:C at 1/4in., 3/8in., 1/2in., and mixed screen sizes has potential in the production of these four greenhouse annuals.

Literature cited

1. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2008. Clean chip residual as a substrate for perennial nursery crop production. J. Environ. Hort. 26:239-246.

2. Broussard, C., E. Bush, and A. Owings. 1999. Effects of hardwood and pine bark on growth response of woody ornamentals. Proc. Southern Nurs. Assoc. Res. Conf. 44:57-60.

3. Cavins, T.J., B.E. Whipker, and W.C. Fonteno. 2005. Timing of PourThru affects pH, electrical conductivity, and leachate volume. Commun. Soil Sci. Plant Anal. 36:1573–1581.

4. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008. WholeTree substrates derived from three species of pine in production of annual vinca. HortTechnology 18:13-17.

5. Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer, Horticultural Substrates Laboratory, North Carolina State University, Raleigh, NC.

6. Griffin, J. 2009. Eastern red-cedar (*Juniperus virginiana*) as a substrate component for container production of woody plants. HortScience 44:1131 (Abstr.).

7. Jenkins, J.R. and W.M. Jarrell. 1989. Predicting physical and chemical properties of container mixtures. HortScience 24:292-295.

8. Murphy, A.M., C.H. Gilliam, G.B. Fain, H.A. Torbert. T.V. Gallagher, J.L. Sibley, and C.R. Boyer. 2011. Low-value trees as alternative substrates in greenhouse production of three annual species. J. Environ. Hort. 29:152-161.

9. Self, R.L. 1975. Comparison of cedar, mahogany, and pine shavings in azalea potting mixtures. Proc. Southern Nursery Assn. Res. Conf. 20:14.

10. Short, P. 2012. President, Canadian Sphagnum Peat Moss Association. St. Albert, AB, Canada. Personal Communication. March 26, 2012.

11. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2010. Growth of containerized *Acer saccharinum* from seed in a cedar-amended substrate. HortScience 45:3971 (Abstr.).

12. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2010. Growth of containerized *Taxodium distichum* in a cedar-amended substrate. Proc. Southern Nurs. Assoc. Res. Conf. 55:344-346.

13. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2011. Cedar substrate particle size affects growth of container-grown rudbeckia. Proc. Southern Nurs. Assoc. Res. Conf. 56:236-240.

14. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

15. Wright, R.D., J.F. Browder, and B.E. Jackson. 2006. Ground pine chips as a substrate for container-grown woody nursery crops. J. Environ. Hort. 24:181-184.

16. Yeager, T., T. Bilderback, D. Fare, C.H. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R.D. Wright. 2007. Best Management Practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assn., Atlanta, GA.

Table 2.1. Physical properties[z] of nine substrates containing peat, perlite, and cedar[y].

Substrate	Air Space[x]		Substrate water holding capacity[w]		Total porosity[v]		Bulk Density $(g \cdot cm^{-3})$[u]	
	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1 (% vol)	Exp. 2 (% vol)	Exp. 1	Exp. 2
80:20 Peat:Perlite	5.1b[t]	3.9c	83.0a	77.5a	88.2ab	81.5b	0.116[ns]	0.136bcd
75:25 Peat:Cedar 1/4”	5.4b	7.9abc	81.9a	77.6a	87.4ab	85.5ab	0.137	0.127de
75:25 Peat:Cedar 3/8”	8.6ab	7.4abc	79.7ab	80.4a	88.4ab	87.8a	0.120	0.123e
75:25 Peat:Cedar 1/2”	8.4ab	8.3abc	81.3a	78.2a	89.7a	86.5a	0.120	0.140bc
75:25 Peat:Cedar Mix[s]	7.8ab	5.8bc	82.3a	80.9a	90.1a	86.6a	0.120	0.130cde
50:50 Peat:Cedar 1/4”	8.2ab	11.6a	76.6bc	72.3b	84.8ab	83.9ab	0.137	0.167a
50:50 Peat:Cedar 3/8”	10.2ab	9.8ab	73.4cd	77.0a	83.7b	86.7a	0.137	0.146b
50:50 Peat:Cedar 1/2”	10.7ab	9.5ab	74.4cd	77.7a	85.2ab	87.2a	0.133	0.140bc
50:50 Peat:Cedar Mix	13.4a	10.4ab	71.9d	76.8a	85.3ab	87.2a	0.137	0.130cde
Optimal range for greenhouse substrates[r]	10-20%		50-65%		60-75%		N/A	
Recommeded range for nursery crops[q]	10-30%		45-65%		50-85%		0.19-0.70	

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

[y]Cedar processed through three different screen sizes: 0.64 cm (1/4"), 0.95 cm (3/8"), and 1.27 cm (1/2").

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

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

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

[u]Bulk density after forced-air dyring at 105.0°C (221.0°F) 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 equal 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.

[ns]Means not significantly different.

Table 2.2. Particle size distribution analysis[z] of nine substrates containing peat, perlite and cedar[y] (Experiment 1)[x].

		Substrates								
U.S. standard sieve no.	sieve opening (mm)[w]	80:20 Peat: Perlite	75:25 Peat: Cedar 1/4”	75:25 Peat: Cedar 3/8”	75:25 Peat: Cedar 1/2”	75:25 Peat: Cedar Mix[v]	50:50 Peat: Cedar 1/4”	50:50 Peat: Cedar 3/8”	50:50 Peat: Cedar 1/2”	50:50 Peat: Cedar Mix
3/8	9.50	1.5[u,ns]	1.4	0.5	0.6	0.4	0.8	0.4	0.4	0.3
1/4	6.35	3.1a	3.1a	2.8ab	3.0a	1.7bc	1.7bc	1.4c	1.0c	1.7bc
6	3.35	13.4a	7.7bc	7.4bc	9.7b	6.4bc	4.4d	5.2cd	9.9b	6.3cd
8	2.36	10.8b	6.0ef	7.4de	9.8bc	6.5ef	5.9f	8.4cd	13.4a	9.5bc
10	2.00	4.2cd	3.6d	4.7cd	5.1c	4.1cd	4.9c	6.4b	8.2a	6.8b
14	1.40	7.1d	12.4bc	13.9b	11.2c	11.4c	16.4a	18.1a	16.8a	18.0a
18	1.00	7.1f	11.2d	11.6d	8.9e	9.4e	16.0a	16.0a	12.9c	14.3b
35	0.50	20.1ab	20.4ab	18.4bc	18.3bc	17.6c	21.9a	20.9a	19.8ab	18.8bc
60	0.25	19.9a	18.4ab	17.0ab	18.8a	19.4a	15.7bc	13.8cd	11.4d	13.5cd
140	0.11	10.3bcd	12.1b	12.2b	11.5bc	16.8a	9.3cde	7.1ef	4.7f	8.4de
270	0.05	2.4cd	3.2bc	3.4b	2.6bcd	4.9a	2.5cd	1.8de	1.1e	2.0d
pan	0.00	0.7bc	0.7bc	0.8b	0.5bcd	1.2a	0.5bcd	0.4cd	0.3d	0.4d
Texture[t]										
Coarse		18.1a	12.1bc	10.7bcd	13.3b	8.6cd	6.9d	7.1d	11.3bc	8.3cd
Medium		29.1e	33.1cde	37.5c	35.0cd	31.5de	43.2b	48.9a	51.3a	48.6a
Fine		52.8b	54.8ab	51.7b	51.7b	60.0a	49.9bc	44.0cd	37.4d	43.1d

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).

[y]Cedar processed through three different screen sizes: 0.64 cm (1/4"), 0.95 cm (3/8"), and 1.27 cm (1/2").

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

[w]1 mm = 0.0394 in.

[v]Cedar mix substrate is an equal mix of each screen size.

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

[t]Coarse = 3.35-9.50 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.

[ns]Means not significantly different.

Table 2.3. Particle size distribution analysis[z] of nine substrates containing peat, perlite and cedar[y] (Experiment 2)[x].

U.S. standard sieve no.	sieve opening (mm)[w]	Substrates								
		80:20 Peat: Perlite	75:25 Peat: Cedar 1/4"	75:25 Peat: Cedar 3/8"	75:25 Peat: Cedar 1/2"	75:25 Peat: Cedar Mix[v]	50:50 Peat: Cedar 1/4"	50:50 Peat: Cedar 3/8"	50:50 Peat: Cedar 1/2"	50:50 Peat: Cedar Mix
3/8	9.50	0.4[u,ns]	0.3	0.8	0.7	0.9	0.2	0.4	1.9	0.7
1/4	6.35	3.4a	2.5ab	2.8a	2.8a	2.5ab	2.4ab	2.6a	3.3a	1.2b
6	3.35	14.7a	7.3d	8.7cd	10.6bc	8.3cd	6.3d	7.9d	12.8ab	6.2d
8	2.36	11.2b	6.5ef	7.5e	10.6bc	7.5ef	6.2f	9.9cd	14.8a	9.0d
10	2.00	4.4cd	3.9d	4.8cd	5.5c	4.4cd	4.5cd	7.4b	8.9a	7.3b
14	1.40	8.1d	13.5c	13.4c	12.6c	12.4c	16.8b	19.4a	17.8b	17.0b
18	1.00	7.6f	12.9c	12.2cd	11.0de	10.5e	14.5b	15.9a	13.3bc	14.2b
35	0.50	19.2bc	22.1a	21.0ab	19.6bc	20.6ab	18.6c	19.3bc	15.0d	20.1bc
60	0.25	18.2a	17.6ab	16.2abc	15.8bc	17.8ab	14.3c	10.6d	7.7e	14.9c
140	0.11	9.7abc	10.0ab	9.2abc	8.6bc	11.1a	10.5ab	4.6d	3.4d	7.4c
270	0.05	2.6b	2.6b	2.7b	2.3bc	2.8b	4.1a	1.4d	1.0d	1.7cd
pan	0.00	0.6bc	0.7b	0.9b	0.5bcd	0.7b	1.5a	0.5bcd	0.2d	0.3cd
Texture[t]										
Coarse		18.4a	10.2bcd	12.3bc	14.1b	11.8bcd	8.9cd	11.0bcd	18.0a	8.1d
Medium		31.3e	36.7d	37.8d	39.1cd	35.3d	42.1c	52.6a	54.7a	47.4b
Fine		50.3ab	53.1a	49.9ab	46.8ab	53.0a	49.0ab	36.5c	27.3d	44.4b

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).

[y]Cedar processed through three different screen sizes: 0.64 cm (1/4"), 0.95 cm (3/8"), and 1.27 cm (1/2").

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

[w]1 mm = 0.0394 in.

[v]Cedar mix substrate is an equal mix of each screen size.

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

[t]Coarse = 3.35-9.50 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.

[ns]Means not significantly different.

Table 2.4. Effect of nine substrates containing peat, perlite, and cedar on pH and electrical conductivity (EC) in petunias[z].

	Exp. 1		Exp. 2		Exp. 1		Exp. 2	
Substrate	pH	EC[y] ($mS \cdot cm^{-1}$)[x]	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)	pH	EC ($mS \cdot cm^{-1}$)
	1 DAP[w]				14 DAP			
80:20 Peat:Perlite	4.82[v,ns]	4.10[ns]	4.84b	4.89[ns]	5.98ab	3.31ab	5.68a	2.88[ns]
75:25 Peat:Cedar 1/4”	4.73	4.02	4.30c	4.27	5.66b	3.77ab	5.06b	3.94
75:25 Peat:Cedar 3/8”	4.71	3.87	4.42c	3.69	5.83ab	3.38ab	4.93b	4.44
75:25 Peat:Cedar 1/2”	4.73	4.70	4.40c	4.02	5.74ab	5.03a	5.14b	3.64
75:25 Peat:Cedar Mix[u]	4.47	4.98	4.32c	4.56	5.81ab	4.15ab	5.30ab	2.65
50:50 Peat:Cedar 1/4”	4.59	4.08	5.07a	3.57	5.97ab	2.71b	5.65a	3.38
50:50 Peat:Cedar 3/8”	4.71	3.39	4.96ab	3.29	6.11a	3.15ab	5.61a	2.88
50:50 Peat:Cedar 1/2”	4.84	4.68	4.86ab	3.41	6.06ab	2.80b	5.60a	3.32
50:50 Peat:Cedar Mix	4.84	2.88	4.77b	3.80	6.10a	2.10b	5.58a	3.00
	30 DAP				45 DAP			
80:20 Peat:Perlite	6.10de	1.06ab	5.54a	0.56[ns]	6.44c	0.59[ns]	6.05abc	0.65[ns]
75:25 Peat:Cedar 1/4”	6.07de	0.57ab	5.50ab	0.38	6.61bc	0.43	5.70cd	0.51
75:25 Peat:Cedar 3/8”	6.18bcde	0.97ab	4.97c	1.03	6.76abc	0.31	5.75cd	0.48
75:25 Peat:Cedar 1/2”	6.14cde	1.01ab	5.10bc	0.76	6.59bc	0.47	5.80bcd	0.32
75:25 Peat:Cedar Mix	5.89e	1.48a	5.30abc	0.89	6.46c	0.50	5.53d	0.43
50:50 Peat:Cedar 1/4”	6.44abc	0.83ab	5.62a	0.78	6.98a	0.35	6.25ab	0.50
50:50 Peat:Cedar 3/8”	6.49ab	0.59ab	5.60a	0.89	6.96a	0.32	6.38a	0.43
50:50 Peat:Cedar 1/2”	6.39abcd	0.64ab	5.62a	1.05	6.91ab	0.37	6.48a	0.48
50:50 Peat:Cedar Mix	6.54a	0.53b	5.74a	0.64	6.92ab	0.37	6.30a	0.40

[z]pH and EC of solution determined using pour-through method on 'Dreams White' Petunia (Experiment 1) and 'Dreams Pink' Petunia (Experiment 2).

[y]EC = electrical conductivity.

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

[w]DAP = days after potting.

[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 = 4).

[u]Cedar mix substrate is an equal mix of each screen size.

[ns]Means not significantly different.

Table 2.5. Effects of substrate on bloom count[z] at termination (35 DAP[y] for Experiment 1 and 45 DAP for Experiment 2) for four greenhouse annuals.

	Petunia		Vinca		Begonia		Celosia	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2[x]**
80:20 Peat:Perlite	19.0a[w]	22.3a	8.1a	22.0a	26.3a	10.0a	60.6a	-
75:25 Peat:Cedar 1/4”	13.4b	16.0bc	2.9bc	13.7bc	10.4bcd	6.8abc	39.9b	-
75:25 Peat:Cedar 3/8”	13.1b	18.6ab	3.9b	14.7b	16.6b	7.1abc	39.7b	-
75:25 Peat:Cedar 1/2”	16.1ab	16.0bc	3.8b	12.6bc	15.4bc	9.9ab	41.2b	-
75:25 Peat:Cedar Mix[v]	13.6b	14.4bc	3.9b	12.6bc	9.4bcd	6.3abc	39.9b	-
50:50 Peat:Cedar 1/4”	5.3c	15.9bc	0.6c	9.9bc	6.4cd	2.4c	18.3c	-
50:50 Peat:Cedar 3/8”	8.3c	14.0bc	0.8c	7.5c	6.6cd	1.5c	24.3bc	-
50:50 Peat:Cedar 1/2”	8.0c	13.1c	2.2bc	9.3bc	10.0bcd	2.5bc	26.1bc	-
50:50 Peat:Cedar Mix	5.4c	13.0c	0.9c	9.5bc	4.4d	1.1c	20.1c	-

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

[y]DAP = days after potting.

[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 substrate is an equal mix of each screen size.

Table 2.6. Effect of substrate on growth indices[z] at termination (35 DAP[y] for Experiment 1 and 45 DAP for Experiment 2) for four greenhouse annuals.

	Petunia		Vinca		Begonia		Celosia	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2[x]**
80:20 Peat:Perlite	29.1a[w]	27.0a	24.0a	25.9a	15.6cd	22.0abc	20.5a	-
75:25 Peat:Cedar 1/4”	29.8a	24.4abc	22.0abc	24.2abc	16.5bcd	23.8ab	17.5abc	-
75:25 Peat:Cedar 3/8”	28.8a	25.0abc	22.9ab	24.4abc	18.4bc	22.5abc	17.9abc	-
75:25 Peat:Cedar 1/2”	30.3a	25.5ab	22.6ab	24.9ab	19.1ab	24.3a	18.6a	-
75:25 Peat:Cedar Mix[v]	27.8ab	21.6c	23.6ab	24.1abc	22.1a	21.4abc	18.5a	-
50:50 Peat:Cedar 1/4”	21.0c	23.8abc	21.0bcd	23.6abc	12.0f	16.5d	11.6d	-
50:50 Peat:Cedar 3/8”	23.4c	22.6bc	21.3bcd	23.1bc	13.6def	19.3bcd	13.3d	-
50:50 Peat:Cedar 1/2”	24.0bc	22.3bc	19.5cd	22.0c	15.3de	18.4cd	13.7cd	-
50:50 Peat:Cedar Mix	21.2c	23.9abc	19.1d	23.8abc	12.3ef	19.4bcd	14.1bcd	-

[z]Growth index = [(height + width1 + width2)/3].
[y]DAP = days after potting
[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 substrate is an equal mix of each screen size.

Table 2.7. Effects of substrate on shoot dry weights[z] at termination for (35 DAP[y] for Experiment 1 and 45 DAP for Experiment 2) for four greenhouse annuals.

	Petunia		Vinca		Begonia		Celosia	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2[x]**
80:20 Peat:Perlite	8.1a[w]	13.5a	6.9a	8.7a	5.1a	4.3a	3.1a	-
75:25 Peat:Cedar 1/4”	3.7bc	7.9bc	3.6a	7.1ab	2.0bc	4.0ab	1.4bc	-
75:25 Peat:Cedar 3/8”	4.3bc	10.8ab	5.7a	6.9ab	4.2ab	3.4abc	1.6bc	-
75:25 Peat:Cedar 1/2”	5.5b	7.6c	5.5a	6.2bcd	2.6abc	4.1a	1.7b	-
75:25 Peat:Cedar Mix[v]	4.5bc	6.9c	5.3a	6.3bc	1.8bc	3.5abc	1.4bc	-
50:50 Peat:Cedar 1/4”	2.1d	7.6c	3.0b	5.3bcd	0.6c	1.3c	0.4d	-
50:50 Peat:Cedar 3/8”	2.7cd	7.5c	2.6b	4.9cd	0.7c	1.5bc	0.9bcd	-
50:50 Peat:Cedar 1/2”	2.7cd	6.9c	2.8b	4.5d	1.5c	1.4c	0.8cd	-
50:50 Peat:Cedar Mix	2.2d	6.5c	1.9b	5.4bcd	1.4c	2.6abc	0.9bcd	-

[z]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.

[y]DAP = days after potting.

[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 $\alpha = 0.05$ ($n = 6$).

[v]Cedar mix substrate is an equal mix of each screen size.

Table 2.8. Effect of nine substrates containing peat, perlite, and cedar on root growth[z] of four annual species.

	Petunia		Vinca		Begonia		Celosia	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2[y]**
80:20 Peat:Perlite	4.0ab[x]	4.5ab	5.0a	4.8a	5.0a	4.1ab	5.0a	-
75:25 Peat:Cedar 1/4”	4.0ab	4.6ab	4.0ab	4.7a	3.5abc	5.0a	4.1ab	-
75:25 Peat:Cedar 3/8”	4.1ab	4.3ab	5.0a	4.7a	3.8ab	4.9a	4.0ab	-
75:25 Peat:Cedar 1/2”	4.5a	4.6ab	4.6a	4.3ab	4.3a	4.9a	4.8a	-
75:25 Peat:Cedar Mix[w]	3.1b	4.0b	4.5a	4.3ab	3.1abcd	4.6a	3.2abc	-
50:50 Peat:Cedar 1/4”	3.1b	5.0a	2.8b	4.1ab	1.5cd	3.5b	1.1d	-
50:50 Peat:Cedar 3/8”	3.5ab	4.9ab	3.1b	4.1ab	1.8bcd	4.5a	2.8bcd	-
50:50 Peat:Cedar 1/2”	4.0ab	5.0a	4.0ab	3.8b	3.1abcd	4.5a	1.3cd	-
50:50 Peat:Cedar Mix	3.0b	4.8ab	2.8b	3.8b	1.3d	4.5a	2.3cd	-

[z]Root growth assessed at study termination (35 DAP for Experiment 1 and 45 DAP for Experiment 2) on 1-5 scale (1 = less than 20% root ball coverage, 3 = 50% root ball coverage, and 5 = 100% root ball coverage).

[y]Celosia was not evaluated in Experiment 2.

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

[w]Cedar mix substrate is an equal mix of each screen size.

Table 2.9. Effect of nine substrates containing peat, perlite, and cedar on marketability ratings^{z} on four annual species.

	Petunia		Vinca		Begonia		Celosia	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2^{y}**
80:20 Peat:Perlite	4.8a^{x}	5.0^{ns}	5.0a	5.0^{ns}	5.0a	4.6^{ns}	4.9a	-
75:25 Peat:Cedar 1/4"	4.5ab	5.0	4.7ab	5.0	3.9bcd	5.0	3.6bcd	-
75:25 Peat:Cedar 3/8"	4.4ab	5.0	5.0a	5.0	4.6ab	5.0	4.0abc	-
75:25 Peat:Cedar 1/2"	5.0a	5.0	5.0a	5.0	4.5ab	5.0	4.5ab	-
75:25 Peat:Cedar Mix^{w}	4.8a	4.9	4.9a	5.0	4.4abc	4.9	4.0abc	-
50:50 Peat:Cedar 1/4"	3.9b	5.0	4.0c	5.0	2.5e	4.4	2.4e	-
50:50 Peat:Cedar 3/8"	4.0b	5.0	4.3bc	5.0	3.1de	4.9	3.0de	-
50:50 Peat:Cedar 1/2"	4.5ab	5.0	4.5abc	5.0	3.6cd	4.6	3.4cd	-
50:50 Peat:Cedar Mix	3.9b	5.0	4.0c	5.0	2.8e	4.5	2.9de	-

^{z}Marketability assessed at study termination (35 DAP for Experiment 1 and 45 DAP for Experiment 2) on 1-5 scale (1= Dead, 2=Not Marketable, 3 = Less Marketable/Stunted, 4 = Marketable, and 5 = Highly Marketable.

^{y}Celosia was not evaluated in Experiment 2.

^{x}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).

^{w}Cedar mix substrate is an equal mix of each screen size.

^{ns}Means not significantly different.

Table 2.10. Effect of nine substrates containing peat, perlite, and cedar on foliar color ratings[z] on four annual species.

	Petunia		Vinca		Begonia		Celosia	
Substrate	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2**	**Exp. 1**	**Exp. 2[y]**
80:20 Peat:Perlite	4.0[x,ns]	5.0[ns]	5.0[ns]	5.0[ns]	5.0a	4.9[ns]	5.0a	-
75:25 Peat:Cedar 1/4”	4.5	5.0	5.0	5.0	4.4ab	5.0	4.1ab	-
75:25 Peat:Cedar 3/8”	4.0	5.0	5.0	5.0	4.9a	5.0	4.1ab	-
75:25 Peat:Cedar 1/2”	4.1	5.0	5.0	5.0	4.9a	5.0	4.9ab	-
75:25 Peat:Cedar Mix[w]	4.9	5.0	5.0	5.0	4.6ab	5.0	4.6ab	-
50:50 Peat:Cedar 1/4”	4.6	5.0	5.0	5.0	4.0b	5.0	4.1ab	-
50:50 Peat:Cedar 3/8”	4.2	5.0	5.0	5.0	4.6ab	5.0	4.1ab	-
50:50 Peat:Cedar 1/2”	4.5	5.0	5.0	5.0	4.6ab	5.0	4.1ab	-
50:50 Peat:Cedar Mix	4.4	5.0	5.0	5.0	4.0b	5.0	4.0b	-

[z]Foliar color ratings assessed at study termination (35 DAP for Experiment 1 and 45 DAP for Experiment 2) on 1-5 scale (1 = Dead, 2 = Moderate Chlorosis, 3 = Some Chlorosis, 4 = Green, and 5 = Lush Green).

[y]Celosia was not evaluated in Experiment 2.

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

[w]Cedar mix substrate is an equal mix of each screen size.

[ns]Means not significantly different.

Chapter III

Evaluation of Eastern Red Cedar as an Alternative to Pine Bark in Nursery Production

Abstract

Pine bark has been the standard container nursery substrate for nearly forty years. However, due to the decline in the timber industry and fluctuations in fuel prices, alternative substrates and amendments are being sought by growers and researchers. This study evaluated locally grown eastern red cedar (*Juniperus virginiana*) as a potential alternative to pine bark in nursery production of 10 ornamental species. Plant growth for 7 of the species evaluated performed as well in 100% cedar as with the pine bark control treatment. Species that have lower pH requirements did not perform as well in substrates amended with high cedar percentages. Premier blueberry did not grow well in cedar above 20%. Formosa azalea and August Beauty gardenia growth in up to 80% cedar was comparable to plants grown in pine bark. Root growth for 8 of the species was similar to or greater than those grown in pine bark. Formosa azalea and Burgundy loropetalum showed slight variations in root growth above 10% cedar. This data concludes that cedar has potential as an amendment to pine bark in nursery production.

Index words: substrate, alternative, amendment, container-grown, woody ornamentals

Species used in this study: Knockout Rose (*Rosa* ×KnockOut®); Reeves spirea (*Spiraea cantoniensis* Lour.); August Beauty gardenia (*Gardenia jasminoides* J. Ellis. 'August Beauty'); Wintergreen boxwood (*Buxus microphylla* Siebold and Zucc. var. *japonica* 'Wintergreen');

Sargents juniper (*Juniperus chinensis* L. var. *Sargentii*); Bugundy loropetalum (*Loropetalum chinensis* var. *rubrum* 'Burgundy'), Recurve ligustrum (*Ligustrum japonicum* L. 'Recurvifolium'); Premier blueberry (*Vaccinium ashei* Reade. 'Premier'); Formosa azalea (*Rhododendron indicum* L. 'Formosa'), Rose Glow lantana (*Lantana camara* L. 'Landmark® Rose Glow'), and Bandana Pink lantana (*Lantana camara* L.'Bandana® Pink')

Significance to the Industry

Recent decline in pine bark (PB) supplies has created concern for nursery growers about its future availability. Therefore, a need has developed to evaluate alternative components for a standard growing substrate. Many growers are looking for substrates that are locally available in sustainable quantities. Eastern red cedar (*Juniperus virginiana)* has become a "weed species" throughout many parts of the Great Plains, Midwest, and Southeast. This study demonstrated that most woody nursery crops grown in varying ratios of PB:Cedar (C) had similar growth to plants grown in a nursery standard of 100% PB.

Introduction

Increasing energy cost has led to the use of pine bark as an alternative resource of clean fuels (12). This increasing demand for bark coincides with the slowly declining timber industry (7). Without a decrease of energy cost in sight, bark shortages could occur. With energy cost having preference over the horticultural industry, the need of an alternative substrate for growing nursery crops increases (8).

Previous research on alternative nursery crop substrates has focused heavily on high wood fiber substrates; mainly evaluating whole pine trees, chipped pine logs, residual material, and hardwood chips in both greenhouse and nursery production (1, 2, 4, 9, 10, 11, 13, 19). This study evaluated locally available eastern red cedar as an amendment to PB. Cedar is a coniferous species native to the Southeastern United States, growing between 12.2–15.2 m (40 and 50 ft) tall, and reaching spreads of 2.4–6.1 m (8 and 20 ft) (3). Specific cultivars of red cedar are excellent landscape plants, but the species, found native to hardwood forests, are thought to have an invasive habit (6).

In 1975, Self et al. (14) evaluated the growth of two azalea species in substrates composed of cedar, mahogany, and pine shavings. Results exhibited best growth in pine shavings followed by cedar shavings. Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) seedling production were evaluated by Griffin (6) using pine bark amended with 0%, 5%, 10%, 20%, 40%, and 80% cedar. Four fertilizers were also analyzed [0.81 kg $N\cdot m^{-3}$ (1.37 $lbs\cdot yd^{-3}$) control release fertilizer (CRF), 1.6 kg $N\cdot m^{-3}$ (2.70 $lbs\cdot yd^{-3}$) CRF, 0.4 kg $N\cdot m^{-3}$ (0.67 $lbs\cdot yd^{-3}$) Urea (46-0-0) or no fertilizer]. Response was similar between both species. Plants growing in 5, 20, and 40% cedar were similar to those grown in 100% pine bark; 10 and 80% cedar exhibited less height. Starr et al. (15) evaluated *Acer saccharinum* seed propagation in substrates composed of pine bark, cedar, and 20% sand with two fertilizer rates [low=4.5 kg $N\cdot m^{-3}$(7.58 $lbs\cdot yd^{-3}$), high=8.9 kg $N\cdot m^{-3}$(15.0 $lbs\cdot yd^{-3}$)]. Fertilizer had no significant effect on plant height. Those grown in 80% cedar had the least amount of growth. Up to 20% cedar had similar growth to those grown in pine bark. Results conclude cedar could be a potential replacement for pine bark with further development of substrate physical properties.

Taxodium distichum was evaluated in PB:sand substrates amended with percentages of eastern red cedar; data concluded there was little difference in plant height between the treatments (16). Starr et al. (17) evaluated *Rudbeckia fulgida* in substrate mixes of pine bark and cedar chips, passed through 0.5cm (0.1875in), 1cm (0.375in), 1.3cm (0.50in), or 1.9cm (0.75in) screen. Plant growth indices were similar and all plants were marketable. Shoot dry weight decreased with an increase in particle size. Cedar chips proved efficient as a container grown substrate for rudbeckia at all 4 screen sizes and performed best in 0.5cm screen size material. Recent data from Murphy et al. (13) has also shown that up to 50% fresh cut eastern red cedar has little to no difference when compared to a growers standard of 75:25 (v:v) peat:perlite in the production of *Petunia ×hybrida* 'Dreams Sky Blue', *Catheranthus roseus* 'Cooler Peppermint', and *Impatiens walleriana* 'Super Elfin Salmon'.

Thus far, limited research with cedar substrate has been conducted on woody nursery crop production. The objective of this study was to evaluate Eastern red cedar as an alternative substrate to PB in the nursery production of woody ornamental crops.

Materials and Methods

Experiment 1 (Exp. 1) was initiated May 16, 2011 and Exp. 2 was initiated April 25, 2012 at the Paterson Greenhouse Complex, Auburn University, Auburn, AL. Seven substrate treatments were evaluated: 100% PB, 95:5 PB:C, 90:10 PB:C, 80:20 PB:C, 60:40 PB:C, 20:80 PB:C, and 100% C. All treatments were incorporated with sand at a 6:1 (v:v) ratio substrate:sand. Cedar used for the Exp. 1 was harvested at ground level and de-limbed on April 7, 2011 at the Auburn Piedmont Research Station, Camp Hill, AL. Cedar was chipped through a Vermeer BC1400XL (Vermeer Co., Pella, IA) on April 12, 2011, then stored until processing through a hammer-mill (Williams Patent Crusher & Pulverizer Co., St. Louis, MO) on May 10, 2011. The study was initiated May 16, 2011. Cedar used for Exp. 2 was harvested and de-limbed April 3, 2012 chipped through a Vermeer BC1400XL (Vermeer Co., Pella, IA) on April 17, 2012 then processed through a hammer-mill (Williams Patent Crusher & Pulverizer Co., St. Louis, MO) on April 23, 2012. Experiment 2 was installed April 25, 2012. All cedar was milled to pass a 9.5 mm (3/8 in.) screen size. Substrates were incorporated with a 6:1 (v:v) ratio of sand, and amended with 8.31 kg·m^{-3} (14 lbs·yd^{-3}) 15.0N-2.64P-9.96K (15-6-12) Polyon (Harrell's Fertilizer, Inc., Lakeland, FL) control release fertilizer (8-9 months), 3.0 kg·m^{-3} (5 lbs·yd^{-3}) dolomitic limestone, and 0.9 kg·m^{-3} (1.5 lbs·yd^{-3}) Micromax (The Scotts Company, Marysville, OH).

Liners for Exp. 1 consisted of KnockOut rose (*Rosa* ×Knockout®), Reeves spirea (*Spiraea cantoniensis*), August Beauty gardenia (*Gardenia jasminoides* 'August Beauty'), Wintergreen boxwood (*Buxus microphylla japonica* 'Wintergreen'), Sargents juniper (*Juniperus chinensis* 'Sargentii'), Burgundy loropetalum (*Loropetalum chinensis* 'Burgundy'), Bandana Pink lantana (*Lantana camara* 'Landmark® Rose Glow'), Recurve ligustrum (*Ligustrum japonicum* 'Recurvifolium'), Premier blueberry (*Vaccinium ashei* 'Premier') and Formosa azalea (*Rhododendron indicum* 'Formosa'). Experiment 2 was conducted similarly with the following exceptions: Bandana Pink lantana (*Lantana camara* 'Bandana® Pink') was substituted for lantana species and substrate treatments were incorporated with 7.12 kg·m^{-3} (12 lbs·yd^{-3}) 17N-2.2P-9.13K (17-5-11) Polyon (Harrell's Fertilizer Inc., Lakeland, FL) control release fertilizer (8-9 months). In both experiments all plugs were transplanted from cell pack trays into a #1 container, except for Premier blueberry and Wintergreen boxwood which were planted in trade gallons. All plants were watered with overhead irrigation [1.27cm/day (0.5 in/day)]. Formosa azalea and Premier blueberry were kept under a 30% shade structure; all other species were placed in full sun.

The experimental design was a complete randomized block design with 8 single pot replications per treatment, except in Exp. 2, Sargents juniper had 6 single pot replications per treatment. Each species was treated as its own separate experiment. Data collected from the experiments includes physical properties (air space, water holding capacity, and total porosity), bulk density and particle-size distribution (n=3) (5). Particle size distribution (PSD) was determined by passing 100g sample [dried at 76.7°C (170°F) forced air oven] through a series of sieves (n=3). Leachates were collected from Formosa azalea using the Virginia Tech PourThru Method (n=4) (18). pH and EC ($mS \cdot cm^{-1}$) was measured at 7, 30, 60, and 180 days after potting (DAP). Growth indices [(height+width1+width2)/3] (cm) were also measured at termination (n=8). Leaf chlorophyll content was quantified nondestructively using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) at 180 DAP (n=8). Measurements were taken on single, healthy, fully expanded leaves. Three readings were recorded and averaged per replication. Root growth ratings were taken at 180 DAP on a scale from 1 to 5, where 1 was less than 20% root ball coverage, and 5 was between 80 to 100% root ball coverage (n=8). Substrate shrinkage was recorded at 180 DAP; with initial measure taken at 1 DAP (n=8).

All data was subject to analysis of variance using the general linear models procedure and multiple comparison of means, conducted using Tukey's Honest Significant Test at $\alpha = 0.05$ (Version 9.2; SAS Institute, Inc., Cary, NC).

Results and Discussion

Physical properties. The recommend range of physical properties for a standard growing media is between 10-30% air space (AS), 45-65% water holding capacity (WHC), and 50-85% total porosity (TP) percent per volume (20). In Exp. 1, substrate treatments containing 80% C (25.0%) and 100% C (29.5%) had higher AS than 100% PB (15.3%), while all other treatments were statistically similar (Table 3.1). Experiment 2 substrate AS exhibited no difference among substrates, all being within the recommended range. Substrate treatments for Exp. 1 had similar WHC to the 100% PB (46.3%). However, 80:20 PB:C (44.0%) and 90:10 PB:C (42.0%) were below the WHC optimal range. In Exp. 2, substrates WHC with cedar were similar to or greater than 100% PB (43.1%), with 20:80 PB:C (57.5%) having the greatest WHC. Those not within the recommended range include: 100% PB (43.1%), 95:5 PB:C (40.7%), and 90:10 PB:C (44.4%). Total porosity varied throughout the treatments in Exp. 1, but was greater for 20:80 PB:C (71.3%) and 100% C (78.0%) treatments. Experiment 2 TP was greatest for 20:80 PB:C (79.7%), with 100% PB (62.1%) having the least. All substrates for both Exp. 1 and Exp. 2 were within the optimum range for TP. Bulk density varied between the recommend ranges of 0.19-0.70 $g \cdot cm^{-3}$ for all treatments for both experiments. Experiment 1 had variability in BD with 100% PB (0.45 $g \cdot cm^{-3}$) having the greatest and 100% C (0.35 $g \cdot cm^{-3}$) the least. In Exp. 2 there was no difference in BD among substrate treatments.

Particle Size Distribution. Analysis of PSD in Exp. 1 showed that there were no differences across any treatment for the distribution of particles left on the 9.50 mm screen (Table 3.2). Many differences occurred in the smaller screen sizes. Therefore, the screens were grouped into three categories: coarse (3.35-9.50 mm), medium (1.00-2.36 mm), and fine (0.00-0.50 mm). Coarse particles for all treatments ranged from 3.4 (100% C) to 15.9% (95:5 PB:C), all substrates had similar values to the 100% PB (10.4%); these particles are responsible for substrate aeration. Medium particles were greatest for 100% C (40.9%) and least for 100% PB (26.3%). Fine particles were similar to 100% PB (63.3%) for all substrates except 60:40 PB:C (48.5%). In Exp. 2 substrates exhibited no difference for 3/8” screen size (Table 3.3). Particle size decreased with increasing cedar percents on the 1/4” screen with 95:5 PB:C (6.4%) having the most and 100% C (0.0%) having the least. After which greater differences occurred in the smaller screen sizes.

Coarse particles for all treatments ranged from 2.7 (100% C) to 24.9% (95:5 PB:C), these results are similar to the those in Exp. 1. The 100% C (2.7%) had the least amount of coarse particles due to its higher content of fine particles when compared to higher PB percentage substrates. Medium particles were higher for 20:80 PB:C (42.0%) and 100% C (41.3%) than all other substrates. The 80:20 PB:C (31.1%) substrate had the least amount of medium particles. Fine particles were greater in high cedar content treatments, with 100% C (60.0%) having the most and 95:5 PB:C (39.0%) having the least. Overall, coarse particles tended to be greater in Exp. 2 than in Exp. 1 for 4 of the 7 substrates. Fine Particles tended to be less in Exp. 2 except for 40 and 100% C.

pH and EC. Substrate pH levels ranged from 6.18 to 7.01 in Exp. 1 (Table 3.4). Each substrate was similar to the 100% PB at 1 (6.32), 30 (6.68), 60 (6.25), and 180 (6.40) DAP. In Exp. 2, substrate pH levels ranged from 5.04 to 7.23. pH at 7 DAP tended to increase with increasing cedar; 100% PB (5.04) having the lowest pH level and 20:80 PB:C (6.05) having the highest. At 30 DAP, pH levels were similar among all substrate treatments. At 60 DAP, all pH levels were greater than the 100% PB (6.35), with 80:20 PB:C (6.95) having the highest. By 180 DAP, pH had returned to increasing with increasing cedar, reaching the highest in 100% C (7.23). In general, pH levels tended to increase with the increasing percentages of cedar in the substrates. Electrical conductivity levels for Exp. 1 had no difference among treatments at 7, 60, and 180 DAP. At 30 DAP, 95:5 PB:C (0.71 $mS \cdot cm^{-1}$) had the highest EC level, all other treatments were similar to 100% PB (0.54 $mS \cdot cm^{-1}$). In Exp. 2 there was no difference in EC among substrates at 7 DAP. Levels varied at 30 DAP, substrates with up to 60% cedar were similar to the control (0.37 $mS \cdot cm^{-1}$). All levels were similar to 100% PB (0.34 $mS \cdot cm^{-1}$) at 60 DAP. By 180 DAP, EC readings had no difference between substrate treatments. Overall, EC levels generally increased at 30 DAP, then declined throughout the remaining of the study with average means being similar at 180 DAP.

Growth Indices. In Exp. 1, growth indices exhibited no statistical differences among Sargents juniper, Reeves spirea, Burgundy loropetalum, and Rose Glow lantana (Table 3.5). Minor differences were observed for Wintergreen boxwood, August Beauty gardenia and KnockOut rose. Boxwood grown in 100% C (15.6) was slightly smaller, but all were similar to 100% PB (18.5). All August Beauty gardenia GI were similar except for 100% C (36.9) having 25% less growth than 100% PB (49.4). KnockOut rose were statistically similar; plants grown in 80:20 PB:C (60.3) were slightly larger than those in 100% PB (59.0). Those exhibiting the greatest difference in GI among treatments include Formosa azalea, Premier blueberry, and Recurve ligustrum. Formosa azalea growth generally declined with increasing cedar levels. When cedar levels exceeded 20%, azaleas were 36% smaller than those grown in 100% PB. Three substrates were similar to 100% PB (42.2) for azalea including: 95:5 PB:C (44.3), 90:10 (40.6), and 80:20 PB:C (41.1). Growth for blueberry was similar to PB (36.9) in treatments with up to 20% C (33.4); above which stunting was visible. Ligustrum exhibited differences among treatments; all cedar substrate GI were similar to or greater than 100% PB (30.3), with 80:20 PB:C (42.4) having 40% greater growth PB.

In Exp. 2, there was no growth difference among all substrate treatments for Reeves spirea, KnockOut rose, Burgundy loropetalum, and Bandana Pink lantana. Growth indices for Sargents juniper were similar to the 100% PB control (21.4) with up to 40% C (24.8). All growth was similar to the control (45.9) for Formosa azalea, except 80:20 P:C (37.6) and 100% C (34.6) having less growth. Boxwood GI were similar to 100% PB (14.9) for all treatments. Gardenia exhibited similar growth to the 100% PB (55.9), except for 100% C (48.6) having 13% less growth. Treatments up to 20% C (55.0) had similar GI to the control (54.4) for Premier blueberry. All treatments GI were similar to or greater than the control (56.5) for Recurve ligustrum.

Leaf Chlorophyll Content. Due to foliage color and texture, LCC was not measured on Burgundy loropetalum, Wintergreen boxwood, and Sargents juniper. Experiment 1 showed no difference in LCC among substrates for August Beauty gardenia, Formosa azalea, Recurve ligustrum, KnockOut rose, Premier blueberry, and Rose Glow lantana (Table 3.6.). Reeves spirea exhibited little difference in LCC with all treatments similar to the control (45.0), with 100% C (49.1) having the highest. In Exp. 2, Reeves spirea, Formosa azalea, Recurve ligustrum, KnockOut rose, and Bandana Pink lantana exhibited no difference in LCC among treatments compared to the 100% PB control treatment. All treatments for August Beauty gardenia and Premier blueberry were similar to the standard 100% PB (60.6, 53.3 respectively) except 90:10 PB:C (58.1, 46.4 respectively). Overall, LCC exhibited no difference among substrates for four species in both studies.

Shrinkage. There was no difference in substrate shrinkage for Sargents juniper, Formosa azalea and Rose Glow lantana in Exp. 1 (Table 3.7). Three substrates experienced greater shrinkage than 100% PB (0.00 cm) for Reeves spirea including: 80:20 PB:C (0.44 cm), 60:40 PB:C (0.50 cm), and 20:80 PB:C (0.50cm). All substrates for Wintergreen boxwood and Premier blueberry experienced similar to or less substrate shrinkage than 100% PB (1.00 cm, 2.56 cm respectively). August Beauty gardenia in cedar substrates exhibited similar shrinkage to 100% PB (0.13 cm) except for 20:80 PB:C (0.81 cm). Substrate shrinkage for KnockOut rose was similar to 100% PB (1.69 cm), except for 80:20 PB:C (3.19 cm) having the greatest. Burgundy loropetalum and Recurve ligustrum substrates exhibited similar shrinkage to the control 100% PB (0.38 cm, 0.25

cm respectively). In Exp. 2, no difference occurred in substrate shrinkage for Sargents juniper, Formosa azalea, August Beauty gardenia, KnockOut rose, Premier blueberry Recurve ligustrum and Bandana Pink lantana. Reeves spirea shrinkage was similar to the 100% PB (0.75 cm) except for 95:5 PB:C (0.13 cm) having less shrinkage. Wintergreen boxwood in cedar experienced similar shrinkage to 100% PB (0.63 cm) except for 20:80 PB:C (1.94 cm) having greater shrinkage. Two substrates, 20:80 PB:C (1.25 cm) and 100% C (1.25 cm), had greater substrate shrinkage than 100% PB (0.31 cm) for Burgundy loropetalum. Overall, there were slight differences is substrate shrinkage among treatments.

Root Ratings. Root ratings for Exp. 1 exhibited no difference in root grown for 9 of the 10 species (Table 3.8). Sargents juniper exhibited a slight variation in root growth in 5% cedar; all substrates were comparable to the 100% PB treatment. In Exp. 2, Reeves spirea, August Beauty gardenia and Bandana Pink lantana showed no difference in RR between substrates. Root ratings for Sargents juniper, KnockOut rose, and Recurve ligustrum were all similar to the control (3.2, 4.1, 4.0 respectively). Most Formosa azalea RR were similar to the control (4.4); those that were not include 80:20 PB:C (3.1) and 100% C (2.8) which was 38% less than 100% PB. Three substrate treatments for boxwood were similar to 100% PB (2.8) including: 95:5 PB:C (3.4), 80:20 PB:C (3.3), and 60:40 PB:C (3.4); remaining treatments had greater RR. Premier blueberry RR were similar to 100% PB (4.6) except 60:40 PB:C (3.0) and 100% C (2.9). Root ratings for Burgundy loropetalum were similar to the control (4.8) for three treatments: 95:5 PB:C (3.8), 90:10 PB:C (4.1), and 60:40 PB:C (4.1); the remaining treatments were up to 44% less (100% C).

Conclusion

Overall, physical properties exhibited an increase in air space and total porosity with an increase in cedar. Bulk density varied, Exp. 1 exhibited a decrease with increasing cedar and Exp. 2 showed no difference among substrates. Particle size had an overall decrease in size with high cedar substrates containing the greatest percentage of fine particles, which are necessary for adequate substrate water holding capacity. In general, 7 of the 10 species grew equally well in substrates amended with up to 100% cedar when compared to PB in Exp. 1. August Beauty gardenia growth was similar to PB in substrates amended with up to 80% cedar. Premier blueberry and Formosa azalea did not grow as well in cedar above 20%. Experiment 2 exhibited similar trends among species. Premier blueberry did not grow as well in cedar above 40%. However, Formosa azalea grew similar to PB in up to 80% cedar. The other 8 species performed similar to those in Exp. 1 with the exception of Sargents juniper, which had a decrease in growth in substrates amended above 40% cedar. These results agree with previous research by Starr et al. (16), where *Taxodium distichum* had similar growth in 40 and 80% cedar chips compared to those grown in PB. Results from Murphy et al. (13) showed that up to 50% cedar may be amended to peat moss without a decrease in the growth of annuals. Overall, data shows that PB amended with cedar provides a suitable substrate for woody nursery crops, except with acid loving species. In conclusion, Eastern red cedar has potential for production of ornamental species.

Literature Cited

1. Boyer, C.R. G.B. Fain, C.H. Gilliam. T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2008. Growth of woody plants in clean chip residual substrate. Poplar Publication. Center for Applied Nursery Research.

2. Broussard, C., E. Bush, and A. Owings. 1999. Effects of hardwood and pine bark on growth response of woody ornamentals. Proc. Southern Nurs. Assoc. Res. Conf. 44:57-60.

3. Dirr, M.A. 1998. Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses. 5th ed. Stipes Publishing LLC, Champaign, IL.

4. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008. WholeTree substrates derived from three species of pine in production of annual vinca. HortTechnology 18:13-17.

5. Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer. Horticultural Substrates Laboratory, North Carolina State University, Raleigh, NC.

6. Griffin, J. 2009. Eastern red-cedar (*Juniperus virginiana*) as a substrate component for container production of woody plants. HortScience 44:1131 (Abstr.).

7. Haynes, R.W. 2003. An analysis of the timber situation in the United States: 1952-2050. Gen. Tech. Rept. PNW-GTR-560. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR.

8. Ingram, D.L., R.W. Henley, and T.H. Yeager. 1991. Growth media for container grown ornamental plants. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

9. Jackson, B.E. and R.D. Wright. 2009. Pine tree substrate: An alternative and renewable substrate for horticultural crop production. ActaHort. 819:265-272.

10. Jackson, B.E., R.D. Wright, and M.C. Barnes. 2010. Methods of constructing a pine tree substrate from various wood particle sizes, organic amendments, and sand for desired physical properties and plant growth. HortScience 45:103-112.

11. Laiche, A.J. and V.E. Nash. 1986. Evaluation of pine bark, pine bark with wood, and pine tree chips as components of a container plant growing media. J. Environ. Hort. 4:22-25.

12. Lu, W. J.L. Sibley. C.H. Gilliam, J.S. Bannon, and Y. Zhang. 2006. Estimation of U.S. bark generation and implications for horticultural industries. J. Environ. Hort. 24:29-34.

13. Murphy, A.M., C.H. Gilliam, G.B. Fain, H.A. Torbert. T.V. Gallagher, J.L. Sibley, and C.R. Boyer. 2011. Low-value trees as alternative substrates in greenhouse production of three annual species. J. Environ. Hort. 29:152-161.

14. Self, R.L. 1975. Comparison of cedar, mahogany, and pine shavings in azalea potting mixtures. Proc. Southern Nursery Assoc. Res. Conf. 20:14.

15. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2010. Growth of containerized *Acer saccharinum* from seed in a cedar-amended substrate. HortScience 45:S234 (Abstr.).

16. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2010. Growth of containerized *Taxodium distichum* in a cedar-amended substrate. Proc. Southern Nurs. Assoc. Res. Conf. 55:344-346.

17. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2011. Cedar substrate particle size affects growth of container-grown rudbeckia. Proc. Southern Nurs. Assoc. Res. Conf. 56:236-240.

18. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

19. Wright, R.D., J.F. Browder, and B.E. Jackson. 2006. Ground pine chips as a substrate for container-grown wood nursery crops. J. Environ. Hort. 24:181-184.

20. Yeager, T., T. Bilderback, D. Fare, C.H. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R.D. Wright. 2007. Best management practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assoc., Atlanta, GA.

Table 3.1. Physical properties of seven substrates containing pine bark and cedar[z].

Substrate	Air Space[y]		Water holding capacity[x]		Total Porosity[w]		Bulk Density[v]	
	Exp. 1	Exp.2	Exp. 1	Exp.2	Exp. 1	Exp.2	Exp. 1	Exp.2
	(% vol)		(% vol)		(% vol)		($g \cdot cm^{-3}$)	
100% PB[u]	15.3b[t]	19.0[ns]	46.3ab	43.1bc	62.7c	62.1c	0.45a	0.31[ns]
95:5 PB:Cedar	22.3ab	24.4	45.0ab	40.7c	67.3bc	65.1bc	0.36de	0.39
90:10 PB:Cedar	21.3ab	25.0	42.0b	44.4abc	63.3c	69.4abc	0.39bcd	0.32
80:20 PB:Cedar	20.3ab	21.1	44.0ab	47.1abc	64.3bc	68.2abc	0.40bc	0.43
60:40 PB:Cedar	22.7ab	19.4	46.3ab	49.1abc	69.0bc	68.6abc	0.37cde	0.38
20:80 PB:Cedar	25.0a	22.2	46.0ab	57.5a	71.3ab	79.7a	0.41b	0.37
100% Cedar	29.5a	21.4	48.5a	54.2ab	78.0a	75.6ab	0.35e	0.40
Recommended Range[s]	10-30%		45-65%		50-85%		0.19-0.70	

[z]Analysis performed using the North Carolina State University porometer (http://www.ncsu.edu/project/hortsublab/diagnostic/porometer/).
[y]Air space is volume of water drained from the sample / volume of the sample.
[x]Water holding capacity is (wet weight - oven dry weight) / volume of the sample.
[w]Total porosity is substrate water holding capacity + air space.
[v]Bulk density after forced-air drying at 105°C (221.0°F) for 48 hrs; 1 $g \cdot cm^{-3}$ = 62.4274 $lb \cdot ft^{-3}$.
[u]PB = pine bark.
[t]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range Test at $\alpha = 0.05$ (n = 3).
[s]Recommended ranges as reported by Yeager, et al., 2007. Best Management Practices Guide for Producing Container-Grown Plants.

Table 3.2. Particle size distribution[z] analysis of seven substrates containing pine bark and cedar[y] (Experiment 1)[x].

U.S. standard sieve no.	sieve opening (mm)[w]	Substrates: 100% Pine Bark (PB)	95:5 PB: Cedar	90:10 PB: Cedar	80:20 PB: Cedar	60:40 PB: Cedar	20:80 PB: Cedar	100% Cedar
3/8	9.50	0.1[v,ns]	0.0	0.0	0.0	0.0	0.0	0.0
1/4	6.35	1.6abc	3.0a	2.3ab	1.7abc	1.8abc	0.7bc	0.0c
6	3.35	8.6ab	12.9a	10.7ab	10.0ab	12.4a	5.9bc	3.4c
8	2.36	6.4b	8.7ab	7.5ab	7.6ab	9.73a	8.0ab	6.5b
10	2.00	2.7d	3.6bcd	3.2cd	3.0d	4.5ab	4.3abc	5.03a
14	1.40	7.8c	9.8c	9.8c	9.4c	12.1b	12.5b	15.6a
18	1.00	9.4c	9.7c	10.2c	10.0c	10.7bc	11.7b	13.7a
35	0.50	31.8a	27.6ab	28.5ab	29.5ab	26.1b	29.8ab	30.8a
60	0.25	26.2a	19.7ab	21.9ab	22.9ab	17.7b	22.0ab	20.5ab
140	0.11	4.4[ns]	3.7	4.5	4.4	3.4	3.7	3.5
270	0.05	0.6[ns]	0.7	0.9	0.8	0.9	0.8	0.6
pan	0.00	0.2[ns]	0.4	0.3	0.4	0.3	0.3	0.1
Texture[u]								
Coarse		10.4abc	15.9a	13.1ab	11.7ab	14.3a	6.7bc	3.4c
Medium		26.3d	31.9bcd	30.8bc	30.2d	37.2ab	36.7abc	40.9a
Fine		63.3a	52.2ab	56.1ab	58.1ab	48.5b	56.7ab	55.6ab

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).

[y]Cedar processed through 0.95 cm (3/8") hammer-mill screen size.

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

[w]1 mm = 0.0394 in.

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

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

[ns]Means not significanly different.

Table 3.3. Particle size distribution[z] analysis of seven substrates containing pine bark and cedar[y] (Experiment 2)[x].

U.S. standard sieve no.	sieve opening (mm)[w]	Substrates: 100% Pine Bark (PB)	95:5 PB: Cedar	90:10 PB: Cedar	80:20 PB: Cedar	60:40 PB: Cedar	20:80 PB: Cedar	100% Cedar
3/8	9.50	0.3[v,ns]	0.4	0.6	0.2	0.1	0.0	0.0
1/4	6.35	5.2ab	6.4a	4.8ab	4.4ab	3.5b	1.4c	0.0c
6	3.35	16.4ab	18.2a	14.6bc	12.3cd	10.5d	5.2e	2.7e
8	2.36	9.7a	10.1a	8.7ab	7.0c	7.0c	7.6bc	6.1c
10	2.00	3.9[ns]	3.9	3.4	3.3	4.3	4.3	4.3
14	1.40	10.3bcd	10.9bc	9.9cd	9.6d	11.5b	14.6a	14.4a
18	1.00	10.4c	11.1c	10.8c	11.1c	13.1b	15.5a	16.4a
35	0.50	25.4d	25.3d	27.7cd	30.5bc	31.5b	31.8b	35.8a
60	0.25	15.0ab	11.8b	16.1a	18.2a	15.2a	16.5a	17.0a
140	0.11	2.4a	1.6b	2.6a	2.6a	2.4a	2.6a	2.6a
270	0.05	0.6ab	0.2b	0.5ab	0.5ab	0.7a	0.4ab	0.4ab
pan	0.00	0.4a	0.1b	0.1b	0.3ab	0.2ab	0.1b	0.1b
Texture[u]								
Coarse		21.9ab	24.9a	20.1ab	16.8bc	14.1c	6.6d	2.7d
Medium		34.3bc	36.0b	32.9bc	31.1c	36.0b	42.0a	41.3a
Fine		43.8cd	39.0d	47.0bc	52.1ab	49.9abc	51.4ab	60.0a

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).
[y]Cedar processed through 0.95 cm (3/8") hammer-mill screen size.
[x]Particle size distribution analysis determined before the addition of incorporated amendments.
[w]1 mm = 0.0394 in.
[v]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on Tukey's Honestly Significant Difference Test at $\alpha = 0.05$ (n = 3).
[u]Coarse = 3.35-9.50 mm; Medium = 1.00-2.36 mm; Fine = 0.00-0.50 mm.
[ns]Means not significanly different.

Table 3.4. Effect of seven substrates containing pine bark and cedar on pH and electrical conductivity (EC) in azaleas[z].

	Exp. 1		Exp. 2		Exp. 1		Exp. 2	
Substrate[y]	**pH**	**EC[x] ($mS\cdot cm^{-1}$)[w]**	**pH**	**EC ($mS\cdot cm^{-1}$)**	**pH**	**EC ($mS\cdot cm^{-1}$)**	**pH**	**EC ($mS\cdot cm^{-1}$)**
	7 DAP[v]				**30 DAP**			
100% PB	6.32ab	0.34[u,ns]	5.04d	0.33[ns]	6.68ab	0.54ab	6.28[ns]	0.37c
95:5 PB:Cedar	6.29b	0.42	5.42c	0.14	6.23b	0.71a	6.66	0.35c
90:10 PB:Cedar	6.33ab	0.40	5.35c	0.14	6.18b	0.50ab	6.87	0.32c
80:20 PB:Cedar	6.64ab	0.38	5.42c	0.16	6.55ab	0.55ab	7.56	0.53c
60:40 PB:Cedar	6.58ab	0.37	5.74b	0.14	6.72ab	0.46b	6.78	0.38bc
20:80 PB:Cedar	6.48ab	0.37	6.05a	0.15	7.01a	0.66ab	6.76	0.52a
100% Cedar	6.68ab	0.34	5.99ab	0.23	6.99a	0.47ab	6.85	0.48ab
	60 DAP				**180 DAP**			
100% PB	6.25ab	0.39[ns]	6.35c	0.34ab	6.40abc	0.24[ns]	6.80c	0.23[ns]
95:5 PB:Cedar	5.66b	0.57	6.65b	0.38ab	6.24c	0.27	6.99b	0.23
90:10 PB:Cedar	6.22ab	0.34	6.90a	0.33b	6.20c	0.25	6.92bc	0.23
80:20 PB:Cedar	6.29a	0.36	6.95a	0.36ab	6.55abc	0.24	7.06ab	0.24
60:40 PB:Cedar	6.52a	0.37	6.90a	0.38ab	6.49abc	0.26	7.18a	0.24
20:80 PB:Cedar	6.71a	0.41	6.93a	0.38ab	6.74ab	0.27	7.19a	0.23
100% Cedar	6.73a	0.37	6.93a	0.40a	6.79a	0.27	7.23a	0.24

[z]pH and EC of solution determined using pour-through method on 'Formosa' azalea.

[y]PB = pine bark.

[x]EC = electrical conductivity

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

[v]DAP = days after potting.

[u]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range (HSD) Test at $\alpha = 0.05$ (n = 4).

[ns] Means not significantly different.

Table 3.5. Effect of seven substrates containing pine bark and cedar on growth indices[z] of 10 woody plant species at termination (180 DAP[y]).

	'Sargentii' juniper		'Reeves' spirea		'Formosa' azalea		'Wintergreen' boxwood	
Substrate[x]	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB	37.4 [w,ns]	21.4 ab	61.6 [ns]	89.4 [ns]	42.2 a	45.9 a	18.5 ab	14.9 ab
95:5 PB:Cedar	34.6	21.0 abc	64.9	101.8	44.3 a	46.6 a	17.2 ab	18.8 a
90:10 PB:Cedar	36.4	20.2 abc	58.7	97.5	40.6 a	42.0 ab	18.4 ab	16.9 ab
80:20 PB:Cedar	40.4	20.5 abc	65.2	112.3	41.1 a	37.6 bc	19.0 ab	13.3 b
60:40 PB:Cedar	36.8	24.8 a	59.2	96.1	32.7 b	43.4 ab	19.7 a	14.6 ab
20:80 PB:Cedar	32.4	13.7 c	59.4	93.9	27.4 b	45.8 a	17.7 ab	18.0 ab
100% Cedar	33.3	14.2 bc	56.5	92.8	26.9 b	34.6 c	15.6 b	16.5 ab
	'August Beauty' gardenia		'KnockOut' rose		'Premier' blueberry		'Burgundy' loropetalum	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB	49.4 a	55.9 a	59.0 ab	62.0 [ns]	36.9 a	54.4 a	46.8 [ns]	49.0 [ns]
95:5 PB:Cedar	49.8 a	50.8 ab	53.2 ab	64.4	32.3 abc	42.6 abc	47.7	48.4
90:10 PB:Cedar	50.2 a	50.9 ab	55.4 ab	65.4	36.1 ab	48.8 ab	50.0	51.6
80:20 PB:Cedar	47.5 a	50.8 ab	60.3 a	57.8	33.4 abc	55.0 a	47.6	52.7
60:40 PB:Cedar	47.9 a	55.6 a	54.6 ab	64.8	27.1 cd	39.4 bcd	46.8	53.6
20:80 PB:Cedar	44.2 a	53.3 ab	50.3 b	63.4	28.0 bcd	33.0 cd	43.8	53.1
100% Cedar	36.9 b	48.6 b	50.9 ab	63.1	20.8 d	27.6 d	43.4	48.0
	'Recurvifolium' ligustrum		'Rose Glow' lantana		'Bandana Pink' lantana			
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2[v]	Exp. 1[v]	Exp. 2		
100% PB	30.3 cd	56.5 b	55.1 [ns]	-	-	48.4 [ns]		
95:5 PB:Cedar	34.3 bcd	58.6 b	56.9	-	-	49.9		
90:10 PB:Cedar	40.9 ab	70.0 a	55.1	-	-	48.8		
80:20 PB:Cedar	42.4 a	58.6 b	56.0	-	-	46.8		
60:40 PB:Cedar	35.0 abcd	55.9 b	57.3	-	-	50.8		
20:80 PB:Cedar	37.7 abc	62.1 ab	56.9	-	-	46.8		
100% Cedar	29.3 d	59.3 ab	47.6	-	-	50.6		

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

[y]PB = pine bark.

[x]DAP = days after potting.

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

[v]Species was not evaluated in this experiment.

[ns]Means not significanly different.

Table 3.6. Effect of seven substrates containing pine bark and cedar on leaf chlorophyll content[z] of ten woody plant species at termination (180 DAP[y]).

	'August Beauty' gardenia		'Reeves' spirea		'Formosa' azalea		'Recurvifolium' ligustrum	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB[x]	70.6 [w,ns]	60.6 a	45.0 ab	43.7 [ns]	55.5 [ns]	58.9 [ns]	62.8 [ns]	65.3 [ns]
95:5 PB:Cedar	70.7	64.5 ab	44.1 b	43.3	56.9	55.7	65.9	61.3
90:10 PB:Cedar	66.8	58.1 b	44.3 b	44.3	54.9	58.7	67.2	63.4
80:20 PB:Cedar	67.1	59.1 ab	46.4 ab	43.8	54.8	59.5	63.9	63.5
60:40 PB:Cedar	71.4	65.1 ab	43.7 b	46.7	55.2	57.8	62.5	67.2
20:80 PB:Cedar	70.6	62.6 ab	45.0 ab	49.0	55.3	61.2	65.8	66.4
100% Cedar	68.5	59.8 ab	49.1 a	45.3	53.3	60.6	70.0	65.4
	KnockOut' rose		**'Premier' blueberry**		**'Rose Glow' lantana**		**'Bandana Pink' lantana**	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2[v]	Exp. 1[v]	Exp. 2
100% PB	50.5 [ns]	42.9 [ns]	53.4 [ns]	53.3 ab	34.4 [ns]	-	-	32.8 [ns]
95:5 PB:Cedar	46.7	44.0	54.8	51.9 ab	33.5	-	-	32.9
90:10 PB:Cedar	50.8	44.5	54.4	46.4 b	37.4	-	-	34.1
20:80 PB:Cedar	49.8	44.3	54.8	51.4 ab	37.8	-	-	32.5
60:40 PB:Cedar	51.2	44.0	54.2	49.9 ab	35.1	-	-	32.5
20:80 PB:Cedar	50.4	42.8	54.7	55.7 a	38.9	-	-	32.7
100% Cedar	50.2	42.3	53.8	49.3 ab	36.0	-	-	32.8

[z]Leaf Chlorophyll Content was taken were taken on single, healthy, fully expanded leaves; three readings were recorded and averaged per replication using a SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) at 180 DAP (n = 8).

[y]DAP = days after potting.

[x]PB = pine bark.

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

[v]Species was not evaluated in this experiment.

[ns]Means not significanly different.

Table 3.7. Effect of seven substrates containing pine bark and cedar on shrinkage[z] of ten woody plant species at termination (180 DAP[y]).

	'Sargentii' juniper		'Reeves' spirea		'Formosa' azalea		'Wintergreen' boxwood	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB[x]	0.31 [w,ns]	1.25 [ns]	0.00 b	0.75 a	1.69 [ns]	0.81 [ns]	1.00 a	0.63 b
95:5 PB:Cedar	0.31	0.75	0.00 b	0.13 b	1.37	0.63	0.25 bc	0.88 b
90:10 PB:Cedar	0.00	0.83	0.25 ab	0.38 ab	1.81	0.50	0.06 c	0.98 ab
80:20 PB:Cedar	0.06	1.08	0.44 a	0.25 ab	1.25	0.88	0.19 c	0.94 b
60:40 PB:Cedar	0.06	1.42	0.50 a	0.56 ab	1.06	0.56	0.38 abc	0.94 b
20:80 PB:Cedar	0.19	2.00	0.50 a	0.44 ab	1.00	1.13	0.94 ab	1.94 a
100% Cedar	0.06	1.75	0.13 ab	0.31 ab	1.06	1.13	1.00 a	1.13 ab
	'August Beauty' gardenia		**'KnockOut' rose**		**'Premier' blueberry**		**'Burgundy' loropetalum**	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB	0.13 b	0.81 [ns]	1.69 b	0.06 [ns]	2.56 a	0.88 [ns]	0.38 abc	0.31 b
95:5 PB:Cedar	0.00 b	0.38	1.94 b	0.25	1.63 bc	0.75	0.25 abc	0.38 b
90:10 PB:Cedar	0.06 b	0.38	2.38 ab	0.13	1.00 c	1.06	0.25 abc	0.75 ab
80:20 PB:Cedar	0.25 b	0.13	2.13 ab	0.31	1.81 abc	0.75	0.00 c	0.88 ab
60:40 PB:Cedar	0.19 b	0.50	2.63 ab	0.44	1.88 ab	0.94	0.13 bc	1.06 ab
20:80 PB:Cedar	0.81 a	0.50	3.19 a	0.38	2.19 ab	0.88	0.75 a	1.25 a
100% Cedar	0.31 b	0.71	2.25 ab	0.56	2.63 a	0.75	0.63 ab	1.25 a
	'Recurvifolium' ligustrum		**'Rose Glow' lantana**		**'Bandana Pink' lantana**			
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2[v]	Exp. 1[v]	Exp. 2		
100% PB	0.25 ab	0.81 [ns]	0.21 [ns]	-	-	0.31 [ns]		
95:5 PB:Cedar	0.25 ab	0.69	0.00	-	-	0.44		
90:10 PB:Cedar	0.13 b	0.69	0.00	-	-	0.19		
20:80 PB:Cedar	0.31 ab	0.50	0.19	-	-	0.31		
60:40 PB:Cedar	0.13 b	0.50	0.06	-	-	0.19		
20:80 PB:Cedar	0.69 a	0.63	0.06	-	-	0.63		
100% Cedar	0.25 ab	0.38	0.31	-	-	0.44		

[z]Shrinkage reported in cm is the difference in substrate level from study initiation to termination, measuring from the top of pot to top of media.

[y]DAP = days after potting.

[x]PB = pine bark.

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

[v]Species was not evaluated in this experiment.

[ns]Means not significanly different.

Table 3.8. Effect of seven substrates containing pine bark and cedar on root growth[z] of ten woody plant species at termination (180 DAP[y]).

	'Sargentii' juniper		**'Reeves' spirea**		**'Formosa' azalea**		**'Wintergreen' boxwood**	
Substrate[x]	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB	3.3 ab[w]	3.2 ab	5.0 [ns]	5.0 [ns]	4.5 [ns]	4.4 a	3.4 [ns]	2.8 b
95:5 PB:Cedar	2.5 b	2.5 b	5.0	5.0	4.6	4.6 a	3.4	3.4 ab
90:10 PB:Cedar	3.1 ab	2.8 ab	5.0	5.0	4.0	4.0 ab	3.5	4.1 a
80:20 PB:Cedar	3.6 ab	4.0 a	5.0	5.0	4.4	3.1 bc	3.5	3.3 ab
60:40 PB:Cedar	3.1 ab	4.2 a	5.0	5.0	4.0	3.6 abc	4.0	3.8 ab
20:80 PB:Cedar	3.3 ab	3.0 ab	5.0	5.0	3.8	4.0 ab	3.1	4.5 a
100% Cedar	3.8 a	2.0 b	5.0	5.0	4.0	2.8 c	3.0	4.1 a
	'August Beauty' gardenia		**'KnockOut' rose**		**'Premier' blueberry**		**'Burgundy' loropetalum**	
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2	Exp. 1	Exp. 2
100% PB	5.0 [ns]	5.0 [ns]	3.8 [ns]	4.1 ab	4.9 [ns]	4.6 a	4.0 [ns]	4.8 a
95:5 PB:Cedar	5.0	5.0	3.9	4.1 ab	4.6	3.6 ab	3.9	3.8 abc
90:10 PB:Cedar	4.9	5.0	4.1	4.8 a	5.0	4.1 a	4.4	4.1 ab
80:20 PB:Cedar	5.0	5.0	4.4	3.5 ab	4.4	4.4 a	3.9	3.5 bcd
60:40 PB:Cedar	4.9	4.9	3.6	3.9 ab	4.6	3.0 b	3.8	4.1 ab
20:80 PB:Cedar	4.9	5.0	4.3	3.0 b	4.1	3.9 ab	3.8	3.0 cd
100% Cedar	4.6	4.0	4.5	2.8 b	4.1	2.9 b	3.6	2.7 d
	'Recurvifolium' ligustrum		**'Rose Glow' lantana**		**'Bandana Pink' lantana**			
Substrate	Exp. 1	Exp. 2	Exp. 1	Exp. 2[v]	Exp. 1[v]	Exp. 2		
100% PB	4.0 [ns]	4.0 ab	5.0 [ns]	-	-	5.0 [ns]		
95:5 PB:Cedar	4.3	4.3 a	5.0	-	-	5.0		
90:10 PB:Cedar	4.4	4.3 a	5.0	-	-	5.0		
80:20 PB:Cedar	4.4	4.0 ab	5.0	-	-	5.0		
60:40 PB:Cedar	4.3	3.0 b	5.0	-	-	5.0		
20:80 PB:Cedar	4.3	4.0 ab	5.0	-	-	5.0		
100% Cedar	3.8	4.0 ab	5.0	-	-	5.0		

[z]Root Growth was on a scale 1 to 5 (1 = 20% root ball coverage, 5 = 80 to 100% root ball coverage).

[y]DAP = days after potting.

[x]PB = pine bark.

[w]Means within column followed by the same letter are not significantly different based on Tukey's Studentized Range Test at α=0.05 (n = 8).

[v]Species was not evaluated in this experiment.

[ns]Means not significanly different.

CHAPTER IV

Eastern Red Cedar as an Alternative Amendment in the Greenhouse Production of Annuals using a Starter Fertilizer

Abstract

Due to the concerns of peat moss availability, potential substrate alternatives for growing plants are being sought by growers and researchers. Eastern red cedar (*Juniperus virginiana* L.) (RC) was evaluated as a potential substrate amended with four different fertilizer rates in greenhouse production of *Antirrhinum majus*, *Viola ×wittrockiana*, and *Petunia ×hybrida*. Only the shoot portion of the RC tree was harvested, de-limbed, chipped, and further processed through a hammer-mill to pass either a 0.125 in. or 0.75 in. screen; the resulting RC substrate was a 50:50 (v:v) ratio mix of both screen sizes. Cedar was used alone or combined with 0, 25, 50, or 75% peat moss (PM). Treatments were compared to a standard of either Pindstrup (European peat product) (P) (Exp. 1 and Exp. 3) or peat moss (Exp. 2 and 3.). A 12N-2.64P-6.64K slow release fertilizer was added to each substrate at 0.0, 0.59, 1.19, or 2.37 $kg{\cdot}m^{-3}$ (0.0, 1.0, 2.0, or 4.0 $lbs{\cdot}yd^{-3}$, respectively). Results showed snapdragons grown in up to 75% RC at the 2.37 $kg{\cdot}m^{-3}$ fertilizer rate were comparable to those grown in 2.37 $kg{\cdot}m^{-3}$ 100% P. Pansies grown in up to 50% RC with 2.37 $kg{\cdot}m^{-3}$ of fertilizer were similar to those grown in 2.37 $kg{\cdot}m^{-3}$ 100% PM. Petunia growth was similar for all substrates with up to 100% cedar when amended with 1.19 $kg{\cdot}m^{-3}$ of fertilizer. In conclusion, data shows RC has potential as an alternative to peat moss amended up to 50% with the addition of fertilizer.

Index words: alternative substrate, peatmoss, annual production

Species used in this study: Eastern red cedar (*Juniperus virginiana* L.); Pansy (*Viola ×wittrockiana* Gams. 'True Blue') and (*Viola ×wittrockiana* Gams. ''Majestic Giant Deep Blue'); Snapdragon (*Anthirrhinum majus* L. 'Montego Pink') and (*Anthirrhinum majus* L. 'Snapshot Pink'); Petunia (*Petunia ×hybirda* Juss. 'Dreams Burgundy')

Significance to the Industry

Peat, which has historically been readily available and relatively inexpensive, has been the most popular substrate component of greenhouse production for the past forty to fifty years. Peat contains stable organic material with high water and air holding capacity. However, peat availability has decreased due to recent concerns regarding the destructive and non-sustainable harvesting of peat. Additionally, Canadian sources of peat moss have been affected in recent years by climate conditions (12). These limitations coincide with the increasing cost in peat extraction, processing, and transportation leading growers to evaluate alternative substrates (9).

Introduction

Previous alternative substrate research has focused on high wood fiber content substrates, evaluating whole pine trees, chipped pine logs, and residual material left from in-field harvesting as potential substrates (1, 2, 5, 16). Recent research has also evaluated low-value forest trees including sweet- gum (*Liquidambar styraciflua* L.), hickory (*Carya sp.* Nutt.) and eastern red cedar (*Juniperus virginiana* L.) (10).

In this study, eastern red cedar (RC) was evaluated as a potential substrate in greenhouse annual production. Red cedar is a coniferous species native to east and central North America, primarily east of the Rocky Mountains growing between 12-15 m (40-50 ft) tall, and reaching spreads of 2-6 m (8-20 ft) (4). It has become known as a 'weed species', indicating RC may have potential to be an economical and viable amendment in standard greenhouse substrates. In 1975, best growth results for two azalea species were shown with ‘pine shavings followed by cedar shavings’ (11). Research, by Griffin (7), evaluated RC in the container production of woody ornamentals. Seedling Chinese pistache (*Pistacia chinensis*) and Indian-cherry (*Frangula caroliniana*) were evaluated in 6 substrate treatments containing pine bark (PB) and varying percentages of RC. Four fertilizer rates were evaluated [0.81 kg $N{\cdot}m^{-3}$ (1.37 $lbs{\cdot}yd^{-3}$) control release fertilizer (CRF), 1.6 kg $N{\cdot}m^{-3}$ (2.70 $lbs{\cdot}yd^{-3}$) CRF, 0.4 kg $N{\cdot}m^{-3}$ (0.67 $lbs{\cdot}yd^{-3}$) Urea (46-0-0) or no fertilizer]. Plant growth for both species in 5, 20, and 40% RC was similar to PB, but less in substrates amended with 10 and 80% RC.

Results from Starr et al. (13) show RC has potential as a replacement for pine bark in the propagation of *Acer saccharinum* seed propagation. Five substrates of RC were evaluated with two fertilizer rates rates [low=4.5 kg $N{\cdot}m^{-3}$(7.58 $lbs{\cdot}yd^{-3}$), high=8.9 kg $N{\cdot}m^{-3}$(15.0 $lbs{\cdot}yd^{-3}$)]. Fertilizer had no effect on plant growth. Plants propagated in 0% and 20% RC had similar root dry weight and shoot dry weight. Starr et al. (14) also evaluated five substrates using PB and RC chips passed through a 0.5cm (0.1875in), 1cm (0.375in), 1.3cm (0.50in), or 1.9cm (0.75in) screen for rudbeckia (*Rudbeckia fulgida*) production. Cedar chips proved efficient as a container grown substrate for rudbeckia at all 4 screen sizes, with best performance in 1/16- inch screen size material, indicating RC also has potential in perennial production. To date, limited research has investigated the use of RC as an alternative substrate for greenhouse annual production. Murphy et al. (10) concluded that greenhouse substrates with up to 50% freshly cut RC exhibited little to no difference in plant growth of petunia (*Petunia* ×*hybrida* Juss. ‘Dreams Sky Blue’), vinca [*Catharanthus roseus* (L.) G. Don ‘Cooler Peppermint’], and impatiens (*Impatiens walleriana* Hook f. ‘Super Elfin Salmon’) when compared to a standard peat: perlite mix.

Thus far, existing studies have evaluated seed production, woody ornamentals and summer annuals. The objective of these studies was to evaluate RC in the greenhouse production of three annual species with the addition of four different fertilizer rates. Positive results from these studies could result in a potential alternative or amendment aiding in the shortages of peat.

Materials and Methods

Three similar but separate experiments were conducted in order to evaluate the effect of fertilizer rate on RC amended substrates in the greenhouse production of annuals. Two forms of peat moss were used *Pindstrup*® (P), a European peat used by a partner nursery and greenhouse operation, and Canadian sphagnum peat moss (PM). The following procedures apply to all experiments. Experiments were conducted at the Paterson Greenhouse Complex, Auburn University, AL. Cedar substrate used was a 50:50 (v:v) ratio mix of 0.6cm (0.25in) and 1.0cm (0.375in) screen sizes. Treatments that were not 100% pure substrate were amended with peat moss. All substrates were amended with 3.0 $kg \cdot m^{-3}$ (5.06 $lbs \cdot yd^{-3}$) dolomitic lime and 0.9 $kg \cdot m^{-3}$ (1.52 $lbs \cdot yd^{-3}$) Micromax. A 12.0N-6.64P-8.64K slow release fertilizer (12-6-8, Harrell's Fertilizer Inc., Lakeland, FL) was added to each substrate at rates of 0.0, 0.59, 1.19, or 2.37 $kg \cdot m^{-3}$ (0.0, 1.0, 2.0, or 4$lbs \cdot yd^{-3}$, respectively) (2-3 month release). Fertilizer rates will be referred to as follows: 0lb, 1lb, 2lbs, and 4lbs. Two species were selected and potted for each experiment. Containers were placed on raised greenhouse benches and watered by hand as needed. Each species was treated as its own experiment. Physical properties [substrate air space (AS), water holding capacity (WHC), total porosity (TP)] were determined using the North Carolina State University porometer method (n=3) (6). Bulk densities (BD) were determined from the same samples used to determine physical properties, and obtained 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) analysis was determined by passing 100g sample [dried in a 76.7°C (170°F) forced air oven] through a series of sieves (n=3). Sieves were shaken for three minutes with a Ro-Tap sieve shaker (Ro-Tap RX-29, W.S. Tyler, Mentor, OH). Analysis of PSD was broken down into three texture sizes [coarse (> 3.35 mm), medium (1.00 to < 3.35 mm) and fine (0.00 to < 1.00 mm)] due to the variation between substrates. Pour-through leachates were obtained from snapdragon at 1, 7, 14, 21, and 45 days after potting (DAP) in order to determine substrate pH and electrical conductivity (EC) (n=4) (15). Growth indices [(height+width1+width2)/3] (cm) were measured at 45 DAP. Marketability/aesthetic plant quality ratings (MK) were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable). Foliar color ratings (FCR) were taken 45 DAP on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green). Shoot dry weights (SDW) were determined at termination after samples were dried at 76.7°C (170°F) for 72 hours (n=4). Data was subjected to analysis of variance using general linear models procedure, and a multiple comparison of means using Tukey's Honest Significant Test (Version 9.2: SAS Institute, Cary, NC). Fertilizer rate was tested for a linear or quadratic response using single degree of freedom orthogonal contrast (Version 9.2; SAS Institute, Inc., Cary, NC).

Experiment 1 (Exp. 1) Cedar used for the experiment was harvested at ground level and de-limbed on August 3, 2011. Cedar was then chipped through a Vermeer BC1400XL (Vermeer Co., Pella, IA) on August 4, 2011; then further processed through a hammer-mill (Williams Patent Crusher & Pulverizer Co., St. Louis, MO) to pass either a 1.0 cm (0.375 in) or a 0.6 cm (0.25 in) screen on August 5, 2011. Study was initiated on August 26, 2011. Five substrates were evaluated as follows: 100% P, 25% RC, 50% RC, 75% RC, and 100% RC. Snapdragon (*Antirrhinum majus* 'Montego Pink') and pansy (*Viola ×wittrockiana* 'True Blue') (200 plug tray) were planted into 0.59 L (0.625 qt) pots for pansy and 0.82 L (0.875 qt) pots for snapdragon with three plugs per pot for snapdragon and one plug per pot for pansy. The experiment, arranged in a randomized block design with 8 single pot replications per treatment, was terminated October 10, 2011.

Experiment 2 (Exp. 2) was initiated on October 11, 2011. Five substrates were evaluated as follows: 100% PM, 25% RC, 50% RC, 75% RC, and 100% RC. Snapdragon (*Antirrhinum majus* 'Montego Pink') and Pansy (*Viola ×wittrockiana* 'Majestic Giant Deep Blue') (200 plug flat) were planted into 1.18 L (1.25 qt) containers with three plugs per pot. The experiment, arranged in a randomized block design with 8 single pot replications per treatment, was terminated November 22, 2011.

Experiment 3 (Exp. 3) was initiated on March 6, 2012. Snapdragon (*Antirrhinum majus* 'Snapshot Pink') and Petunia (*Petunia ×hybrida* 'Dreams Burgundy') (200 plug flat) were planted into 1.18 L (1.25 qt) containers with three plugs per pot. Six substrates were evaluated as follows: 100% PM, 25% RC, 50% RC, 75% RC, 100% RC, and 100% P. The experiment, arranged in a randomized block design with 7 single pot replications per treatment, was terminated April 16, 2012.

Results and Discussion

Experiment 1. There is not a greenhouse best management practice guide as there is for nursery production (17). However, there are optimum ranges for AS, WHC, and TP (8). Physical properties showed that AS was greatest for 100% RC (35.7%), with 100% P (8.4%) having 76% less (Table 4.1). All treatments were above the AS optimal range (10-20%), except 25% RC (19.9%) and 100% P (8.4%). Substrate WHC was 53% greater for 100% P (80.1%) than 100%

RC (52.2%). Those within the recommended WHC range (50-65%) were 100% RC and 75% RC (61.3%). There was no difference in TP among substrates; all were above the optimal range (60-75%). Bulk density was greatest for 100% RC (0.14 $g \cdot cm^{-3}$) and least for 100% P (0.10 $g \cdot cm^{-3}$).

Particle size distribution analysis was broken down into three texture sizes (coarse, medium and fine) due to the variation between substrates (Table 4.2). Coarse particles aid in the aeration of a container substrate; these particles ranged from 2.1 (100% RC) to 21.2% (100% P). Medium particles had a 157% increase with RC compared to 100% P, 100% RC (69.4%) having the most. Pindstrup (51.9%) had more fine particles than any other substrate, similar only to 25% RC (47.9); 100% RC (28.5) having 45% less fine particles than 100% P.

Substrate pH levels at 1 DAP varied around the optimum pH range (5.4 to 5.8) for snapdragon (Table 4.3) (3). At 14 DAP, pH increased ranging from 5.38 to 6.86; levels tended to increase with RC. Leachate pH results were highest for substrates composed of RC at 28 DAP, reaching 7.06 (2lbs). By 45 DAP, pH levels tended to decrease; however, 100% RC substrate pH levels remained above the optimum range. pH had an overall decreasing linear response to the fertilizer exhibited by 50% RC at 1 DAP and 75% RC at 14 DAP; and an increasing linear response by 25% RC at 1 DAP. Only 75% RC had a quadratic response in pH to the fertilizer at 1 DAP. Initial EC (1 DAP) tended to increase with increasing fertilizer rate, regardless of substrate. Electrical conductivity exhibited no difference among substrates at 14 and 28 DAP. By 45 DAP, EC tended to decrease with increasing RC percentages, ranging from 0.32 (0lb 100% C) to 1.07 (4lbs 100% P) $mS \cdot cm^{-1}$. Electrical conductivity exhibited a increasing linear response to fertilizer rate by all substrates at 1 DAP; and by 100% P and 25% RC at 45 DAP. A linear decrease in EC in response to fertilizer was shown by 100% P at 28 DAP. Quadratic responses to the fertilizer rates were seen in EC levels by 25% RC and 75% RC at 1 DAP; and 100% P at 28 and 45 DAP.

Snapdragon growth parameters show a linear response to fertilizer for all substrates (Table 4.4). Growth index was similar for both 2lbs and 4lbs 100% P. Only 25% RC 4lbs was similar to these P treatments, together having greater growth than all other treatments. Snapdragon FCR were similar for all substrates, exhibiting lush green and green ratings, with the exception of 1lb 100% RC (3.1) and all 0lb treatments which were chlorotic. Marketability ratings for snapdragon decreased with increasing RC percentages. Substrates treatments that produced marketable ratings include: 4lbs 100% P (4.9), 25% RC (4.9), and 50% RC (4.5); 2lbs 100% P (4.8) and 25% RC (4.3); and 1lb 100% P (4.4). All other substrate treatments experienced stunting and discoloration. Snapdragon SDW was greatest for 4lbs 100% P (5.7g) which was similar to 4lbs 25% RC (5.0g) and 2lbs 100% P (4.7g).

Within each substrate a linear response to fertilizer rate was noted for three of the four pansy growth parameters (Table 4.5). Growth indices for pansy were similar to snapdragon, 4lbs 100% P and 25% RC were similar to 2lbs 100% P; all having greater growth than all other treatments. Foliar color ratings tended to decrease with decreasing fertilizer across all substrates. Pansy treatments with rating of discoloration and stunting include 2lbs 100% RC (3.6); 1lb 75% RC (3.4) and 100% RC (3.5); and all 0lb treatments. Pansy marketability ratings were similar to snapdragons. Marketable pansies included 100% P (5.0) and 25% RC (4.8) at 4lbs; 100% P (4.8) and 25% RC (4.4) at 2lbs; and 100% P (4.4) at 1lb. Shoot dry weights for pansy were greatest for 4lbs 100% P (1.5g); with five treatments similar including 4lbs 25% RC (1.0g); 2lbs 100% P (1.2g) and 25% RC (0.9g); 1lb100% P (1.1g); and 0lb 100% P (0.8g). Overall, growth tended to increase in substrates with increasing fertilizer rates and decreasing RC percentages.

Experiment 2. Air space increased with RC percentages, ranging from 8.5% (100% PM) to 34.4% (100% RC); 100% PM had 75% less AS than 100% RC (Table 4.6). Substrates with mixed percentages of peat and RC were within the optimum range for AS. Substrate WHC differed from Exp. 1, ranging from 52.1% (100% RC) to 78.6% (100% P), decreasing 34% with increasing RC. Only 100% RC was within the WHC optimum range. Similar to results in Experiment 1, TP showed no difference among substrates, all being above the optimum range. Bulk density increased 25% with RC, percentages ranged from 0.12 $g \cdot cm^{-3}$ (100% PM) to 0.15 $g \cdot cm^{-3}$ (100% RC).

Particle size distribution showed a 77% increase in coarse particles for 100% PM (11.3%) compared to 100% RC (2.6%) (Table 4.7). Medium substrate particles (30.5% to 70.8%) increased with RC percentages, with 100% RC having the highest percentage of medium particles by 132% compared to 100% PM. Fine particles were similar for 3 of the 5 substrates, ranging from 26.6% (100% RC) to 58.2% (100% PM); 100% RC having 54% less.

Leachate results at 1 DAP revealed pH levels similar to the optimum (5.4 to 5.8) ranging from 5.09 to 5.96; substrates with high RC content tended to have higher pH values (Table 4.8) (3). At 14 DAP, pH values were above the optimum range for all substrates, and increased with increasing RC. pH values tended to increase throughout the remainder of the study for cedar substrates. By 45 DAP, pH levels ranged from 6.00 (4lbs 25% RC) to 7.02 (4lbs 100% RC), increasing with RC percentages. pH exhibited a linear decrease to the fertilizer at 14 DAP for 100% PM and 28 DAP for 50% RC. A quadratic response in pH to fertilizer rates occurred with 100% RC at 28 DAP and 25% RC at 45 DAP. Substrate EC levels at 1 DAP exhibited no difference among treatments. At 14 DAP, EC values tended to increase with RC percentage and fertilizer rate. Electrical conductivity levels were higher for high RC content substrates at 28

DAP. By 45 DAP, EC increased with increasing RC. Slight linear increase was seen with increasing fertilizer at 14 DAP for 100% PM and 25% RC; and at 45 DAP for 100% PM and 100% RC. A quadratic response to fertilizer was exhibited by 100% PM and 75% RC at 45 DAP.

Snapdragon GI had a linear response to fertilizer rate for all substrates (Table 4.9). Snapdragons grown in 50% and 25% RC at 4lbs; and 2lbs 25% RC had similar FCR to those grown in 100% PM. Plants that were marketable included: 4lbs 100% PM, 25% RC, and 50% RC; 2lbs 100% PM and 25% RC; and 1lb 100% PM. Snapdragon SDW increased with fertilizer for all substrates. Plants grown in 4lbs 25% RC and 50% RC; 2lbs 100% PM and 25% RC; and 1lb 100% PM had similar SDW to those grown in 4lbs 100% PM.

Three of four growth parameters exhibited linear response for all substrates for pansy (Table 4.10). Growth index were similar for 100% PM treatments with fertilizer; those similar to these treatments include 4lbs 25% and 50% RC. Foliar color ratings and MK followed a similar trend. Pansy exhibited lush green or green FCR for 100% PM treatments and at 4lbs 25% RC, 50% RC, and 75% RC; 2lbs 25% RC, and 50% RC; and 1lb 25% RC. Marketability ratings for pansies grown in 25% RC were similar to those grown in 100% PM. Pansy SDW increased with fertilizer for each substrate except 100% RC. Plants grown in 4lbs 25%, 50%, and 75% RC; and 2lbs 25% RC had similar or greater SDW than those grown in 1lb and 2lbs 100% PM.

Experiment 3. Physical properties for Exp. 3 showed a similar trend as previous studies. Substrate AS were within or lower than the optimum range, 100% PM (4.6%) having 79% less AS than 100% RC (21.7%) (Table 4.11). Substrate WHC ranged from 60.5% (100% RC) to 83.8% (100% P), 100% RC having 28% less WHC. Though no substrates were within the optimum range, TP was greatest for 100% P (90.6%), all other substrates were similar. Bulk density (0.12 to 0.19 $g{\cdot}m^{-3}$) was similar for all substrates except 100% P (0.12 $g{\cdot}m^{-3}$).

Particle size distribution analysis showed coarse particles to decrease in RC substrates above 25% RC (32.7%) (Table 4.12). The 100% RC (3.1%) substrate had 91% fewer coarse particles than 25% RC. Medium particle distribution increased with RC percentage with 100% P (21.5%) having 69% less than 100% RC (69.6%). Fine particle size were similar for all RC amended substrates; 100% P (56.7%) had the greatest percentage with 100% C (27.3%) having 52% less.

Initially, pH levels ranged from 4.81 to 6.16, falling below the optimum range for snapdragon (5.4 to 5.8) (Table 4.13) (3). Substrates with 100% PM, P, and RC tended to have lower pH levels than those of mixed percentages. At 14 DAP, substrate treatments containing more than 25% RC had higher pH than the PM and P substrates, reaching a pH level of 7.51 (2lbs 100% RC). Most pH levels increased by 28 DAP; high RC percentages continued to have the highest pH levels. All substrates had similar pH levels except for the 100% P treatments at 45 DAP. pH had a decreasing linear response to the fertilizer rates by 100% PM, 25% RC, and 100% RC at 1 DAP; and an increasing linear response with 100% PM at 45 DAP. Pindstrup and 100% RC pH had a quadratic response to the fertilizer at 1 DAP; with 100% PM having a quadratic response at 28 and 45 DAP.

At 1 DAP, EC ratings tended to increase with increasing fertilizer rates ranging from 0.86 (0lb 100% RC) to 3.41 $mS{\cdot}cm^{-1}$ (4lbs 100% PM). At 14 and 28 DAP there was no difference in EC levels among substrate treatments. By 45 DAP, EC ratings had decreased with little difference among substrates and fertilizer rates. Those with the lowest levels include 0lb, 1lb, and 2lbs 100% P; and 0lb 100% RC. Overall, EC levels decreased throughout the study with an increasing linear response to the fertilizer by all substrates at 1 DAP. Substrates which showed a quadratic response for EC include 100% PM, 75% RC, 100% RC, and 100% P at 1 DAP; and 100% P at 28 DAP.

Growth index for Snapdragon experienced a linear increase in response to fertilizer rate for all substrates (Table 4.14). Plants grown in 4lbs 100% P, 25% RC, 50% RC, and 75% RC; 2lbs 100% P and 1lb 100% P were all similar, exhibiting the greatest growth. Snapdragon displayed lush green or green FCR for all substrates at 4lbs and 2lbs, except for 100% RC. Plants grown in 4lbs 25, 50, and 75% RC; 2lbs 25 and 50% RC; 1lb 25% RC; and 1lb 25% RC had similar MK to those grown in 4lbs 100% PM. Snapdragon SDW varied, snapdragons grown in 4lbs 25% RC and 50% RC were similar to those in 100% P and 100% PM at the 4lbs fertilizer rate.

Petunia GI had a linear increase in response to the fertilizer rates in all substrates except 100% P (Table 4.15). All petunias were similar in growth except those grown in the 0lb rate, excluding P, and the 1lb rate for 75% RC and 100% RC. Increasing with fertilizer rates, both FCR and MK were greatest for petunias grown in the 4lbs fertilizer rate, except for those plants in 100% RC. Petunia SDW was greatest for substrates with the 4lbs fertilizer rate; those similar include 4lbs 100% PM, 100% P, 25% and 50% RC.

Conclusion

Overall, these experiments agree with previous research by Murphy et al. (10), showing RC to have potential as an amendment to peat. Physical properties were similar for each experiment with slight variances; these differences could be due to RC decomposition in the months stored before use. Particle size distribution tended to have a similar trend across substrates for each experiment; coarse particles were least in substrates with higher percentages of RC. Results from these experiments show that plants can be grown successfully in RC with additional fertilizer. Snapdragons grown in up to 75% RC at the 4lbs fertilizer rate were comparable to those grown in 4lbs 100% P (Exp. 3). Pansies grown in up to 50% RC with 4lbs of fertilizer were similar to those grown in 4lbs PM (Exp. 2). Petunia growth was similar for all substrates with up to 100% RC when amended with 2lbs of fertilizer (Exp. 3). In conclusion, additional trials with a greater number of species would be necessary before advising growers to make a transition to RC in their production practices.

Literature Cited

1. Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2008. Clean chip residual as a substrate for perennial nursery crop production. J. Environ. Hort. 26:239-246.

2. Broussard, C., E. Bush, and A. Owings. 1999. Effects of hardwood and pine bark on growth response of woody ornamentals. Proc. Southern Nurs. Assoc. Res. Conf. 44:57-60.

3. Cavins, T.J., B.E. Whipker, and W.C. Fonteno. 2000. Monitoring and managing pH and EC using the pourThru extraction method. NC State University Hort. Info. Leaflet 590:1-17.

4. Dirr, M.A. 1998. Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses. 5th ed. Stipes Publishing LLC, Champaign, IL.

5. Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008. WholeTree substrates derived from three species of pine in production of annual vinca. HortTech. 18:13-17.

6. Fonteno, W.C., C.T. Hardin, and J.P. Brewster. 1995. Procedures for determining physical properties of horticultural substrates using the NCSU Porometer, Horticultural Substrates Laboratory, North Carolina State University, Raleigh, NC.

7. Griffin, J. 2009. Eastern red-cedar (*Juniperus virginiana*) as a substrate component for container production of woody plants. HortScience 44:1131 (Abstr.).

8. Jenkins, J.R. and W.M. Jarrell. 1989. Predicting physical and chemical properties of container mixtures. HortScience 24:292-295.

9. Kuepper, G. and Gegner, L. 2004. Organic crop production overview. Rep. IP170. Natl. Sustainable Agric. Info. Serv., Butte, MT.

10. Murphy, A.M., C.H. Gilliam, G.B. Fain, H.A. Torbert. T.V. Gallagher, J.L. Sibley, and C.R. Boyer. 2011. Low-value trees as alternative substrates in greenhouse production of three annual species. J. Environ. Hort. 29:152-161.

11. Self, R.L. 1975. Comparison of cedar, mahogany, and pine shavings in azalea potting mixtures. Proc. Southern Nursery Assoc. Res. Conf. 20:14.

12. Short, P. 2012. President, Canadian Sphagnum Peat Moss Association. St. Albert, AB, Canada. Personal Communication. March 26, 2012.

13. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2010. Growth of containerized *Acer saccharinum* from seed in a cedar-amended substrate. HortScience 45:S234 (Abstr.).

14. Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2011. Cedar substrate particle size affects growth of container-grown rudbeckia. Proc. Southern Nurs. Assoc. Res. Conf. 56:236-240.

15. Wright, R.D. 1986. The pour-through nutrient extraction procedure. HortScience 21:227-229.

16. Wright, R.D., J.F. Browder, and B.E. Jackson. 2006. Ground pine chips as a substrate for container-grown woody nursery crops. J. Environ. Hort. 24:181-184.

17. Yeager, T., T. Bilderback, D. Fare, C.H. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, and R.D. Wright. 2007. Best Management Practices: Guide for producing nursery crops. 2nd ed. Southern Nursery Assnoc, Atlanta, GA.

Table 4.1. Physical properties[z] of five substrates containing Pindstrup, peatmoss, and cedar[y] (Experiment 1).

Substrate[t]	Air Space[x]	Substrate Water Holding Capacity[w]	Total Porosity[v]	Bulk Density[u]
	% vol	% vol	% vol	($g \cdot cm^{-3}$)
Pindstrup	8.4d[s]	80.1a	88.5[ns]	0.10d
75:25 Peat:Cedar	19.9c	70.2b	90.1	0.11c
50:50 Peat:Cedar	21.9c	67.6b	89.5	0.12bc
25:75 Peat:Cedar	28.7b	61.3c	90.0	0.13b
100% Cedar	35.7a	52.2d	87.9	0.14a
Optimal range for greenhouse substrates[r]	10-20%	50-65%	60-75%	N/A
Recommeded range for nursery crops[q]	10-30%	45-65%	50-85%	0.19-0.70

[z]Analysis performed using the North Carolina University porometer procedure.

[y]Cedar processed through three different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.), and 1.27 cm (1/2in.).

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

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

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

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

[t]European peat product; substrates that were not pure substrate were amended with peat moss.

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

[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.

Table 4.2. Particle size distribution[z] analysis of five substrates containing Pindstrup[y] and cedar[x] (Experiment 1)[w].

		Substrates				
U.S. standard sieve no.	sieve opening (mm)[v]	Pindstrup	75:25 Peat: Cedar	50:50 Peat: Cedar	25:75 Peat: Cedar	100% Cedar
3/8	9.50	2.3a[u]	0.0b	0.8b	0.0b	0.0b
1/4	6.35	4.8a	0.3b	1.4b	0.8b	0.0b
6	3.35	14.1a	5.1bc	6.6b	4.3bc	2.1c
8	2.36	8.6b	8.9b	9.4b	10.4ab	11.4a
10	2.00	3.2c	6.0b	6.1b	7.6b	10.6a
14	1.40	7.9d	17.0c	17.4c	21.2b	26.0a
18	1.00	7.3c	14.7b	15.7b	17.3b	21.4a
35	0.50	15.7a	19.8a	16.8a	18.8a	16.7a
60	0.25	17.6a	15.4ab	12.3abc	11.7bc	7.4c
140	0.11	13.8a	9.4b	9.8b	6.2bc	3.4c
270	0.05	4.0a	2.8a	3.2a	1.4b	0.9b
pan	0.00	0.7a	0.3bc	0.5ab	0.2c	0.2c
Texture[t]						
Coarse		21.2a	5.4bc	8.8b	5.1bc	2.1c
Medium		27.0d	46.7c	48.5bc	56.6b	69.4a
Fine		51.9a	47.9ab	42.6b	38.3bc	28.5c

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).

[y]European peat product

[x]Cedar processed through two different screen sizes: 0.64 cm (1/4"), 0.95 cm (3/8").

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

[v]1 mm = 0.0394 in.

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

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

Table 4.3. Fertilizer rate effect on pH and electrical conductivity of cedar amended substrates in pansies (Experiment 1)[z].

		1 DAP[y]		14 DAP		28 DAP		45 DAP	
			EC[w]		EC		EC		EC
Substrate	**Rate (lbs)[x]**	**pH**	**mS·cm^{-1}**	**pH**	**mS·cm^{-1}**	**pH**	**mS·cm^{-1}**	**pH**	**mS·cm^{-1}**
100% Pindstrup[v]	0	5.02	1.61	5.59	1.74	5.30	1.24	5.04	0.40
100% Pindstrup	1	5.01	2.42	5.49	1.74	5.46	0.75	5.71	0.34
100% Pindstrup	2	5.05	2.58	5.38	2.04	5.30	0.64	5.05	0.65
100% Pindstrup	4	5.00	4.00	5.50	1.88	5.26	0.58	4.70	1.07
75:25 Peat:Cedar	0	5.48	1.54	5.99	2.02	6.21	0.69	6.08	0.41
75:25 Peat:Cedar	1	5.59	2.01	6.01	2.12	6.07	1.18	6.04	0.36
75:25 Peat:Cedar	2	5.76	2.87	5.98	2.11	6.16	0.75	6.05	0.59
75:25 Peat:Cedar	4	5.72	4.31	5.97	2.30	6.31	0.67	5.69	0.63
50:50 Peat:Cedar	0	5.73	1.40	6.31	1.60	6.52	0.62	6.72	0.35
50:50 Peat:Cedar	1	5.67	2.37	6.31	1.43	6.48	0.63	7.41	0.44
50:50 Peat:Cedar	2	5.52	2.47	6.28	1.53	6.42	0.90	6.43	0.38
50:50 Peat:Cedar	4	5.52	3.23	6.26	1.40	6.63	0.38	6.22	0.51
25:75 Peat:Cedar	0	6.00	1.33	6.55	0.99	6.86	0.60	6.71	0.33
25:75 Peat:Cedar	1	5.95	1.66	6.61	0.97	6.89	0.58	6.65	0.34
25:75 Peat:Cedar	2	5.75	2.55	6.51	1.03	6.87	0.40	6.58	0.37
25:75 Peat:Cedar	4	6.01	3.78	5.77	1.62	6.85	0.37	6.48	0.36
100% Cedar	0	6.38	0.93	6.75	0.75	6.89	0.45	6.72	0.32
100% Cedar	1	6.21	1.10	6.80	0.64	6.96	0.55	6.76	0.32
100% Cedar	2	6.46	1.52	6.86	0.75	7.06	0.48	7.52	0.36
100% Cedar	4	6.29	2.00	6.80	0.84	7.03	0.45	6.77	0.39
	HSD [u]	***0.38***	***1.03***	***1.06***	***2.46***	***0.57***	***1.05***	***1.66***	***0.46***
				Fertilizer Rate Response					
100% Pindstrup		NS[t]	L***	NS	NS	NS	L*	NS	L*** Q**
75:25 Peat:Cedar		L*	L*** Q*	NS	NS	NS	NS	NS	L*
50:50 Peat:Cedar		L*	L***	NS	NS	NS	NS	NS	NS
25:75 Peat:Cedar		Q*	L*** Q*	L*	NS	NS	NS	NS	NS
100% Cedar		NS	L***	NS	NS	NS	NS	NS	NS

[z]pH and EC of solution determined using pour-through method on 'True Blue' pansy.

[y]DAP = days after potting.

[x]Lbs·yd^{-3} of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Inc., Lakeland, FL).

[w]Electrical conductivity = EC

[v]European peat product.

[u]Tukey's Honest Significant Difference Test α = 0.05 (n = 4).

[t]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4.4. Fertilizer rate effect on growth of 'Montego Pink' snapdragon in cedar amended substrates[z] (Experiment 1).

Substrates	Rate[y]	Growth Parameters GI[x]	FCR[w]	MK[v]	SDW[u]
Pindstrup[t]	0	16.1	3.8	3.4	1.8
Pindstrup	1	18.3	4.4	4.4	3.6
Pindstrup	2	21.9	4.8	4.8	4.7
Pindstrup	4	23.9	4.9	4.9	5.7
75:25 Peat Moss:Cedar	0	4.9	2.9	2.0	0.1
75:25 Peat Moss:Cedar	1	11.7	4.1	3.0	0.5
75:25 Peat Moss:Cedar	2	17.8	4.8	4.3	2.0
75:25 Peat Moss:Cedar	4	21.2	5.0	4.9	5.0
50:50 Peat Moss:Cedar	0	5.0	2.8	2.0	0.1
50:50 Peat Moss:Cedar	1	10.9	4.1	2.8	0.8
50:50 Peat Moss:Cedar	2	16.5	4.1	3.8	1.8
50:50 Peat Moss:Cedar	4	18.2	4.6	4.5	3.0
25:75 Peat Moss:Cedar	0	5.0	2.6	2.0	0.1
25:75 Peat Moss:Cedar	1	9.5	4.6	2.4	0.5
25:75 Peat Moss:Cedar	2	9.4	4.8	2.4	0.2
25:75 Peat Moss:Cedar	4	16.7	4.9	3.5	2.4
100% Cedar	0	5.1	2.6	2.0	0.1
100% Cedar	1	6.3	3.1	2.0	0.1
100% Cedar	2	8.5	4.3	2.3	0.2
100% Cedar	4	14.7	4.6	3.5	1.2
	HSD[s]	***3.6***	***1.1***	***1.0***	***1.5***
		Fertilizer Rate Response			
100% Pindsrtup		L***[r]	L***	L*** Q*	L***
75:25 Peat:Cedar		L***Q*	L*** Q*	L***	L*** Q***
50:50 Peat:Cedar		L***Q**	L*** Q***	L***	L***
25:75 Peat:Cedar		L***	L*** Q*	L***	L*** Q***
100% Cedar		L*** Q**	L***	L*** Q**	L**

[z]Cedar processed through two different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.).

[y]Lbs·yd^{-3} of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Fertilizer, Inc., Lakeland, FL).

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

[w]Foliar color ratings were taken 45 days after potting (DAP) on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green).

[v]Marketability/aesthetic quality ratings were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/ chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable).

[u]Shoot 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.

[t]Eurpean peat product.

[s]Tukey's Honest Significant Difference Test α = 0.05 (n = 8).

[r]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Talbe 4.5. Fertilizer rate effect on growth of 'True Blue' pansy in cedar amended substrates[z] (Experiment 1).

Substrates	Rate[y]	GI[x]	FCR[w]	MK[v]	SDW[u]
		Growth Parameters			
Pindstrup[t]	0	7.7	3.1	3.3	0.8
Pindstrup	1	9.6	4.3	4.4	1.1
Pindstrup	2	11.3	4.6	4.8	1.2
Pindstrup	4	11.9	5.0	5.0	1.5
75:25 Peat Moss:Cedar	0	1.8	2.4	2.0	0.0
75:25 Peat Moss:Cedar	1	6.4	4.5	3.4	0.4
75:25 Peat Moss:Cedar	2	8.0	4.9	4.4	0.9
75:25 Peat Moss:Cedar	4	10.6	4.8	4.8	1.0
50:50 Peat Moss:Cedar	0	1.6	2.4	2.0	0.1
50:50 Peat Moss:Cedar	1	2.5	4.0	2.4	0.1
50:50 Peat Moss:Cedar	2	6.2	4.8	3.5	0.3
50:50 Peat Moss:Cedar	4	6.7	4.5	3.5	0.5
25:75 Peat Moss:Cedar	0	1.5	2.4	2.0	0.0
25:75 Peat Moss:Cedar	1	2.4	3.4	2.3	0.1
25:75 Peat Moss:Cedar	2	2.8	4.3	2.8	0.1
25:75 Peat Moss:Cedar	4	6.2	4.9	3.9	0.3
100% Cedar	0	1.5	2.4	1.9	0.1
100% Cedar	1	2.3	3.5	2.0	0.0
100% Cedar	2	2.1	3.6	2.1	0.1
100% Cedar	4	4.5	4.4	3.1	0.2
	HSD [s]	***2.2***	***1.5***	***1.0***	***0.7***
		Fertilizer Rate Response			
100% Pindstrup		L***[r]	L*	L*** Q*	L***
75:25 Peat:Cedar		L*** Q*	L*** Q***	L*** Q**	L***
50:50 Peat:Cedar		L***	L***	L***	L*
25:75 Peat:Cedar		L*** Q**	L*** Q*	L*** Q**	NS
100% Cedar		L***	L*** Q*	L*** Q**	NS

[z]Cedar processed through two different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.).

[y]$Lbs \cdot yd^{-3}$ of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Fertilizer, Inc., Lakeland, FL).

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

[w]Foliar color ratings were taken 45 days after potting (DAP) on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green).

[v]Marketability/aesthetic quality ratings were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/ chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable).

[u]Shoot 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.

[t]Eurpean peat product.

[s]Tukey's Honest Significant Difference Test $\alpha = 0.05$ ($n = 8$).

[r]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4.6. Physical properties[z] of five substrates containing peat and cedar[y] (Experiment 2).

Substrate	Air Space[x]	Substrate Water Holding Capacity[w]	Total Porosity[v]	Bulk Density[u]
	% vol	% vol	% vol	$(g \cdot cm^{-3})$
100% Peat Moss	8.5d[t]	78.6a	87.1[ns]	0.12c
75:25 Peat:Cedar	10.3cd	78.0a	88.3	0.13b
50:50 Peat:Cedar	15.9bc	73.3b	89.2	0.13b
25:75 Peat:Cedar	20.2b	67.4c	87.7	0.14a
100% Cedar	34.4a	52.1d	86.5	0.15a
Optimal range for greenhouse substrates[s]	10-20%	50-65%	60-75%	N/A
Recommeded range for nursery crops[r]	10-30%	45-65%	50-85%	0.19-0.70

[z]Analysis performed using the North Carolina University porometer procedure.

[y]Cedar processed through three different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.), and 1.27 cm (1/2in.).

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

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

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

[u]Bulk density after forced-air dyring at 105.0°C (221.0°F) 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]Recommended ranges as reported by Jenkins and Jarrell, 1989. Predicting physical and chemical properties for container mixtures.

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

Table 4.7. Particle size distribution[z] analysis of five substrates containing peat and cedar[y] (Experiment 2)[x].

U.S. standard sieve no.	sieve opening (mm)[w]	Substrates: 100% Peat Moss	75:25 Peat: Cedar	50:50 Peat: Cedar	25:75 Peat: Cedar	100% Cedar
3/8	9.50	0.9b[v]	0.3b	0.3b	0.1b	0.0b
1/4	6.35	1.7b	1.3b	1.2b	0.8b	0.0b
6	3.35	8.8b	8.1b	5.1bc	4.4bc	2.6c
8	2.36	7.9c	9.6bc	8.8c	11.5ab	12.7a
10	2.00	3.3d	5.1c	5.6c	7.6b	9.6a
14	1.40	9.2e	15.4d	19.1c	23.4b	27.1a
18	1.00	10.1e	13.8d	15.5c	19.1b	21.4a
35	0.50	21.8a	21.7a	21.0a	18.8b	16.7c
60	0.25	18.3a	14.8ab	14.5ab	9.8bc	6.7c
140	0.11	12.8a	7.6ab	7.6ab	3.8b	2.6b
270	0.05	4.3a	1.9bc	1.1c	0.5c	0.5c
pan	0.00	0.9a	0.3b	0.1b	0.1b	0.1b
Texture[u]						
Coarse		11.3a	9.7ab	6.6bc	5.3cd	2.6d
Medium		30.5d	44.0c	49.0c	61.6b	70.8a
Fine		58.2a	46.3ab	44.4ab	33.1bc	26.6c

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).

[y]Cedar processed through two different screen sizes: 0.64 cm (1/4"), 0.95 cm (3/8").

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

[w]1 mm = 0.0394 in.

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

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

Table 4.8. Fertilizer rate effect on pH and electrical conductivity of cedar amended substrates in pansies (Experiment 2)[z].

		1 DAP[y]		14 DAP		28 DAP		45 DAP	
Substrate	Rate (lbs)[x]	pH	EC[w] $mS \cdot cm^{-1}$	pH	EC $mS \cdot cm^{-1}$	pH	EC $mS \cdot cm^{-1}$	pH	EC $mS \cdot cm^{-1}$
100% Peat Moss	0	5.14	1.76	6.26	0.26	5.72	0.28	6.01	0.22
100% Peat Moss	1	5.10	1.96	6.25	0.30	5.68	0.25	6.09	0.27
100% Peat Moss	2	5.09	2.05	6.29	0.30	5.69	0.23	6.06	0.26
100% Peat Moss	4	5.31	1.81	5.94	0.51	5.77	0.24	6.16	0.25
75:25 Peat:Cedar	0	5.42	1.53	6.07	0.25	6.04	0.26	6.03	0.23
75:25 Peat:Cedar	1	5.23	1.71	6.16	0.30	5.99	0.24	6.09	0.22
75:25 Peat:Cedar	2	5.12	1.81	5.94	0.31	5.91	0.23	6.53	0.23
75:25 Peat:Cedar	4	5.31	1.44	5.91	0.50	5.97	0.25	6.00	0.25
50:50 Peat:Cedar	0	5.30	1.55	6.54	0.36	6.78	0.26	6.66	0.27
50:50 Peat:Cedar	1	5.36	1.75	6.64	0.40	6.82	0.27	6.74	0.26
50:50 Peat:Cedar	2	5.43	1.71	6.57	0.37	6.66	0.25	6.50	0.26
50:50 Peat:Cedar	4	5.23	1.98	6.47	0.44	6.60	0.27	6.74	0.25
25:75 Peat:Cedar	0	5.60	1.65	6.78	0.32	6.64	0.32	6.93	0.30
25:75 Peat:Cedar	1	5.70	1.68	6.75	0.42	6.82	0.32	6.84	0.30
25:75 Peat:Cedar	2	5.52	1.64	6.75	0.39	6.86	0.29	6.70	0.28
25:75 Peat:Cedar	4	5.43	1.58	6.74	0.48	6.81	0.30	6.84	0.32
100% Cedar	0	5.83	1.34	6.79	0.52	6.79	0.35	6.99	0.30
100% Cedar	1	5.79	1.26	6.71	0.46	6.92	0.34	6.88	0.31
100% Cedar	2	5.96	1.35	6.77	0.64	6.86	0.34	6.91	0.31
100% Cedar	4	5.92	1.33	6.74	0.60	6.67	0.33	7.02	0.33
	HSD [v]	***0.59***	***1.74***	***0.46***	***0.32***	***0.39***	***0.06***	***0.42***	***0.04***
				Fertilizer Rate Response					
100% Peat Moss		NS[u]	NS	L*	L**	NS	NS	NS	L* Q***
75:25 Peat:Cedar		NS	NS	NS	L**	NS	NS	Q***	NS
50:50 Peat:Cedar		NS	NS	NS	NS	L*	NS	NS	NS
25:75 Peat:Cedar		NS	NS	NS	NS	NS	NS	NS	Q*
100% Cedar		NS	NS	NS	NS	Q*	NS	NS	L*

[z]pH and EC of solution determined using pour-through method on 'True Blue' pansy.

[y]DAP = days after potting.

[x]$Lbs \cdot yd^{-3}$ of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Inc., Lakeland, FL).

[w]Electrical conductivity = EC

[v]Tukey's Honest Significant Difference Test $\alpha = 0.05$ ($n = 4$).

[u]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4.9. Fertilizer rate effect on growth of 'Montego Pink' snapdragon in cedar amended substrates[z] (Experiment 2).

Substrates	Rate[y]	Growth Parameters			
		GI[x]	FCR[w]	MK[v]	SDW[u]
100% Peat Moss	0	8.5	5.0	2.0	1.2
100% Peat Moss	1	14.6	5.0	4.9	3.5
100% Peat Moss	2	15.3	5.0	5.0	4.3
100% Peat Moss	4	17.3	5.0	5.0	4.7
75:25 Peat Moss:Cedar	0	6.8	2.0	1.0	1.0
75:25 Peat Moss:Cedar	1	10.7	4.5	3.4	2.4
75:25 Peat Moss:Cedar	2	13.6	5.0	5.0	3.5
75:25 Peat Moss:Cedar	4	17.5	5.0	5.0	4.5
50:50 Peat Moss:Cedar	0	7.0	2.0	1.0	1.3
50:50 Peat Moss:Cedar	1	8.7	3.1	2.0	1.1
50:50 Peat Moss:Cedar	2	10.9	4.6	3.0	1.5
50:50 Peat Moss:Cedar	4	15.9	5.0	5.0	4.5
25:75 Peat Moss:Cedar	0	6.8	2.0	1.0	1.2
25:75 Peat Moss:Cedar	1	7.7	2.5	1.4	1.2
25:75 Peat Moss:Cedar	2	10.1	4.1	2.6	1.5
25:75 Peat Moss:Cedar	4	12.5	4.9	3.5	2.5
100% Cedar	0	6.7	2.0	1.0	1.0
100% Cedar	1	7.1	2.4	1.1	1.0
100% Cedar	2	8.5	2.8	1.6	1.0
100% Cedar	4	10.2	4.0	2.8	1.6
	HSD [t]	***2.5***	***0.8***	***0.7***	***1.3***
		Fertilizer Growth Response			
100% Peat Moss		L***[s] Q***	NS	L*** Q***	L*** Q***
75:25 Peat:Cedar		L***	L*** Q***	L*** Q***	L***
50:50 Peat:Cedar		L*** Q***	L*** Q*	L*** Q***	L*** Q***
25:75 Peat:Cedar		L***	L***	L*** Q*	L***
100% Cedar		L***	L*** Q**	L*** Q***	NS

[z]Cedar processed through two different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.).

[y]$Lbs \cdot yd^{-3}$ of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Fertilizer, Inc., Lakeland, FL).

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

[w]Foliar color ratings were taken 45 days after potting (DAP) on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green).

[v]Marketability/aesthetic quality ratings were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/ chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable).

[u]Shoot 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.

[t]Tukey's Honest Significant Difference Test $\alpha = 0.05$ (n = 8).

[s]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4.10. Fertilizer rate effect on growth of 'Majestic Giant Deep Blue' pansy in cedar amende substrates[z] (Experiment 2).

		Growth Parameters			
Substrates	**Rate[y]**	**GI[x]**	**FCR[w]**	**MK[v]**	**SDW[u]**
100% Peat Moss	0	9.9	4.4	2.5	1.1
100% Peat Moss	1	14.2	4.9	4.1	1.7
100% Peat Moss	2	16.3	5.0	4.8	2.7
100% Peat Moss	4	16.6	5.0	4.9	3.3
75:25 Peat Moss:Cedar	0	7.7	2.5	1.4	0.8
75:25 Peat Moss:Cedar	1	11.3	4.1	3.0	1.3
75:25 Peat Moss:Cedar	2	13.8	4.9	4.8	1.8
75:25 Peat Moss:Cedar	4	16.0	5.0	5.0	2.9
50:50 Peat Moss:Cedar	0	7.9	2.4	1.3	0.9
50:50 Peat Moss:Cedar	1	8.9	3.1	2.1	0.8
50:50 Peat Moss:Cedar	2	11.9	4.5	3.8	1.3
50:50 Peat Moss:Cedar	4	14.6	5.0	4.6	2.4
25:75 Peat Moss:Cedar	0	7.9	1.8	1.1	0.7
25:75 Peat Moss:Cedar	1	8.6	2.4	1.6	0.8
25:75 Peat Moss:Cedar	2	9.9	3.4	2.5	1.0
25:75 Peat Moss:Cedar	4	12.9	4.9	4.3	1.7
100% Cedar	0	7.7	2.0	1.1	0.6
100% Cedar	1	7.2	2.1	1.3	0.7
100% Cedar	2	8.0	2.4	1.4	0.9
100% Cedar	4	9.1	3.4	2.3	0.8
	HSD[t]	***2.4***	***1.0***	***1.0***	***1.5***
		Fertilizer Rate Response			
100% Peat Moss		L***[s] Q***	L*	L*** Q***	L***
75:25 Peat:Cedar		L***	L*** Q***	L*** Q***	L***
50:50 Peat:Cedar		L***	L***	L***	L***
25:75 Peat:Cedar		L*** Q*	L*** Q*	L*** Q*	L*
100% Cedar		L*	L*** Q*	L***	NS

[z]Cedar processed through two different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.).

[y]Lbs·yd^{-3} of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Fertilizer, Inc., Lakeland, FL).

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

[w]Foliar color ratings were taken 45 days after potting (DAP) on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green).

[v]Marketability/aesthetic quality ratings were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/ chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable).

[u]Shoot 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.

[t]Tukey's Honest Significant Difference Test $\alpha = 0.05$ (n = 8).

[s]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4.11. Physical properties[z] of six substrates containing Pinsdrup, peat and cedar[y] (Experiment 3).

Substrate	Air Space[x]	Substrate Water Holding Capacity[w]	Total Porosity[v]	Bulk Density[u]
	% vol	% vol	% vol	($g \cdot cm^{-3}$)
100% Peat Moss	4.6c[t]	75.2b	79.8b	0.18a
75:25 Peat:Cedar	7.6c	74.2b	81.8b	0.19a
50:50 Peat:Cedar	14.3b	69.2c	83.5b	0.18a
25:75 Peat:Cedar	19.5a	64.3d	83.8b	0.17a
100% Cedar	21.7a	60.5d	82.2b	0.15ab
100% Pindstrup[s]	6.7c	83.8a	90.6a	0.12b
Optimal range for greenhouse substrates[r]	10-20%	50-65%	60-75%	N/A
Recommeded range for nursery crops[q]	10-30%	45-65%	50-85%	0.19-0.70

[z]Analysis performed using the North Carolina University porometer procedure.

[y]Cedar processed through three different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.), and 1.27 cm (1/2in.).

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

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

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

[u]Bulk density after forced-air dyring at 105.0°C (221.0°F) 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]European peat product.

[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.

Table 4.12. Particle size distribution[z] analysis of six substrates containing Pindstrup[y], peat and cedar[x](Experiment 3)[w].

		Substrates					
U.S. standard sieve no.	sieve opening (mm)[v]	100% Peat Moss	75:25 Peat: Cedar	50:50 Peat: Cedar	25:75 Peat: Cedar	100% Cedar	100% Pindstrup
3/8	9.50	0.8ab[u]	2.5a	1.0ab	0.4ab	0.0b	2.2ab
1/4	6.35	5.2bc	10.5a	4.8bc	2.8c	0.0d	6.5b
6	3.35	16.3ab	19.7a	10.1cd	6.6de	3.1e	13.1bc
8	2.36	10.5a	11.9a	10.3a	11.1a	11.3a	7.5b
10	2.00	4.8d	5.3d	6.7c	8.8b	10.3a	2.9e
14	1.40	11.4c	13.1c	17.4b	24.5a	26.2a	5.0d
18	1.00	10.4d	9.4d	12.8c	18.3b	21.8a	6.1e
35	0.50	17.5a	13.4a	16.4a	16.4a	16.7a	14.1a
60	0.25	12.6ab	8.2b	11.5b	7.7b	7.5b	17.9a
140	0.11	7.2b	3.9bcd	6.3bc	2.5d	2.7cd	17.1a
270	0.05	2.4b	1.4cd	2.0bc	0.8d	0.4d	5.7a
pan	0.00	0.9b	0.7b	0.8b	0.3c	0.1c	1.8a
Texture[t]							
Coarse		22.3b	32.7a	15.8bc	9.7cd	3.1d	21.8b
Medium		37.1c	39.7c	47.1b	62.6a	69.6a	21.5d
Fine		40.6b	27.7bc	37.0bc	27.7bc	27.3c	56.7a

[z]Particle size distribution determined by passing a 100g [76.7°C (170°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).

[y]European peat product

[x]Cedar processed through two different screen sizes: 0.64 cm (1/4"), 0.95 cm (3/8").

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

[v]1 mm = 0.0394 in.

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

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

Table 4.13. Fertilizer rate effect on pH and electrical conductivity of cedar amended substrates in petunias (Experiment 3)[z].

		1 DAP[y]		14 DAP		28 DAP		45 DAP	
			EC[w]		EC		EC		EC
Substrate	**Rate (lbs)[x]**	**pH**	**mS·cm⁻¹**	**pH**	**mS·cm⁻¹**	**pH**	**mS·cm⁻¹**	**pH**	**mS·cm⁻¹**
100% Peat Moss	0	5.79	1.26	5.80	1.84	6.30	0.78	5.93	0.59
100% Peat Moss	1	5.75	1.69	5.86	2.10	6.30	0.63	5.93	0.69
100% Peat Moss	2	5.61	2.04	5.91	1.69	6.40	0.47	5.82	0.88
100% Peat Moss	4	5.57	3.41	5.88	1.50	6.22	0.58	6.93	0.67
75:25 Peat:Cedar	0	6.00	1.17	6.31	1.21	6.67	0.72	6.38	0.49
75:25 Peat:Cedar	1	5.92	1.45	6.50	1.14	6.97	0.35	6.37	0.47
75:25 Peat:Cedar	2	5.90	1.54	6.47	1.24	6.85	0.43	6.36	0.48
75:25 Peat:Cedar	4	5.69	2.56	6.33	1.39	6.79	0.54	6.23	0.61
50:50 Peat:Cedar	0	6.10	1.17	6.73	1.25	6.89	0.74	6.56	0.58
50:50 Peat:Cedar	1	6.00	1.46	6.68	1.36	7.00	0.65	6.56	0.50
50:50 Peat:Cedar	2	6.11	1.36	6.81	1.21	6.95	0.69	6.42	0.77
50:50 Peat:Cedar	4	5.92	2.56	6.71	1.35	6.90	0.80	6.34	0.64
25:75 Peat:Cedar	0	6.01	1.79	6.84	1.09	7.13	0.76	6.45	0.65
25:75 Peat:Cedar	1	5.99	1.34	6.86	1.05	7.15	0.76	6.50	0.64
25:75 Peat:Cedar	2	5.99	1.35	6.87	1.00	7.19	0.62	6.58	0.55
25:75 Peat:Cedar	4	6.03	2.58	6.74	1.17	7.16	0.70	6.67	0.56
100% Cedar	0	6.16	0.86	6.84	0.85	7.28	0.57	6.51	0.37
100% Cedar	1	5.72	1.54	6.83	1.01	7.29	0.75	6.40	0.55
100% Cedar	2	5.76	1.21	7.51	0.96	7.37	0.57	6.42	0.52
100% Cedar	4	5.77	2.99	6.83	0.95	7.33	0.52	6.51	0.45
Pindstrup[v]	0	4.81	1.12	4.78	2.22	5.05	1.26	5.37	0.32
Pindstrup	1	5.42	0.95	4.63	2.37	5.25	0.80	5.23	0.28
Pindstrup	2	5.76	2.01	4.55	2.44	5.35	0.40	5.21	0.24
Pindstrup	4	4.92	3.14	4.81	1.47	4.88	1.00	5.36	0.45
	HSD [u]	***0.38***	***1.03***	***1.06***	***2.46***	***0.57***	***1.05***	***1.66***	***0.46***
					Fertilizer Rate Response				
100% Peat Moss		L***[t]	L*** Q*	NS	NS	Q*	NS	L** Q*	NS
75:25 Peat:Cedar		L***	L***	NS	NS	NS	NS	NS	NS
50:50 Peat:Cedar		NS	L**	NS	NS	NS	NS	NS	NS
25:75 Peat:Cedar		NS	L* Q***	NS	NS	NS	NS	NS	NS
100% Cedar		L*** Q***	L*** Q*	NS	NS	NS	NS	NS	NS
100% Pindstrup		Q***	L*** Q**	NS	NS	NS	Q*	NS	NS

[z]pH and EC of solution determined using pour-through method on 'Dreams Burgundy' petunia.

[y]DAP = days after potting.

[x]Lbs·yd^{-3} of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Inc., Lakeland, FL).

[w]Electrical conductivity = EC

[v]European peat product.

[u]Tukey's Honest Significant Difference Test α = 0.05 (n = 4).

[t]Non Significant (NS), Linear (L), or Quadratic (Q) response at p ≤ 0.05 (*), 0.01 (**), or 0.001 (***).

Table 4.14. Fertilizer rate effect on growth of 'Snapshot Pink' snapdragon in cedar amended substrates[z] (Experiment 3).

		Growth Parameters			
Substrates	**Rate** [y]	**GI**[x]	**FCR**[w]	**MK**[v]	**SDW**[u]
100% Peat Moss	0	8.6	5.0	2.9	0.4
100% Peat Moss	1	16.1	4.3	4.3	4.4
100% Peat Moss	2	16.3	4.9	4.4	5.8
100% Peat Moss	4	15.7	4.1	4.1	4.6
75:25 Peat Moss:Cedar	0	12.1	4.0	4.1	0.8
75:25 Peat Moss:Cedar	1	15.0	4.3	4.3	3.6
75:25 Peat Moss:Cedar	2	16.1	4.7	4.7	3.4
75:25 Peat Moss:Cedar	4	20.0	5.0	4.9	6.2
50:50 Peat Moss:Cedar	0	5.7	2.0	2.0	2.0
50:50 Peat Moss:Cedar	1	15.0	4.0	3.9	2.3
50:50 Peat Moss:Cedar	2	16.9	4.7	4.6	4.2
50:50 Peat Moss:Cedar	4	21.9	5.0	5.0	5.7
25:75 Peat Moss:Cedar	0	6.3	1.9	1.9	1.8
25:75 Peat Moss:Cedar	1	12.0	3.4	3.3	0.6
25:75 Peat Moss:Cedar	2	14.4	4.0	3.9	2.3
25:75 Peat Moss:Cedar	4	19.0	5.0	4.9	4.6
100% Cedar	0	6.3	1.7	1.6	0.1
100% Cedar	1	8.0	2.4	2.1	0.1
100% Cedar	2	10.7	3.3	2.7	0.4
100% Cedar	4	11.9	2.4	2.9	0.5
Pindstrup[t]	0	13.0	3.7	4.0	1.8
Pindstrup	1	19.0	4.6	5.0	7.2
Pindstrup	2	21.0	4.7	5.0	7.3
Pindstrup	4	22.0	5.0	5.0	9.1
	HSD [s]	***4.3***	***1.2***	***1.1***	***4.4***
		Fertilizer Rate Response			
100% Peat Moss		L***[r] Q***	NS	L*** Q***	L*** Q***
75:25 Peat:Cedar		L***	L***	L*** Q*	L***
50:50 Peat:Cedar		L*** Q*	L*** Q***	L*** Q**	L***
25:75 Peat:Cedar		L***	L***	L***	L** Q*
100% Cedar		L***	L** Q***	L***	NS
100% Pindstrup		L*** Q***	L***	L** Q*	L*** Q*

[z]Cedar processed through two different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.).

[y]$Lbs \cdot yd^{-3}$ of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Fertilizer, Inc., Lakeland, FL).

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

[w]Foliar color ratings were taken 45 days after potting (DAP) on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green).

[v]Marketability/aesthetic quality ratings were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/ chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable).

[u]Shoot 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.

[t]Eurpean peat product.

[s]Tukey's Honest Significant Difference Test $\alpha = 0.05$ ($n = 7$).

[r]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

Table 4.15. Fertilizer rate effect on growth of 'Dreams Burgundy' petunia in cedar amended substrates[z] (Experiment 3).

		Growth Parameters			
Substrates	**Rate[y]**	**GI[x]**	**FCR[w]**	**MK[v]**	**SDW[u]**
100% Peat Moss	0	8.6	2.6	2.0	0.2
100% Peat Moss	1	16.0	4.0	4.3	3.8
100% Peat Moss	2	18.6	4.7	4.89	5.2
100% Peat Moss	4	20.7	5.0	5.0	7.7
75:25 Peat Moss:Cedar	0	8.7	2.9	2.1	0.1
75:25 Peat Moss:Cedar	1	14.3	4.0	3.9	1.8
75:25 Peat Moss:Cedar	2	15.7	4.4	4.3	3.8
75:25 Peat Moss:Cedar	4	20.1	5.0	5.0	6.5
50:50 Peat Moss:Cedar	0	0.0	1.0	1.0	0.0
50:50 Peat Moss:Cedar	1	12.6	3.6	3.0	1.2
50:50 Peat Moss:Cedar	2	16.0	4.1	4.0	3.1
50:50 Peat Moss:Cedar	4	19.4	4.9	5.0	6.1
25:75 Peat Moss:Cedar	0	0.0	1.3	1.0	0.0
25:75 Peat Moss:Cedar	1	9.4	3.7	2.7	0.7
25:75 Peat Moss:Cedar	2	14.7	4.6	3.9	1.6
25:75 Peat Moss:Cedar	4	17.7	5.0	4.7	3.7
100% Cedar	0	0.0	1.0	1.0	0.0
100% Cedar	1	5.9	2.0	1.7	0.1
100% Cedar	2	11.4	4.4	3.3	1.0
100% Cedar	4	14.0	4.4	3.9	2.0
Pindstrup[t]	0	20.1	3.0	2.9	1.2
Pindstrup	1	17.3	4.1	4.4	3.3
Pindstrup	2	17.9	4.7	4.9	4.2
Pindstrup	4	20.6	5.0	5.0	6.9
	HSD[s]	***9.9***	***0.9***	***0.8***	***3.8***
		Fertilizer Rate Response			
100% Peat Moss		L***[r]	L*** Q**	L*** Q***	L***
75:25 Peat:Cedar		L***	L***	L*** Q***	L***
50:50 Peat:Cedar		L*** Q*	L*** Q***	L*** Q***	L***
25:75 Peat:Cedar		L***	L*** Q***	L*** Q**	L***
100% Cedar		L***	L*** Q***	L***	L*
100% Pindstrup		NS	L*** Q*	L*** Q***	L***

[z]Cedar processed through two different screen sizes: 0.64 cm (1/4in.), 0.95 cm (3/8in.).

[y]$Lbs\cdot yd^{-3}$ of 12.0N-2.64P-6.64K slow release fertilizer (12-6-8, Harrell's Fertilizer, Inc., Lakeland, FL).

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

[w]Foliar color ratings were taken 45 days after potting (DAP) on a scale of 1 to 5 (1 - dead, 2 - some chlorosis, 3 - moderate, 4 - normal green, 5 - lush green).

[v]Marketability/aesthetic quality ratings were taken at 45 DAP on a scale of 1 to 5 (1 - dead, 2 - stunted/ chlorosis, 3 - stunted/no chlorosis, 4 - marketable, 5 - highly marketable).

[u]Shoot 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.

[t]Eurpean peat product.

[s]Tukey's Honest Significant Difference Test $\alpha = 0.05$ (n = 7).

[r]Non Significant (NS), Linear (L), or Quadratic (Q) response at $p \leq 0.05$ (*), 0.01 (**), or 0.001 (***).

CHAPTER V
FINAL DISCUSSION

Peat moss and pine bark are currently the main components in soilless substrates for container production. However, alternative substrates to peat moss are being sought due to environmental concerns of peat harvesting, climate conditions, and fuel cost. Concerns regarding the declining timber industry and fuel cost have also resulted in the search for pine bark alternatives. The purpose of these studies was to evaluate eastern red cedar as an alternative substrate in both greenhouse and nursery plant production. These specific objectives were part of an effort to develop possible alternatives that will be able to provide the same productivity as pine bark and peat moss. It would prove beneficial for the alternative substrates to be locally available, provide similar physical properties, and have less impact on the environment with lower transportation cost.

In *Chapter 2* physical properties showed substrates with higher cedar percentages to have an increase in air space, resulting in water holding capacity to decrease in cedar amended substrates. Particle size distribution exhibited the peat moss:perlite control treatment to have a greater percent of coarse and fine particle sizes than substrates with 50% cedar. Data shows plant growth in 50% cedar ground at 1/4in. was similar to the control treatment for two of the four species. Petunia, vinca, begonia and celosia expressed similar growth in 25% cedar at 1/4in., 3/8in., and 1/2in. screen sizes to those grown in the control. Shoot dry weights indicated a decrease with an increase in cedar content and screen size for each annual species. Similar or greater root growth was apparent for substrates containing 25% cedar compared to the control treatment (80:20 P:PL). Treatments with 25% cedar exhibited marketability ratings comparable to the control treatment for three of the four species. Foliar color ratings showed similarities for all substrates with each species. In conclusion, data shows that peat amended with 25% cedar at 1/4in., 3/8in., 1/2in., and mixed screen sizes has potential in the production of these four greenhouse annuals.

Chapter 3 showed physical properties to have had an increase in air space and total porosity with an increase in cedar. Bulk density varied, Exp. 1 exhibited a decrease with increasing cedar and Exp. 2 showed no difference among substrates. Particle size had an overall decrease in size with high cedar substrates containing the greatest percentage of fine particles, which are necessary for adequate substrate water holding capacity. In general, 8 of the 10 species grew equally well in substrates amended with up to 80% cedar when compared to PB in Exp. 1. Premier blueberry and Formosa azalea did not grow as well in cedar above 40%. Experiment 2 exhibited similar trends among species. Premier blueberry did not grow as well in cedar above 40%. However, Formosa azalea tended to withstand up to 80% cedar. All other 8 species performed similar to the previous experiment with the exception of Sargents juniper, which grew equally well in substrates amended with up to 80% cedar. This data shows that PB amended with cedar provides a suitable substrate for woody nursery crops, except with acid loving species.

In *Chapter 4,* physical properties for each experiment varied, the differences could be due to decomposition of the cedar in the months stored before use or the packing of the substrates for the determination of physical properties could have occurred differently for each experiment. Particle size distribution tended to have a similar trend across substrates for each experiment, coarse particles greatest with higher percentages of cedar. Results from these experiments show that plants can be grown successfully in cedar with additional fertilizer. Snapdragons grown in up to 75% RC with 4lbs of fertilizer were comparable to those grown in 4lbs control treatment. Pansies grown in up to 50% cedar with 4lbs of fertilizer were similar to those grown in 4lbs 100% peat moss. Petunia growth was similar for all substrates with up to 100% cedar when amended with 2lbs of fertilizer. This shows that these species are able to growing in cedar amended substrates with the addition of fertilizer, some species more versatile than others.

These studies show that eastern red cedar can be used successfully as an amendment in greenhouse substrates at up 75% (by volume) with 4lbs of fertilizer (12.0N-2.64P-6.64K), above which stunting and foliar discoloration occurs. Studies also demonstrate that pine bark may be amended with up to 80% cedar in the nursery production of woody ornamentals, with the exception of acidic loving plants. These studies have shown that eastern red cedar is a source of locally available substrate that is economical and sustainable.