EVALUATION OF EASTERN REDCEDAR AS A SUBSTRATE FOR CONTAINER-GROWN PLANT PRODUCTION

by

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Abstract

The nursery industry in the United States, particularly in the Great Plains region is growing; however, materials used in creation of artificial substrates used to grow ornamental nursery crops continue to increase in price. Eastern Redcedar (*Juniperus virginiana* L.) is an indigenous plant throughout much of the United States and, in the Great Plains, it has become a pest. Use of wood-based substrates (primarily composed of pine trees) has been proven effective in both nursery and greenhouse production. Eastern Redcedar chips (JVC) could become a local and sustainable resource for the horticulture industry throughout the Midwest. Experiments were conducted to determine if JVC could be used as a substrate to replace or supplement three major substrate components; pine bark (PB), perlite, or peat moss. Four studies evaluated ornamental crop growth: two focused on comparing nursery crop production in PB and JVC, one focused on greenhouse production in peat moss, and the last on plant propagation in perlite. The first experiment (Chapter 2) involved combining ratios of JVC and PB with two fertilizer rates to grow woody plants. It was shown that while higher levels of fertilizer produced larger plants, that plants grown at either rate of fertilizer showed the same growth trends. As JVC content increased more than 20%, growth measurements such as shoot dry weight and plant height decreased. This decrease in growth can be attributed to the physical properties of JVC, which showed that as JVC content increased so did airspace with a corresponding decrease in container capacity. A follow-up experiment (Chapter 4) evaluated several different particle sizes of JVC and a PB control. It showed that despite the different particle sizes JVC substrate produced less growth than plants grown in PB though plants grown in JVC were all similar to each other. Another experiment (Chapter 3) was conducted to evaluate if JVC as a replacement for peat moss in producing greenhouse-grown annual crops. JVC's low container capacity hindered plant growth with each increase in JVC content associated with a decrease in growth. Finally a propagation experiment (Chapter 5) used a combination of finely-ground JVC and perlite to grow cuttings of woody and herbaceous plants. It was shown that, in most cases, JVC and perlite were equivocal rooting cuttings. This work demonstrates that JVC can be used as a PB and peat moss supplement, but not a replacement nursery and greenhouse crop production. Use of JVC as a perlite replacement for plant propagation is recommended.

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Dedication

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Chapter 1 - Use of Alternative Substrates in Container-grown Nursery Crop Production

Soil provides mechanical anchorage and support for plants in addition to serving as a reservoir of water, nutrients, and oxygen for roots (Harris et al., 2004). Artificial (soil-less) substrates contain one or more materials utilized to duplicate these properties. Generally used in containerized production systems, artificial substrates offer some advantages over soil culture such as increased mechanization and reduced labor, container weight, and variability for a consistent production scheme (Chadler et al., 1957). Most methods of substrate handling isolate the materials from soil minimizing the chance of contamination from soil borne organisms that can cause disease and crop failure. Additionally artificial substrates can be sterilized without fear of releasing toxic elements trapped in soil colloids (Chadler et al., 1957). Nutrients in the substrates can more easily be controlled and monitored, minimizing plant loss due to toxicity. If nutrient levels do reach a toxic state they can more readily be removed through leaching with irrigation water. This allows for greater control and maintenance of substrate pH and nutrients (Chadler et al., 1957).

Pine Bark & Peat Substrates

Pine bark was a waste product of the timber industry in the 1950's; it is composed of bark and cambium tissue left over from trees processed in equipment designed to strip logs, producing a straight log or pole (Self, 1978). Pine bark is then hammer-milled to obtain a desirable particle size and aged for use by the horticulture industry. In the United States, pine bark is the primary material used in substrates and often comprises a large percent (by volume) of container substrates, sometimes up to 100% (De Werth, 1971; Laiche, 1974; Pokorny, 1966; Pokorny

1979). However, a reduction in pine bark availability has resulted in an increase in price (Lu et al., 2006). This reduction in availability is due to reduced timber production, closing timber processing mills to other regions or abroad, and the use of pine bark as a fuel wood to offset increasing energy costs. Additionally, higher transportation costs from the processing site (either mills or in field) to consumers have become more expensive (Lu et al., 2006). This has led to demand for an alternative to pine bark as a substrate. As a result, research on alternatives to pine bark has been an increasing area of interest in recent years. Alternative substrates are meant to either replace or supplement pine bark and peat supplies.

Container-grown plant production in greenhouses primarily uses peat moss as a substrate. While world peat reserves are abundant, the threat of peat-mining destroying non-recoverable peat bogs and damaging whole ecosystems has led to concern among environmentalists as well as scientific and governmental agencies in Europe (Carlile, 2004; Clark, 2008; Riviere et al., 2008; Robertson, 1993). This has, in turn, led to tighter regulations of peat use in some countries such as the United Kingdom (Holmes, 2009). While currently there are no regulations on peat use in the United States or Canada (primary source of peat moss for the United States), there are rising concerns about native bogs. Additionally, increased cost of production and transportation has led to increasing prices. These factors have led to demand for alternative substrates for the greenhouse industry (Griffith, 2007; Landis and Morgan, 2009; Lu et al., 2006).

The search for alternative materials focuses on finding materials that are stable, pest free, easy to handle and mechanize, local, sustainable, and affordable. Research in this area has explored many different substrate possibilities such as: Kenaf (Marianthi 2005, Wang 1994), Pulp Mill boiler (Bi and Evans, 2009), poultry feathers (Evans and Vancey 2007), rubber (Evans and Harkess, 1997), composted cotton burrs (Wang and Blessington, 1990), earthworm castings

(Hidalgo and Harkess, 2002), and saw dust (Wright et al., 2008) among many materials. Unfortunately most of these alternative substrates cannot be utilized as the primary material in a substrate mix, often only being able to be used up to 25% of the substrate by volume or less in a containerized production system. Many have only been evaluated in a greenhouse production system and not in outdoor nursery crop production. Other alternative materials such as rice hulls (Buck and Evans, 2010; Chadler et al., 1957; Evans et al., 2004; Evans and Gachukia, 2008; Evans et al., 2011; Sambo et al., 2008) and coconut coir (Arenas et al., 2002; Evans et al., 1996; Meerow, 1994) have shown great potential but primarily for greenhouse production systems. Overall, alternative nursery production substrates have been explored less than greenhouse substrates resulting in a poverty of choices in that type of production. However, one type of substrate previously disregarded is showing great potential as a pine bark replacement in both nursery and greenhouse production systems.

Wood-based Substrates

In 1986 Laiche and Nash tested three materials containing increasing amounts of wood starting with milled pine bark, fresh pine bark, and then pine tree chips. They demonstrated that pine bark outperformed the other two materials, with the freshly milled bark performing better than pine chips. They speculated that this was due to the lower water holding capacity (which could be altered with different particle sizes) in addition requiring more nitrogen due to immobilization (Laiche and Nash, 1986). Based on this study it was commonly understood that wood-based substrates would not work due to nitrogen immobilization and the fear that wood would rapidly decay. Despite this, various wood-based substrate materials were developed and used in Europe, albeit for peat replacement rather than nursery production (Gumy, 2001; Schilling, 1999; Schmilewski, 2008). A study published in 2005, the first study on wood-based substrates since Laiche and Nash's study, demonstrated that wood-based materials could be utilized successfully for both nursery and greenhouse production. The study by Wright and Browder examined plants grown in traditional pine bark and a material made of loblolly pine (*Pinus taeda* L.) logs chips, normally used for paper manufacturing, that were ground further to a size similar to pine bark, in addition to a mixture of 75% chipped pine logs to 25% PB (Wright and Browder, 2005). The study showed that chipped pine logs could be a feasible substrate that showed no shrinkage of the substrate and produced viable plants that did not differ greatly from plants grown in pine bark (Wright and Browder, 2005). Shortly after this experiment work began on three different substrates based on pine products, chipped pine logs, WholeTree, and clean chip residual; the primary difference between the three substrates being the amount of green material (needles) in the substrate. The material with the greatest green material content is clean chip residual, made from a byproduct produced from thinning pine plantations with mobile equipment directly by the field for clean chips (Boyer et al., 2008a). This residual material is usually sold either as boiler fuel or, more commonly, left on the forest floor. It is composed of 50% wood, 40% bark, and 10% needles (Boyer et al., 2008a). WholeTree is processed from whole pine trees and consists of wood, bark, needles, cones and other parts, resulting in a substrate that contains about 80 percent wood and twenty percent other tree parts (Fain et al., 2008a). Finally the substrate containing the least green material is the previously mentioned chipped pine logs, consisting of 90 to 100% wood, 10% bark, and no needles (Wright and Browder, 2005; Jackson et al., 2010). Some additional advantages that these substrates share is that they can be produced in close proximity to growers in timber regions, minimizing transport and shipping, it can be used immediately after milling without composting or aging, and their physical properties can easily be manipulated by altering particle size during the hammermilling process. Furthermore, these substrates can be utilized using pre-existing equipment (Boyer et al., 2008a, Fain et al., 2008b, Jackson et al., 2010).

Clean Chip Residual

In 2005 and 2006 two experiments were conducted using 19.05 mm and 12.70 mm loblolly pine clean chip residual alone or blended with peat and compared to a pine bark or pine bark mixed with peat (Boyer et al., 2008a; Boyer et al., 2008b). The first evaluated several outdoor perennials and showed that in general, plants grown in clean chip residual lagged in growth early on in the production cycle, with plants grown in substrates containing peat growing larger. However many plants grown in 100% wood material, both clean chip residual and pine bark, produced marketable crops (Boyer et al., 2008b). The authors speculated that differences in growth between substrates were likely due to physical properties, with 100% wood substrates having higher air space and lower water holding capacity (Boyer et al., 2008b). Later in 2006 three annuals were evaluated. Generally it reflected the 2005 study in that physical properties resulted in decreased growth in clean chip residual substrates. However, as long as the treatment contained peat clean chip residual and pine bark were similar (Boyer et al., 2008a). Additionally, in 2005, an experiment was conducted on clean chip residual's effects on woody plants (Boyer et al., 2009). Five substrates were used consisting of a pine bark control and four 100% hammermilled clean chip residual to pass a 3.18 cm, 1.91, cm, 1.27, cm, or 0.95 cm screen and were used to grow five woody species. All substrates had a lower water holding capacity than recommended, though 0.95 cm and 1.27 cm clean chip residuals were similar to the pine bark control (Boyer et al., 2009). While there were some differences in most measurements, plants grown in clean chip residual and pine bark were comparable at most screen sizes, though growth did tend to decrease as particle size increased (Boyer et al., 2009).

Chipped Pine Logs

A study using poinsettia compared plant growth in two screen sizes of chipped pine logs, mixtures of chipped pine log and peat, and a peat-lite control with four different fertilizer rates (Jackson et al., 2008a). Airspace was high within wood containing treatments but within recommended ranges. It was demonstrated that generally plants grown in chipped pine tree substrate had less growth compared to peat-lite within the same fertilizer rate. However, when plants grown in chipped pine log substrate were compared with peat-lite grown with 100 $mg \cdot L^{-1}$ less nitrogen the plants had comparable in growth. Showing that chipped pine logs can be used successfully with additional fertilizer (Jackson et al., 2008a). In another study, pine chips were ground to pass a 4.76 mm screen and compared to a commercial substrate. This study also showed that chipped pine log-based substrates requires about 100 $mg \cdot L^{-1}$ more nitrogen fertilizer than peat to obtain the same growth (Wright et al., 2008). This need for more nitrogen was explored to see how immobilization could result in smaller plants when grown in chipped pine logs (Jackson et al., 2009b). The substrates used were pine tree substrate, pine bark, and peat-lite. It was shown that nitrogen immobilization was highest in pine tree substrate, then pine bark, followed by peat-lite (Jackson et al., 2009b). Generally nitrogen immobilization occurred in the first days after potting and increased with each measurement date through the rest of the study in all substrates. Additionally, it was shown that 28 days after planting more than twice the amount of nitrogen was immobilized in pine tree substrate compared with pine bark and more than five times the amount of peat-lite (Jackson et al., 2009b). Substrate CO^2 efflux, an indirect measure of microbial activity (Carlile and Wilson, 1991), increased as fertilizer rate increased in all substrates and at each measurement date and was highest in pine tree substrate and lower in peat-lite, indicating high microbial activity (Jackson et al., 2009b) This study showed that more nitrogen is immobilized in pine tree substrate compared with pine bark or peat-lite under greenhouse conditions (Jackson et al., 2009b). Complementary studies have evaluated the effect of chipped log substrates in a plant production system deomonstrating that this type of substrate has a lower buffering capacity than pine bark and peat moss and that chipped pine log maintains good physical structure when stored over a long period of time (Jackson et al., 2009a, Jackson et al., 2009c).

WholeTree

Annual bedding plants were grown in WholeTree substrates (0.64-cm screen size) blended to create three substrates: 100% WholeTree substrate, 20% WholeTree, and 50% WholeTree with the remaining volume composed of peat (Fain et al., 2008a). These treatments were compared to a peat-lite mix. There were four rates of starter fertilizer added at the beginning of the experiment. It was shown that airspace increased with increasing percentages of WholeTree with a corresponding decrease in water holding capacity, just as in other wood-based substrate studies. Additionally, pH increased with increasing percentages of WholeTree (Fain et al., 2008a). In general, this study showed that WholeTree substrate is an acceptable substrate component in addition to peat, to replace a large percentage of peat in greenhouse production. Another study evaluated WholeTree substrate derived from longleaf pine (*Pinus Palustris* mill.) and slash pine (*Pinus elliottii* engelm.) compared to loblolly pine. It demonstrated that they are similar to loblolly pine and can be used as alternative substrates with few differences in plant growth (Fain et al., 2008b).

Overall wood substrate

An experiment was conducted in 2010, which compared WholeTree and chipped pine log for annual greenhouse crop production (Gaches et al., 2010). Using 50% WholeTree substrate or chipped pine log and two different types of 50% peat to grow two crops. The results showed that WholeTree and chipped pine log substrate mixed with at least 50% peat is interchangeable. The differences were negligible for the most part, and both show great promise as substrates for greenhouse container production (Gaches et al., 2010). Finally, a study was conducted to compare WholeTree substrate and clean chip residual (Murphy et al., 2010). Substrates were composed of hammermilled pine to pass a 9.53 mm screen were used to make 0%, 25%, 50%, 75% or 100% clean chip residual or WholeTree substrate with the remaining composed of pine bark. It was shown that plants grown in up to 75% alternative substrate, either WholeTree or clean chip residual, were comparable to 100% pine bark (Murphy et al., 2010). Overall substrates derived from Loblolly pine demonstrate that they can be utilized in large part or wholly for both nursery and greenhouse substrate, and in some ways are interchangeable. However, plant production in these substrates differs greatly between the two environments, greenhouse and nursery, with these wood-based materials performing less efficiently than other peatmoss replacements but performing well in the nursery environment.

Sustainable Substrates for the Great Plains

As the nursery industry continues to grow demand for alternatives to expensive and erratically available nursery production materials will increase. The search for alternative substrate materials focuses on finding materials that are stable, pest free, easy to handle and mechanize, local, sustainable, and affordable. In the future this may lead to a nursery industry defined by locally available material for consumption instead of a standardized production scheme. One such region is the Great Plains, which stretches throughout the middle part of the United States and Canada. This region offers unique challenges facing the local nursery industry including the current necessity to import, at great expense, pine bark and peat. Utilization of native and naturalized species of herbaceous and woody plants as a substrate could augment or hopefully replace industry standards in the same way as other alternative substrates have in the Southeast U.S. as mentioned previously. Three species are currently being investigated as sources of alternative substrate for the Great Plains: Switchgrass (*Pacicum vergatum* L.), Eastern Redcedar (*Juniperus virginiana* L.), and Hedge-Apple (*Maclura pomifera* Raf.). Switchgrass is currently being evaluated in Wooster, Ohio has been tested primarily as a peat replacement for greenhouse grown crop production (Altland and Krause, 2009; Altland and Krause, 2010).

Switchgrass

Switchgrass is an indigenous plant to the United States and found throughout the grasslands of the Great Plains. It is currently being evaluated as a biofuel as well as an alternative substrate (Altland and Krause, 2009, Altland, 2010). It is a perennial grass species with flat blades usually 50 to 140 cm tall (Barker et al., 1986). It reproduces both sexually and asexually with 3.5 to 6 mm long spiklets or more commonly through rhizomes, which result in forming large clumps (Barker et al., 1986). A nursery production experiment showed that switchgrass alone, at two particle sizes (1.25 or 2.5 cm), or mixed with 30 or 50% peat all resulted in vigorous roses (*Rosa* L. ‘ChewMayTime’). Generally air space decreased with increasing amounts of peat reaching a more ideal airspace level with more peat. Coarser switchgrass had the highest airspace (Altland and Krause, 2009). In general, fine ground switchgrass had more favorable physical properties with or without peat than coarser ground switchgrass. The pH of switchgrass substrates was generally high (6.5 to 7.5) and appeared to provide very little buffering capacity against irrigation and fertilizer (Altland and Krause, 2009). In finer-ground switchgrass treatments shoot dry weight of roses was highest in 30% peat followed by switchgrass alone and then 50% peat. Root mass was only marginally affected, decreasing as peat increased. When exposed to varying degrees of fertilizer root growth generally decreased with the most roots appearing in coarser switch grass alone (Altland and Krause, 2009). To counteract the high pH of switchgrass an experiment was conducted adding elemental sulfur and municipal solid waste compost (Altland and Krause, 2010). It was shown that combinations of peatmoss, switchgrass, and compost improved the physical properties of switchgrass substrate by increasing container capacity and also decreasing pH to a more acceptable level. However, combinations of switchgrass and peat or switchgrass and compost were not as effective at buffering pH as all three combined. Elemental sulfur was also effective at lowering pH though levels higher than 0.59 kg/m^3 were no more effective (Altland and Krause, 2010). Finally a study on multiple crops being explored for biofuel including switchgrass, willow (*Salix* spp.), corn stover (*Zea mays* L. ssp.), and giant miscanthus (*Miscanthus x giganteus*) were explored for growing annual vinca and compared to pine bark over two experiments (Altland, 2010). It was shown that no biofuel crop alone was suitable for vinca production alone due to a high airspace and lower container capacity. However in combination with 20% peatmoss, or 20% peatmoss and 10% municipal solid waste compost physical properties were changed resulting in a more ideal balance of container capacity and airspace which resulted in all crops being similar to each other in growth (Altland, 2010). In experiment two, however, plants grew larger than in the first experiment showing more growth differences. Pine bark produced the most growth, followed by switchgrass which was statically similar to corn stover (Altland, 2010).

Eastern Redcedar

Eastern Redcedar (*Juniperus virginiana* L.) is a common and indigenous tree native to every state in the U.S. east of the 100^{th} meridian, and grows in USDA hardiness zones 3 to 9 (Dirr, 2009; van Haverbeke and Read, 1976). The species has a pyramidal shape when young though it can range from columnar to broadly pyramidal in the wild with thin, shredding reddish-brown to grey bark. (Dirr, 2009; Barker et al., 1986). The leaves are green to blue-green, flat, closely pressed together and overlap each other forming "scales" (Barker et al., 1986). It ranges from 40 to 50 feet high and 8 to 20 feet in spread, though typically Eastern Redcedar in the prairies of the Great Plains are shorter than average. Eastern Redcedar is dioecious with female trees producing blue, berry-like cones with a waxy bloom usually bearing a single seed (Dirr, 2009; Holthuijzen and Sharik, 1984). Stands of Eastern Redcedar usually maintain a 1:1 sex ratio with male trees producing staminate cones at 4 years of age while female trees produce ovate cones by 10 years of age (van Harbeke and Read, 1976; Vasiliauskas and Aarssen 1991). Though Owensby places seed production from 6 to 7 years of age (Owensby et al., 1973). Eastern Redcedar also has sexual dimorphism with male trees having greater height and truck diameter, probably due to a greater cost of reproduction in female plants. Both sexes generally have equal canopy cover (Barker et al., 1986; Vasiliauskas and Aarssen 1991).

Juniper trees species in general are utilized for essential and volatile oil production used in several industries and Eastern Redcedar wood is likewise used in this manner, though the leaves are not used due to poisonous components (Dunford et al., 2007; Eller and Taylor, 2004; Semen and Hiziroglu, 2005). Eastern Redcedar oil has a broad range of uses due to its unique odor and ability to repel pests in addition to its antibacterial, fungal, and termite-resisting abilities. It is found in products such as perfume, insecticides, acaricides, cockroach repellents, and mosquito repellent (Adams, 1987; Adams et al., 1988; Appel and Mack, 1989; Carter, 1976; Clark et al., 1990; Curtis et al., 1987; McDaniel and Dunn, 1994; Oda et al., 1977; Panella et al., 1997; Semen and Hiziroglu, 2005). The heartwood of Eastern Redcedar contains the most oil of all parts of the wood. Older trees contain more oil (1 to 4%) depending and the age of the tree

(Dunford et al., 2007). Contents of Eastern Redcedar oil also differ depending on the age of the wood (fresh vs. aged) and the method of extraction such as Steam distillation, continuous partial pressure, solvent extraction or super critical fluid extraction (Dunford et al., 2007; Semen and Hiziroglu, 2005). Generally, the oil is made up of 80% β- and α- cedrene, 3 to 14% cedrol and a small amount of cedrenol. Other important chemicals found the oil are cuparene, widdrol, curcumene, and thujopsene, which are used for their aromatic qualities (Dunford et al., 2007; Eller and Taylor, 2004; Semen and Hiziroglu, 2005). However two of these oils have known antibacterial, cuparene, and antifungal, widdrol, properties and derivatives (Ishikawa et al., 2001; Nuñez et al., 2006).

Eastern Redcedar seeds are spread through seed drop, bird droppings, and small to medium sized mammals with 71 species known to forage on them (van Dresal, 1938). Eastern Redcedar seed viability declines exponentially overtime with only 5.5% being viable after 14 months, resulting in a low seed bank in the soil (Holthuijzen and Sharik, 1984). Additionally, only 22% to 30% of the seeds make it directly from the tree to the soil, most of which is removed by mammals (Holthuijzen and Sharik, 1984; Holthijzen et al., 1986). The remaining 65% of the seeds are removed by birds (Holthijzen et al., 1986). Dispersion by birds is more common and effective for Eastern Redcedar seeds and results in an increase in germination by 1.5 to 3.5 greater than hand pulping of the cones and moving the seeds up to 12 m (Holthijzen et al., 1986). Many of the bird species that consume Eastern Redcedar cones are not forest obligates and will disperse seeds through more open areas that have some structures for bird perches such as fencelines (McDonnell and Stiles, 1983; Holthuijen and Sharik, 1985).

Eastern Redcedar colonizes abandoned fields quickly with fast growth rates due to its ability to effectively exploit resources (soil nutrients and water). Eastern Redcedar can actively photosynthesize year-round, even at 0°c in the winter or under low soil moisture conditions. Significant photosynthesis still occurs with twig water potential at -30 bars (Ormsbee et al., 1976). Eastern Redcedar also has a low stomatal conductance and ability to maintain stomatal opening at low water potentials (Bahari et al., 1985) This means that the growing season for Eastern Redcedar is effectively year-round allowing for carbon gains while surrounding grasses are dormant (Eggemyer et al., 2006; Ormsbee et al., 1976). Additionally, Eastern Redcedar produces a rapidly growing, deeply penetrating tap root capable of absorbing water from deep soil horizons to avoid summer drought and to access water when the upper profile is frozen (Eggmeyer, 2005; Kramer, 1949). However Eastern Redcedar is adapted to full sun and is shade intolerant (Fowells, 1965, Ormsbee et al., 1976). Eastern Redcedar foliage and buff (leaf matting and soil directly under the plant) also have negative allelopathic (the biochemical interactions either beneficial or detrimental between both plants and microorganisms) effects on some prairie grass species' seed germination (Rice, 1979; Stipe and Bragg, 1989; Smith, 1986). However foliage and buff have a neutral to positive effect on established plants (Smith, 1986).

Eastern Redcedar has many detrimental effects on the Great Plains grasslands. Just a few rapidly growing individual trees can greatly alter ecosystems and can serve as a catalyst for accelerated Eastern Redcedar encroachment (Ganguli et al., 2008; Hoch et al., 2002). An isolated tree has a significant effect on species composition of that portion of the prairie where the tree crown develops in less than 2 decades (Gehring and Bragg, 1992). This detrimental effect changes the ecosystem to the point that even with tree removal its reversion to the original prairie composition will be slow and unlikely. As trees grow larger the understory environment becomes unfavorable to herbaceous plants (Gehring and Bragg, 1992). Eastern Redcedar is also associated with significant decreases in plant species richness, resulting when increasing Eastern Redcedar density forms monocultures when the trees reach 1500 trees/ha (Briggs et al., 2002). Stem density, species richness, forb cover, and grass cover decreases under Eastern Redcedar (Linneman and Palmer, 2006). A single tree's influence extends beyond its canopy diameter, decreasing other plant's growth, solar radiation, and temperature around it, particularly on the North side due to the tree's shadow. This results in a continuous increase in herbaceous standing crops radiating outward from the tree's drip line to 3 m and to 5 m (Engle et al., 1987; Linneman, 2004; Linneman and Palmer, 2006). Eastern Redcedar affects animal diversity as well. The diversity and abundance of small mammals decreased in prairie communities with increasing Eastern Redcedar coverage (Horncastle et al., 2004; Horncastle et al., 2005). Additionally grassland bird species decrease in abundance with increasing woody cover from Eastern Redcedar, though open-habitat generalists and woodland bird species do increase in abundance and diversity (Chapman et al., 2004; Coppedge et al. 2001). On dry, intact prairie ecosystems characterized by steep slopes, nutrient poor, and dry soil usually not used for agriculture show more resilience to the effects of Eastern Redcedar. Removal of those trees results in the area regaining its native prairie species, making restoration of those areas possible with Eastern Redcedar removal (Pierce and Reich, 2010).

There has been widespread increase in Eastern Redcedar forest in the Great Plains over the last 60 years (Beilmann and Brenner, 1951; Bidwell et al., 1990; Hoch and Briggs, 1999; Owensby et al., 1973). Aerial photos from the Flint Hills of Kansas show that conversion of prairie to closed canopy forest can take place in 40 years (Briggs et al., 2002). A study in 2000 showed a 120% increase in closed canopy Eastern Redcedar in the Flint Hills of Kansas after 15 years from 1985 to 2000 (Hoch, 2000). In Oklahoma an estimated 762 acres of land are lost to Eastern Redcedar infestation per day (Drake and Todd, 2002). Plant species diversity is not an effective barrier to Eastern Redcedar encroachment and in some cases enhances Redcedar encroachment (Ganguli et al., 2008). Increased livestock grazing increases Eastern Redcedar establishment by decreasing competition by other plants (Schmidt and Stubbendieck, 1993). Large scale Eastern Redcedar establishment has an adverse effect on livestock by reducing grazing areas and increasing livestock handling (Engle, 1985; Engle et al., 1987; Stritzke and Rollins, 1984). Fire is historically the most effective control of Eastern Redcedar. Fires previously took place every 1 to 6 years in the Great Plains, pre settlement (Ansley and Rasmussen, 2005; Engle and Stritzke, 1992; Frost, 1998; Owensby et al., 1973, Ortmann et al., 1998,). Eastern Redcedar cannot re-sprout and fire effectively kills it, usually by destroying most seedlings and small trees. However, fire loses effectiveness as tree size increases necessitating manual removal (Owensby et al., 1973, Ortmann et al., 1998). Human suppression of fire is one of the major factors in the spread of Eastern Redcedar in into Great Plains grasslands (Bragg, 1976; Bragg and Hulbert, 1976; Blan, 1970; Briggs and Gibson, 1992; Kucera, 1960;). For example, spread of Eastern Redcedar from 1937 to 1969 increased by 34% in non-burned fields compared to 1% increase in burned areas (Bragg and Hulbert, 1976)(Figs. 2-1, 2-2).

The abundance of Eastern Redcedar in the Great Plains, coupled with its status as a nuisance species, makes it an ideal candidate to be used as a substrate for container-grown plant production. This, in addition to the positive environmental and economic impact of Eastern Redcedar removal, makes Eastern Redcedar consumption not only sustainable but also environmentally friendly and could help to slow the expansion of Eastern Redcedar across the Great Plains and help to preserve grassland ecosystems. Eastern Redcedar has been explored as a substrate prior to this study. First in a 1975 study where the growth of two azalea species were compared in either Eastern Redcedar or loblolly pine. This study showed that azalea grew best in pine shavings followed by Eastern Redcedar shavings (Self, 1975). The next study on Eastern Redcedar as a nursery substrate was published in 2009 and evaluated Chinese pistache (*Pistacia chinensis* L.) and Indian-cherry (*Frangula caroliniana* [Walter] A. Gray) grown in six substrates composed of varying ratios of Eastern Redcedar chips and pine bark with four fertilizer rates (Griffin, 2009). It was demonstrated that Chinese pistache grown in 5%, 20%, and 40% Eastern Redcedar were comparable in height and shoot dry weight to 100% bark. Whereas 10% and 80% Eatern Redcedar had both less height and shoot dry weight compared to pine bark (Griffin, 2009). Finally, a greenhouse study evaluated Eastern Redcedar, WholeTree, sweetgum (*Liquidambar styraciflua* L.), and hickory (*Caray* Sp. Nutt.) combined with pine bark in 50:50 or 75:25 wood to pinebark ratios, and compared to a 75:25 peat to perlite standard. This study showed that Petunia (*Petunia* x *hybrida* Juss. 'Dream Sky Blue'), Vinca (*Catharanthus roseus* (L.) G.Don 'Cooler Peppermint'), and Bedding Impatiens (*Impatiens walleriana* Hook.f. 'Super Elfin Salmon') grown in 50:50 to 75:25 Eastern Redcedar: peatmoss have similar growth to the standard peat mix and equal to or better than WholeTree in a greenhouse-grown annual study (Murphy, 2011).

Hedge-Apple

Hedge-Apple (*Maclura pomifera* Raf.), also commonly known as Osage-Orange, is a common tree found in windbreaks thoughout the Great Plains. A native tree throughout the states of Arkansas, Oklahoma and Texas, it is known for its tolerance of poor site conditions and thriving in places most other trees do not (Dirr, 2009). Hedge-Apple commonly reaches 20 to 40 feet high with a low, round, irregular canopy with a spread as large as 60 feet. The bark is deeply furrowed and trees often form thickets in the wild (Barker et al., 1986; Dirr, 2009). The tree often has spines though spineless cultivars are available. Hedge-Apple has large (3 to 6 inches) spherical, fleshy, multiple fruit with embedded drupes and hair incased in a yellow-green, wrinkly, corky rind, often falling from the tree, breaking open, and causing a mess in the landscape (Barker et al., 1986; Dirr, 2009). It is also known for its exceptionally durable and decay-resistant wood, which is used for lumber, fence posts, and furniture (Dirr, 2009; U.S. Forest Product Laboratory, 1961). This resistance to decay comes from its anti-fungal properties due to the presence of stilbenes, primarily pentahydroxystilbenes and the more abundant tetra hydroxystilbene (Barnes and Gerber, 1955; Wang et al., 1976; Wang and Hart 1983). Additionally, the fruits have insect repellent properties both as lone fruit, and extracted chemicals (Peterson, et al., 2002; Ufkes and Grams, 2007). Further, many properties of both the wood and seeds have medical and nutritional benefits for humans, such as anti-bacterial and fungal properties, cytotoxicity, essential fatty acids, high linoleic acid, and the oil can provide UV resistance applicable to cosmetics (Fatnassi et al., 2009; Peterson and Brockemyer, 1953; Jones and Soderber, 1979; Mahmoud, 1981).

Objectives

The main focus of this manuscript and the research within is the use of Eastern Redcedar as a wood-based substrate for nursery production, greenhouse annuals, and as a propagation material. Hedge-Apple is evaluated as another indigenous wood-based plant material for the nursery industry. The use of Eastern Redcedar as a material for containerized plant production could help to decrease prices for containerized nursery and greenhouse production. Additionally the use of Eastern Redcedar could help to prevent the expansion of Eastern Redcedar and possibly reduce its current land coverage by providing further financial incentive for tree removal. This could help to preserve native ecosystems and the slow recovery of reclaimed areas from stands of Eastern Redcedar.Literature Cited

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Figure 1-1 Eastern Redcedar expansion across the Great Plains.

Figure 1-2 Visual differences between controlled and uncontrolled areas for Eastern Redcedar. Two properties side by side, the left is a managed (burned) field while the right is fully invated by Eastern Redcedar.

Chapter 2 - Use of Eastern Redcedar (*Juniperus virginiana*) as a Pine Bark Supplement for Container-grown Nursery Production

Pine bark- (PB) based substrates continue to be the industry standard for container production of woody ornamentals throughout the Southeast U.S. (Yeager et al., 2007). However, because of decreased timber production, PB has become less available for the nursery industry with a corresponding increase in price (Lu et al., 2006). This price increase is compounded further by shipping costs, particularly in regions lacking a pine based timber industry. This has led to a demand for alternative substrates to supplement or replace PB, particularly in regions that lack indigenous pine species. Eastern Redcedar (*Juniperus virginiana* L.) grows throughout most of the Great Plains region of the United States. Primarily kept in check by wild fires, Eastern Redcedar is aggressively expanding into grasslands and abandoned fields especially in areas where controlled burning is rarely practiced (Bragg, 1976; Bragg and Hulbert, 1976; Blan, 1970; Briggs and Gibson, 1992; Frost, 1998; Kucera, 1960). Eastern Redcedar is associated with significant decreases in plant species richness, and changes in animal diversity and abundance on grassland mammals and birds (Briggs et al., 2002; Chapman et al., 2004; Coppedge et al. 2001; Horncastle et al., 2004; Horncastle et al., 2005).

Previous studies have shown that multiple types of coniferous species' wood can be used as substrate components in a PB-based substrate or as complete replacements (Altland et al., 2008; Fain et al., 2008a). Several products made from pine trees (primarily *Pinus taeda* L.) have been evaluated. These products contain various amounts of green material (needles), including pine tree substrate (chipped pine logs), WholeTree (whole pine trees), and clean chip residual (all parts of the pine tree excluding the heartwood) (Boyer et al., 2008a; Fain et al., 2008b; Jackson et al., 2008). The use of Eastern Redcedar wood as a container substrate has been shown to be viable (Griffin, 2009). Chinese pistache (*Pistacia chinensis* L.) and Indian-cherry (*Frangula caroliniana* [Walter] A. Gray) were grown in six substrates composed of varying ratios of Eastern Redcedar chips and pine bark with four fertilizer rates. It was demonstrated that Chinese pistache grown in 5%, 20%, and 40% Eastern Redcedar were comparable in height and shoot dry weight to 100% bark. Whereas 10% and 80% Eatern Redcedar had both less height and shoot dry weight compared to pine bark (Griffin, 2009). However Eastern Redcedar's use has not been fully explored. Use of Eastern Redcedar as a substrate component for container plant production could decrease production costs for nursery growers in the Great Plains while simultaneously providing incentive to reduce the Eastern Redcedar population, curbing its advance through the native grassland prairie. However, Eastern Redcedar has known allelopathic properties and has been shown to inhibit seed germination in some indigenous grass species (Stipe and Bragg, 1989; Smith, 1986). Allelopathy research has primarily focused on the allelopathic properties of fresh leaves and leaf droppings on the soil surface (Stipe and Bragg, 1989; Smith, 1986). The allelopathic abilities of the heartwood are unknown as well as whether Eastern Redcedar can affect non-grass plants through allelopathy.

The purpose of this study is to determine if Eastern Redcedar can be used as a substrate component for the nursery industry by substituting portions or completely replacing PB as the primary component in a 80:20 PB: sand (by volume) substrate. Additionally, two rates of fertilizer were used to determine if plants grown in Eastern Redcedar- containing substrates required additional fertilizer in order to produce plants similar to those grown in PB.

Materials and Methods

Eastern Redcedar chips (JVC) used in this study were harvested from logs allowed to age for six months in the Barber County, KS area (Queal Enterprises, Pratt, KS). Logs were processed into chips using a horizontal woodgrinder (Rotochoper, St. Martin, MN). Further processing occurred through a hammermill (A. WW Grinder INC., Model 5-2 0-4, Witchita, KS) to pass a 19.05 mm screen on 18 May 2009. Eastern Redcedar chips were then blended with pine bark (SunGro, Bellevue, WA) and sand, in six volume:volume ratios resulting in six substrate treatments. All substrates contained 20% Sand, then a portion of JVC consisting of 0%, 5%, 10%, 20%, 40%, or 80% with the remaining percentage comprised of PB. Each substrate blend was pre-plant incorporated with 0.68 kg/m^3 of Micromax (The Scotts Company, Marysville, OH) and either a low (4.5 kg/m^3) or high (8.9 kg/m^3) treatment rate of controlled release fertilizer (Professional Horticulture Osmocote Classic, 12 to 14 month release, The Scotts Company, 18 N-2.62 P-9.96 K, 8 to 9 month release, Marysville, OH) to make 12 mixes by substrate and fertilizer.

The study was conducted at the John C. Pair Horticultural Research Center (Haysville, KS) on four woody species, with each species treated as a separate experiment. Two woody species, Chinese Pistache (*Pistacia chinensis* L.) and Baldcypress (*Taxodium distichum* L. [Rich.]) were transplanted into three-gallon containers (Olympian Heavy weight-Classic 1200, Nursery Supplies INC®, Fairless Hills, PA) on 20 May 09. Chinese Pistache liners were grown from seeds collected at the John C. Pair Research Horticultural Center, germinated in spring 2008 and grown in 5.1 cm x 5.1 cm x 15.2 cm bottomless band containers in a 8 pine bark: 1 sand by volume substrate with Osmocote Plus 15 N-3.9 P-10 K (The Scotts Company, Marysville, OH) incorporated and over-wintered at the station. Baldcypress seeds, collected from a native population (Ingram, TX), were grown in the same conditions as the Chinese Pistache. A Third woody species, Silver Maple (*Acer saccharinum* L.), was planted from seed (Lincoln Oaks Nursery, Bismarck, ND) on 24 June 09 using 3.79 L containers (Olympian Heavy Weight C200, Nursery Supplies INC®, Fairless Hills, PA). Silver Maple seed were planted 3 per container and germinated in a shade house before being moved to the container pad 14 days later. Plants were thinned to one plant per container at 35 days after planting (DAP). Chinese Pistache and Silver Maple were terminated on 9 September 09, 113 DAP. Baldcypress was terminated one week later (120 DAP).

Substrate pH and electrical conductivity (EC) were determined at 15, 29, 43, 57, 71, 85, 99, and 113 DAP using the PourThru technique (Wright, 1986) on Baldcypress as a representative of all other plant species. Substrate shrinkage (cm below the top of the container) was measured at 15 and 113 DAP. Leaf greenness (an indirect measurement of leaf chlorophyll content) was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ) at 15, 29, 43, 57, 71, 85, 99, and 113 DAP on Chinese Pistache. Plant height was measured at 15, 85, and 113 DAP. Caliper (15.24 cm from the substrate surface) was measured on 113 DAP for all species. Dry shoot and root weights of all species were recorded at the conclusion of the study (113 DAP) by drying in a forced air oven (The Grieve Co. Model SC-400, Round Lake, IL) at 70°C for 7 days. Leaf samples (four replications per treatment of substrate and fertilizer level) of Chinese Pistache were analyzed (Brookside laboratories, New Knoxville, OH) for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn). Foliar N was determined by combustion analysis using 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectromertry (Thermo Jarrel Ash, Offenbach, Germany).

Substrates were analyzed for particle size distribution by passing a 100 g air-dried sample through a series of sieves. Sieves were shaken for 3 minutes with a Ro-tap (Ro-tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations per minute, 159 taps per minute). Substrate air space, container capacity, substrate bulk density, and total porosity were determined by using a NCSU Porometer (Fonteno and Bilderback, 1993) using 347.5 cubic centimeter samples in a 7.6 cm aluminum cylinder each with eight holes for measuring drainage and saturation with four replications.

The experimental design was a randomized complete block design with a factorial arrangement of treatments. There were six substrate blends and two fertilizer rates, for a total of 12 treatments, which were used to grow four woody plant species. Treatments were replicated eight times. Data was analyzed using the Waller-Duncan K-ratio T Test (Version 9.1 SAS Institute INC., Cary, NC).

Results and Conclusions

Substrate pH did not differ based on fertilizer level, thus pH was analyzed based only on substrate treatment (Table 2-1). Substrate pH of 80% JVC was consistently the highest at each date with an exception at 99 DAP where 40% JVC was statistically similar to 0% JVC. Substrate pH generally decreased with increasing PB content with 0% JVC and frequently 5% JVC having the lowest pH. As time progressed, substrate pH became more similar with the pH of substrates containing large percentages of PB, increasing at each measurement date most likely due to the high pH of irrigation water (average 7.61) (Table 2-1).

Substrate EC did differ based on fertilizer level with the high fertilizer treatment generally having a higher EC (Table 2-2). In the low fertilizer treatment there was a tendency for the EC of 80% JVC to be higher than other substrate treatments and all other substrates were somewhat similar to each other. However, differences in EC for any treatment were not great. This was mostly true of the high fertilizer treatment as well with more dates than the low fertilizer treatment where no substrate was statistically different. While 80% JVC had a higher EC, often other substrates containing 10% to 40% JVC being similar to it while 0% to 10% usually had a lower EC and were statically similar to each other.

Physical properties varied based on substrate (Table 2-3). Substrates containing 0%, 5%, 20%, and 40% JVC had the highest total porosity while 80% and 10% JVC had the lowest. However all substrates were within the recommended levels of 50 to 85% (Yeager et al., 2007). Air space was within recommended ranges (10 to 30) except 5% and 10% JVC which were slightly below average (9.1 and 8.2 respectively) (Yeager et al., 2007). However, the highest airspace belonged to 80% JVC which was 29.9% followed by 40% JVC which had 20.8% airspace both of which were higher than the 0% JVC control (12.6%). Container capacity was within recommended ranges for all substrates containing 40% JVC or less. The lowest container capacity was in 80% JVC which was 39.3% and below the recommended ranges of 45 to 65% (Yeager et al., 2007). This was followed by 40% JVC, which had a lower container capacity compared to the other substrates, which were all somewhat similar to each other. This is similar to other studies conducted on wood-based substrates that showed increasing airspace and decreasing container capacity with increasing percentages of wood-based components in a substrate mix including clean chip residual, pine tree substrate, or WholeTree (Boyer et al., 2008b; Jackson et al., 2008; Fain et al., 2008a) Bulk density was within recommended ranges for all substrates. There were no differences based on substrate for shrinkage, indicating the JVC-based substrates do not decompose over a one-season production cycle. Increases in airspace and corresponding decreases in container capacity are linked to the differences in particle size distribution (Table 2-4). There was a high proportion (43.75%) of coarse material (2 mm or larger) in 80% JVC, followed by 40% JVC (29.40%) which was similar to 80% JVC and all other substrates. Substrates containing 20% or less JVC were statistically similar to each other in coarse material. Medium sized particles (between 2.00 and 0.5mm) was highest in 0% JVC, followed by 40% JVC, and the least amount of medium particles was in 80% JVC; 5% to 20% JVC were similar to both 0% and 40% JVC. There were no differences between substrate fine particles (less than 0.5mm). These results explain the difference in physical properties between substrates that contain 20% JVC or less, 40% JVC, and 80% JVC. The 80% followed by the 40% JVC had coarser material and decreased medium size material. This corresponds to the increase in airspace and decrease in container capacity in these substrates. The pores in 40 and 80% JVC substrates were larger and less readily held water.

Baldcypress

Each growth measurement of Baldcypress, except 15 DAP for plant height, was significantly affected by fertilizer level (Table 2-5; Figs. 2-1 and 2-1). At 15 DAP plants grown in 10%, 40%, and 5% JVC were tallest; 0% JVC and 80% JVC had less growth. However, by 85 DAP in the low fertilizer treatment, plants in all treatments were similar up to 40% JVC which showed less growth, followed by 80% JVC. The high fertilizer treatment at 85 DAP was unaffected by substrate. Additionally, while fertilizer had an effect on height at 113 DAP substrate treatments did not. Caliper for the low fertilizer treatment was similar in substrates containing up to 40% JVC, which decreased at 80% JVC. Caliper in the high fertilizer substrates containing up to 40% JVC were similar; 80% JVC had less caliper than all other treatments. Shoot dry weight for the low fertilizer treatment was similar up to 20% JVC, decreasing at 40%, then 80% JVC. The high fertilizer treatment produced plants that were similar up to 40% JVC with less growth in 80% JVC. Root dry weights of plants grown in the low fertilizer treatment were similar in 0% and 5% JVC, decreasing at 10% to 20% JVC, and decreasing again at 40% and 80% JVC. The high fertilizer treatments' effects on root dry weight was more ambiguous favoring 0%, 10%, and 20% JVC, with a decrease in growth at 80% JVC; 5% and 40% JVC were both similar to all substrates for root dry weight. Generally for Baldcypress, for every growth measurement in both fertilizer rates for which there were differences, 80% JVC had less growth followed by 40% JVC in the low fertilizer treatments.

Chinese Pistache

Height of Chinese Pistache at 15 DAP varied by fertilizer but not by substrate (Table 2-6; Figs. 2-3 and 2-4). By 85 DAP there were no differences based on fertilizer but substrates containing 5% to 40% JVC were similar to each other (plant height and dry weight) with a decrease in growth at 80% JVC. The 0% JVC treatment was statistically similar to all other treatments. By 113 DAP all substrates up to 40% JVC were similar with 80% JVC still producing the least growth. This was reflected in shoot dry weight in the high fertilizer treatment. The low fertilizer treatments shoot dry weight was similar except the decrease in growth happened at 40% JVC with 80% JVC being similar. A trend toward decreased root dry weight based on substrate (but not fertilizer) favored substrates containing less JVC (0% to 10%) with the least root weight at 80% JVC. Caliper for the low fertilizer treatment was not affected by substrate. Caliper for the high fertilizer was largely similar. This data is similar to the Baldcypress. Less growth occurred in 80% JVC regardless of fertilizer level and in the low fertilizer level, when there was a difference based on fertilizer, a decrease in 40% JVC treatment. Leaf greenness did not differ based on substrate or fertilizer level past 43 DAP (data not shown).

Leaf tissue was also analyzed for nutrient content. Nitrogen levels varied by fertilizer level but not by substrate; with higher fertilizer plants having more N content (Table 2-7). Nitrogen levels were below recommended ranges for the low fertilizer treatment most likely due to fertilizer rate rather than any innate quality of the substrates. Phosphorus was unaffected by fertilizer rate with the highest P content found in 80% JVC with all other substrates having less P content but similar to each other; P was within recommended ranges. Potassium content was also unaffected by fertilizer rate and was highest in 40% JVC and lowest in 10% JVC with all other substrates being similar to these two. Additionally while being the lowest K content, 10% JVC was also the only treatment to below the recommended ranges of 1.02 to 1.58% (Mills and Jones, 1996). Magnesium, S, and B all fell with recommended ranges regardless of substrate or fertilizer level. Calcium was mostly higher than recommended for both the low and high fertilizer treatments; while there was no difference based on fertilizer level both the low fertilizer 0% JVC and high fertilizer 20% JVC were within recommended ranges of 0.6 to 1.41% Ca (Mills and Jones, 1996). For Fe and Mn most substrates were much higher than recommended levels at both fertilizer rates with the lowest Fe found in high fertilizer 80% JVC at 680.70 ppm whereas the recommended level was only 24 to 60 ppm (Mills and Jones, 1996). The exception for Mn was both low and high fertilizer 80% JVC fell within the recommended range of 14 to 98 ppm; Mn content was highest in 0% JVC and decreased with each increase of JVC (Mills and Jones, 1996). Other studies using wood-based substrates derived from pine were associated with high Mn content, though none exhibited signs of toxicity (Fain et al. 2008a; Boyer et al., 2008a; Boyer et al., 2008b). Both Zn and Al also had higher ppm than recommended for every substrate treatment. Finally Cu was below recommended ranges in the low fertilizer treatment for each substrate except 80% JVC which was higher than recommended. The high fertilizer treatment resulted in all substrates having lower than recommended levels of Cu. Over all most nutrient content tended to either be similar or be higher in 0% JVC.

Silver Maple

Plant height was not affected by fertilizer level (Table 2-8). At 63 DAP all substrates containing some portion of PB were similar and taller than plants grown in 80% JVC (Fig. 2-5). By 91 DAP the drop off in growth at 80% JVC remained, however there were more differences in substrates containing some portion of PB, though none were as great as the difference without any PB portion. This was also true of caliper in both the high and low fertilizer level. Shoot dry weight and root dry weight showed the same trends. For plants grown in low fertilizer shoot dry weight and root dry weight was similar up to 20% JVC, with a decrease at 40% then 80% JVC. High fertilizer shoot and root dry weights were generally similar up to 40% JVC, with a drop in weight at 80% JVC. These trends in growth are similar to those seen in Baldcypress and Chinese Pistache; a decrease in growth at 80% JVC, and in the low fertilizer treatments 40% JVC.

This decrease in growth associated with 80% JVC and, to a lesser extent, 40% JVC is likely linked to the corresponding increases in airspace and decreases in container capacity associated with both substrates. It is likely that plants grown in 80% JVC and 40% JVC are more prone to water stress due to the lower water holding capacity in those substrates. This resulted in less growth regardless of fertilizer level. This is consistent with the results of experiments using clean chip residual which also had less plant growth in plants as wood content increased (Boyer et al., 2008a; Boyer et al., 2008b). Plants grown in high fertilizer in 40% JVC fared better in terms of growth compared to plants grown with low fertilizer in 40% JVC substrates. However even while often similar these plants experienced less growth compared to other plants within the high fertilizer treatment with exception of 80% JVC. This shows that while high fertilizer does have an effect, the trends within each fertilizer remained the same: a decrease in growth at 40% JVC, and again at 80% JVC. This differs, however, from studies using chipped pine logs which also had decreased growth. However, this decreased growth was attributed to N-immobilization (Jackson et al., 2008). It was demonstrated that generally plants grown in chipped pine tree substrate had less growth compared to peat-lite within the same fertilizer rate. However, when plants grown in chipped pine log substrate were compared with peat-lite grown with 100 mg.L-1 less nitrogen the plants had comparable in growth (Jackson et al., 2008). While this study did not evaluate N-immobilization in the substrate, foliar N content was similar at each fertilizer rate. Additionally, the low fertilizer treatments had lower than recommended levels of N-content. The combined stress of a low water holding capacity and a low amount of available N from the low fertilizer treatment is probably the reason for less growth in 40% JVC in the low fertilizer treatments.

There was no apparent effect on plant growth due to allelopathic chemicals within the Eastern Redcedar wood. Eastern Redcedar chips used in this experiment did not contain any green material, which has been the main focus of allelopathic studies. If Eaststern Redcedar wood has allelopathic qualities or effects species outside of grasses is unknown (Stipe and Bragg, 1989; Smith, 1986). The JVC used in this experiment could have resulted in decreased growth in higher concentrations of JVC due to allelopathy, possibly synergizing with the low container capacity resulting in decreased growth. However the low container capacity alone seems more compelling based on this data. Other studies on wood-based artificial substrates showed that decreasing the particle size increased water holding capacity and plant growth when compared to larger particle sizes (Boyer et al, 2008b; Jackson et al, 2008). Manipulation of particle size could adjust JVC so that it could increase container capacity and thus increase growth.

Eastern Redcedar processed through a 19.05 mm screen is a viable substrate component replacing up to 20% of the PB in a substrate. While it can complement PB it cannot replace it as a primary substrate component in a containerized nursery substrate without resulting in decreased growth for some woody species. However, while JVC did result in less plant growth in 40% JVC and 80% JVC, the decrease in overhead costs due to using a less expensive substrate component could offset this loss while still producing marketable plants.

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Table 2-1 Change in pH of Eastern Redcedar- and PB-based substrates over 113 days.

Substrate[z]	15 DAP[y]	29 DAP	43 DAP	57 DAP	71 DAP	85 DAP	99 DAP	113 DAP
0% JVC: 80% PB	5.69 cd[x]	5.07 e	5.93 de	6.31 d	6.35 d	6.98 c	6.81 c	7.20 cb
5% JVC: 75%: PB	5.54 d	5.03 e	5.82 e	6.23 d	6.49 cd	6.79 c	7.04 b	6.95 d
10% JVC: 70% PB	5.46 d	5.41 d	6.03 d	6.34 d	6.62 cd	6.98 c	6.99 cb	7.01 dc
20% JVC: 60% PB	5.84 c	6.12 c	6.26 c	6.59 c	6.89 b	7.31 b	7.09 b	7.18 cb
40% JVC: 40% PB	6.80 b	6.89 b	6.79 b	6.95 b	7.01 b	7.36 b	7.48 a	7.28 b
80% JVC: 0% PB	7.69 a	8.16 a	7.63 a	7.30 a	7.45 a	7.62 a	7.65 a	7.48 a

[z]Substrate treatments were: PB = pine bark, JVC = *Juniperus virginiana* chips. Substrates mixed on volume basis with each treatment containing 20% sand. Species used for this measurement was Baldcypress.

[y]DAP = days after planting.

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=4).

[w]Average pH of irrigation water was 7.61.

Table 2-2 Change in electrical conductivity (mS/cm) Eastern Redcedar- and PB- based substrates over 113 days.

	Low Fertilizer (4.5 kg/m^3)[w]							
Substrate[z]	15DAP[y]	29DAP	43DAP	57DAP	71DAP	85DAP	99DAP	113DAP
0% JVC: 80% PB	1.21 ab[x]	1.38 a	0.94 b	0.82 b	0.64 b	0.86 c	0.92 ns	0.59 b
5% JVC: 75%: PB	1.13 ab	1.15 bc	0.83 b	0.70 b	0.69 ab	0.84 c	0.92	0.60 b
10% JVC: 70% PB	1.28 ab	1.18 ab	0.96 ab	0.78 b	0.65 b	0.91 bc	0.92	0.61 b
20% JVC: 60% PB	1.35 a	0.94 cd	0.90 b	0.81 b	0.74 ab	1.02 ab	1.09	0.66 b
40% JVC: 40% PB	0.90 b	0.82 d	0.87 b	0.87 b	0.79 ab	0.92 abc	1.11	0.75 b
80% JVC: 0% PB	1.13 ab	1.03 bc	1.13 a	1.06 a	0.88 a	1.03 a	1.01	1.04 a
	High Fertilizer (8.9 kg/m^3)							
0% JVC: 80% PB	1.92 a	1.44 a	0.86 ns	0.87 b	0.71 b	0.86 c	1.08 ns	0.72 ns
5% JVC: 75%: PB	1.86 a	1.45 a	0.93	0.89 b	0.72 b	1.07 cb	1.06	0.87
10% JVC: 70% PB	1.59 ab	1.54 a	0.96	0.99 ab	0.71 b	0.86 c	1.15	0.86
20% JVC: 60% PB	1.32 b	1.21 ab	0.95	1.19 ab	0.83 ab	1.13 bc	1.12	0.77
40% JVC: 40% PB	1.23 b	1.03 bc	1.34	1.16 ab	0.96 a	1.20 b	1.30	0.81
80% JVC: 0% PB	1.58 ab	1.30 ab	1.15	1.48 a	0.96 a	1.55 a	1.21	0.77

[z]Substrate treatments were: PB = pine bark, JVC = *Juniperus virginiana* chips. Substrates mixed on volume basis with each treatment containing 20% sand. Species used for this measurement was Baldcypress.

[y]DAP = days after planting.

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=

[w]Substrates were pre-plant incorporated with either a low or high rate of controlled release fertilizer Osmocote (The Scotts Company, Marysville, OH; 19 N-2.62 P -9.96 K; 12 to 14 month release) consisting of either a low rate (4.5 kg/m^3) or a high rate (8.9 kg/m^3). Nutrients with significant differences are separated by high and low, nutrients that are not significantly different

[v]Average EC of irrigation water was 0.91.

[ns]Means not significantly different.

Table 2-3 Physical properties of pine bark- and Eastern Redcedar-based substrates[z].

Substrates[y]	Air space[x] (% Vol)	Container capacity[w] (% Vol)	Total porosity[v] (% Vol)	Bulk density[u] (g/cm^3)	Shrinkage[t] (mm)
0% JVC: 80% PB	12.6 c[s]	63.0 b	75.5 a	0.51 bc	1.13 [ns]
5% JVC: 75%: PB	9.1 cd	66.5 a	75.6 a	0.50 c	0.63
10% JVC: 70% PB	8.2 d	62.0 b	70.2 b	0.52 b	0.63
20% JVC: 60% PB	10.4 cd	63.9 ab	74.3 a	0.51 bc	0.81
40% JVC: 40% PB	20.8 b	55.2 c	75.9 a	0.51 bc	0.56
80% JVC: 0% PB	29.9 a	39.3 d	69.1 b	0.58 a	0.75
Recommended	10 to 30	45 to 65	50-85	0.19-0.70	

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

[y]Treatments were: PB = pine bark, JVC = *Juniperus virginiana* chips. Substrates mixed on volume basis with each treatment containing 20% sand.

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

[w]Container capacity is (wet wt. - oven dry wt.) / volume of the sample.

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

[u]Bulk density after forced-air drying at 105°C for 48 h.

[t]Shrinkage is the difference in substrate from the top of the container to the media surface at the beginning of the experiment and at termination.

[s]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests ($\alpha = 0.05$, n = 3).

[r]Recommended ranges as reported by Yeager et al., (2007).

[ns]Means not significantly different.

Table 2-4 Particle size analysis of pine bark- and Eastern Redcedar-based substrates.

U.S. Standard sieve no.	Sieve opening (mm)	Substrate[z]					
		0% JVC: 80% PB	5% JVC: 75%: PB	10% JVC: 70% PB	20% JVC: 60% PB	40% JVC: 40% PB	80% JVC: 0% PB
1/4"	6.30	2.19 b[x]	2.71 ab	2.23 b	2.87 ab	4.09 ab	7.42 a
10	2.00	22.40 b	20.62 b	23.93 b	21.11 b	25.31 b	36.33 a
25	0.71	30.32 [ns]	29.13	29.33	28.71	28.95	27.35
35	0.50	12.39 a	12.51 a	12.04 a	12.27 a	11.62 a	8.30 b
60	0.25	23.42 [ns]	24.47	22.99	24.35	21.78	14.67
140	0.11	8.02 [ns]	9.20	8.19	9.20	7.27	5.18
pan	0.00	0.96 bc	1.37 a	1.29 a	1.49 a	0.98 b	0.76 c
Coarse [x]		24.89 b	23.33 b	26.15 b	23.98 b	29.40 ab	43.75 a
Medium		42.71 a	41.63 ab	41.37 ab	40.99 ab	40.57 b	35.64 c
Fine		32.40 [ns]	35.04	32.48	35.03	30.03	20.61

[z]Substrate treatments were: PB = pine bark, JVC = Juniperus virginiana chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[x]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on waller-duncan K ratio t tests at α=0.05 (n=3).

[w] Coarse = 2.00 mm and greater; Medium = less than 2.00 and greater than 0.5 mm; fine = Less than 0.5 mm.

[ns]Means not significantly different

Table 2-5 Main effects of pine bark- and Eastern Redcedar-based substrates and fertilizer treatment on the growth of Baldcypress (*Taxodium distichum*) at 113 days after planting.

	Plant height[z] 15 DAP[y] (cm)	Plant height 85 DAP (cm)		Plant height 113 DAP (cm)		Caliper[x] (mm)		Shoot dry weight[w] (g)		Root dry weight[v] (g)	
Substrate[u]	Fertilizer level[t]:	Low	High	Low	High	Low	High	Low	High	Low	High
0% JVC: 80% PB	61.42 c[s]	104.56 ab	103.56 [ns]	113.00 [ns]	116.50 [ns]	20.39 ab	21.95 a	87.74 a	126.44 ab	109.78 ab	161.35 a
5% JVC: 75%: PB	71.71 ab	102.44 ab	103.75	114.69	117.44	21.04 a	22.93 a	94.76 a	124.96 ab	131.91 a	121.60 ab
10% JVC: 70% PB	74.33 a	106.56 a	106.63	115.44	119.38	20.71 ab	23.01 a	90.08 a	135.28 a	97.21 bc	154.81 a
20%: JVC: 60% PB	67.46 b	101.50 ab	108.19	116.25	118.94	19.91 ab	22.36 a	86.58 a	128.30 ab	95.90 bc	160.13 a
40% JVC: 40% PB	75.63 a	95.63 cb	107.56	109.06	127.44	18.96 b	21.34 a	72.65 b	116.44 b	69.06 cd	136.76 ab
80% JVC: 0% PB	62.25 c	90.50 c	102.00	103.69	113.69	15.20 c	18.28 b	48.45 c	79.74 c	50.18 d	83.98 b

[z]Plants were measured from the top of the substrate to the apical meristem.

[y]DAP = days after planting

[x]Plants were measure six inches from the top of the substrate.

[w]Shoots were harvested at the container surface and oven dried at 70˚C for 48 h .

[v]Roots were washed of substrate and oven dried at 70˚C for 48 h.

[u]Substrate treatments were: PB = pine bark, JVC = *Juniperus virginiana* chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[t]Substrates were pre-plant incorporated with either a low (4.5 kg/m3) or high (8.9 kg/m3) rate of controlled release fertilizer Osmocote (The Scotts Company, Marysville, OH; 19 N-2.62 P -9.96 K; 12 to 14 month release). Significant differences based on fertilizer rate are separated by High and Low, measurements that are not significantly different between fertilizer treatments are not separated.

[s]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[ns]Means not significantly different

Table 2-6 Main effects of pine bark- and Eastern Redcedar-based substrates and fertilizer treatment on the growth of Chinese Pistache (*Pistacia chinensis*) at 113 days after planting.

	Plant height[z] 15 DAP[y] (cm)		Plant height 85 DAP (cm)	Plant height 113 DAP (cm)	Caliper[x] (mm)		Shoot dry weight [w] (g)		Root dry weight [v] (g)
Substrate[u] Fertilizer level[t]:	Low	High			Low	High	Low	High	
0% JVC: 80% PB	75.25 [ns]	67.06 [ns]	120.06 ab[s]	109.78 a	1.60 [ns]	1.69 ab	94.74 a	114.91 a	54.56 a
5% JVC: 75%: PB	68.38	67.94	126.53 a	115.41 a	1.70	1.73 ab	94.86 a	122.96 a	68.76 a
10% JVC: 70% PB	73.19	66.38	130.38 a	120.03 a	1.70	1.88 a	113.38 a	138.66 a	64.32 a
20%: JVC: 60% PB	69.00	67.38	128.22 a	116.75 a	1.57	1.79 a	95.64 a	129.13 a	56.07 ab
40% JVC: 40% PB	69.56	69.44	124.72 a	113.16 a	1.57	1.75 ab	74.35 b	116.63 a	51.36 ab
80% JVC: 0% PB	71.88	69.06	111.91 b	94.99 b	1.53	1.51 b	57.40 b	79.18 b	34.77 b

[z]Plants were measured from the top of the substrate to the apical meristem.

[y]DAP = days after planting

[x]Plants were measure six inches from the top of the substrate.

[w]Shoots were harvested at the container surface and oven dried at 70˚C for 48 h .

[v]Roots were washed of substrate and oven dried at 70˚C for 48 h.

[u]Substrate treatments were: PB = pine bark, JVC = *Juniperus virginiana* chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[t]Substrates were pre-plant incorporated with either a low (4.5 kg/m3) or high (8.9 kg/m3) rate of controlled release fertilizer Osmocote (The Scotts Company, Marysville, OH; 19 N-2.62 P -9.96 K; 12 to 14 month release). Significant differences based on fertilizer rate are separated by High and Low, measurements that are not significantly different between fertilizer treatments are not separated.

[s]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[ns]Means not significantly different

Table 2-7 Leaf nutrient content of Chinese Pistache (*Pistacia chinensis*) grown in pine bark- and Eastern Redcedar-based substrates 113 days after planting.

	Tissue Content[y]									
	N (%)		P (%)	K (%)	Ca (%)		Mg (%)		S (%)	
Substrates[z] Fertilizer level[v]:	Low	High			Low	High	Low	High	Low	High
0% JVC: 80% PB	1.96 [ns]	2.53 [ns]	0.19 b[x]	1.11 ab	1.20 [ns]	1.43 [ns]	0.30 a	0.23 [ns]	0.14 [ns]	0.163 a
5% JVC: 75%: PB	1.86	2.45	0.19 b	1.11 ab	1.87	1.59	0.28 ab	0.23	0.13	0.155 ab
10% JVC: 70%	1.78	2.30	0.16 b	1.00 b	1.86	1.49	0.25 ab	0.22	0.13	0.143 ab
20%: JVC: 60%	2.00	2.40	0.19 b	1.12 ab	2.11	1.27	0.28 ab	0.18	0.14	0.155 ab
40% JVC: 40%	1.82	2.22	0.18 b	1.19 a	2.35	1.73	0.26 ab	0.18	0.13	0.145 ab
80% JVC: 0% PB	1.89	2.14	0.23 a	1.11 ab	1.81	1.57	0.19 b	0.19	0.13	0.135 b
Sufficiency range[u]:	2.13 to 2.81%		0.16 to 0.25%	1.02 to 1.58%	0.6 to 1.41%		0.18 to 0.38%		0.14 to 0.16%	

	B (ppm)		Fe (ppm)		Mn (ppm)		Cu (ppm)		Zn (ppm)	Al (ppm)
Substrates Fertilizer level:	Low	High	Low	High	Low	High	Low	High		
0% JVC: 80% PB	44.60 [ns]	31.43 b	1070.50 ab	763.30 [ns]	970.60 a	596.68 a	2.28 b	2.68 [ns]	34.56 a	59.50 [ns]
5% JVC: 75%: PB	35.95	32.48 b	1061.70 ab	882.20	802.70 ab	493.00 a	2.28 b	2.00	28.78 ab	52.33
10% JVC: 70%	35.70	29.38 b	1194.90 a	850.50	659.70 b	441.85 ab	2.93 b	1.75	27.35 b	61.80
20%: JVC: 60%	42.53	26.65 b	1061.00 ab	761.90	384.60 c	292.98 b	2.63 b	3.10	24.29 bc	70.01
40% JVC: 40%	46.30	38.18 ab	924.10 ab	897.30	131.80 d	118.60 c	2.00 b	1.25	15.78 d	51.21
80% JVC: 0% PB	49.68	45.10 a	844.00 b	680.70	89.80 d	76.35 c	6.65 a	2.35	20.40 cd	42.86
Sufficiency range:	15 to 65		24 to 60		14 to 98		3 to 5		11 to 15	12 to 38

[z]Substrate treatments were: PB = pine bark, JVC = Juniperus virginiana chips. Substrates mixed on volume basis with each treatment containing 20% sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg×kg.

[x]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=4).

[v]Substrates were pre-plant incorporated with either a low (4.5 kg/m3) or high (8.9 kg/m3) rate of controlled release fertilizer Osmocote (The Scotts Company, Marysville, OH; 19 N-2.62 P -9.96 K; 12 to 14 month release). Significant differences based on fertilizer rate are separated by High and Low, measurements that are not significantly different between fertilizer treatments are not separated.

[u]Sufficiency range published by Mills and Jones (1996).

Table 2-7 Main effects of pine bark- and Eastern Redcedar-based substrates and fertilizer treatment on the growth of Silver Maple (*Acer sacharinum*) at 91 days after planting.

	Plant height[z] 63 DAP[t] (cm)	Plant height 91 DAP (cm)	Caliper[y] (mm)		Shoot dry weight[x] (g)		Root dry weight[w] (g)	
Substrate[v] Fertilizer level[u]:			Low	High	Low	High	Low	High
0% JVC: 80% PB	23.46 a[s]	26.79 ab	4.50 ab	5.72 a	2.98 ab	4.85 a	2.20 ab	3.60 a
5% JVC: 75%: PB	21.75 a	24.46 b	4.68 ab	5.55 a	2.87 b	4.38 a	2.42 ab	3.65 a
10% JVC: 70% PB	24.33 a	27.46 ab	5.30 a	5.22 a	3.97 a	4.20 a	3.15 a	2.70 ab
20%: JVC: 60% PB	24.71 a	29.79 a	4.90 ab	5.62 a	3.20 ab	4.90 a	2.75 a	3.70 a
40% JVC: 40% PB	21.29 a	23.71 b	4.18 b	4.90 a	1.63 c	3.60 ab	1.42 b	2.65 ab
80% JVC: 0% PB	12.00 b	12.85 c	2.43 c	2.43 b	0.48 d	0.43 b	0.40 c	0.33 b

[z]Plants were measured from the top of the substrate to the apical meristem.

[y]Plants were measure six inches from the top of the substrate.

[x]Shoots were harvested at the container surface and oven dried at 70˚C for 48 h.

[w]Roots were washed of substrate and oven dried at 70˚C for 48 h.

[v]Substrate treatments were: PB = pine bark, JVC = *Juniperus virginiana* chips. Substrates mixed on volume basis with each treatment

[u]Substrates were pre-plant incorporated with either a low (4.5 kg/m3) or high (8.9 kg/m3) rate of controlled release fertilizer Osmocote (The Scotts Company, Marysville, OH; 19 N-2.62 P -9.96 K; 12 to 14 month release). Significant differences based on fertilizer rate are separated by High and Low, measurements that are not significantly different between fertilizer treatments are not separated.

[t]DAP = days after planting.

[s]Means within column followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

Figure 2-1 Visual differences of Baldcypress (*Taxodium distichum*) grown in six substrates composed of pine bark- and Eastern Redcedar (JVC)-based substrates in a low fertilizer (4.5 kg/m^3) treatment, 113 days after planting. From left to right: 0% JVC, 5% JVC, 10% JVC, 20% JVC, 40% JVC, and 80% JVC. All substrates contained 20% sand with the remaining content composed of PB.

Figure 2-2 Visual differences of Baldcypress (*Taxodium distichum*) grown in six substrates composed of pine bark- and Eastern Redcedar (JVC)-based substrates in a high fertilizer (8.9 kg/m^3) treatment, 113 days after planting. From left to right: 0% JVC, 5% JVC, 10% JVC, 20% JVC, 40% JVC, and 80% JVC. All substrates contained 20% sand with the remaining content composed of PB.

Figure 2-3 Visual differences of Chinese Pistache (*Pistacia chinensis*) grown in six substrates composed of pine bark- and Eastern Redcedar (JVC)-based substrates in a low fertilizer (4.5 kg/m^3) treatment, 113 days after planting. From left to right: 0% JVC, 5% JVC, 10% JVC, 20% JVC, 40% JVC, and 80% JVC. All substrates contained 20% sand with the remaining content composed of PB.

Figure 2-4 Visual differences of Chinese Pistache (*Pistacia chinensis*) grown in six substrates composed of pine bark- and Eastern Redcedar (JVC)-based substrates in a high fertilizer (8.9 kg/m^3) treatment, 113 days after planting. From left to right: 0% JVC, 5% JVC, 10% JVC, 20% JVC, 40% JVC, and 80% JVC. All substrates contained 20% sand with the remaining content composed of PB.

Figure 2-5 Visual differences of Silver Maple *(Acer sacharinum)* grown in six substrates composed of pine bark (PB)- and Eastern Redcedar (JVC)-based substrates with either a low (4.5 kg/m^3) or high fertilizer (8.9 kg/m^3) treatment. Each substrate contained 20% sand. From left to right: low fertilizer treatments containing 0% JVC, 5% JVC, 10% JVC, 20% JVC, 40% JVC, and 80% JVC followed by high fertilizer treatments containing 0% JVC, 5% JVC, 10% JVC, 20% JVC, 40% JVC, and 80% JVC.

Chapter 3 - Eastern Redcedar as a Substrate Component Used to Produce Petunia, New Guinea Impatiens, and Vinca

Peatmoss is a primary component of substrates used for container-production of greenhouse annuals. However, demand for alternative substrates to either completely or partly replace peatmoss has risen as the cost of peat has increased over time (Griffith, 2007; Landis and Morgan, 2009; Lu et al., 2006). Additionally, increasing concerns about the environmental impact of peat-mining on non-recoverable peat bogs has led to concern and government regulation in some countries in Europe (Carlile, 2004; Clark, 2008; Holmes, 2009; Riviere et al., 2008; Robertson, 1993). While the United States' prime source of peat is Canada, there is speculation that it is only a matter of time before regulations on peat mining occur in North America. Several new materials have been explored as alternative greenhouse substrates such as: kenaf (Marianthi, 2005; Wang, 1994), pulp mill ash (Bi and Evans, 2009), poultry feathers (Evans and Vancey, 2007), rubber (Evans and Harkess, 1997), composted cotton burrs (Wang and Blessington, 1990), and earthworm castings (Hidalgo and Harkess, 2002).. Additionally, other alternative materials have a long history of use as substrates, such as rice hulls (Buck and Evans, 2010; Chadler et al., 1957; Evans and Gachukia, 2004; Evans and Gachukia, 2008; Evans et al., 2011; Sambo et al., 2008) and coconut coir (Arenas et al., 2002; Chadler et al., 1957; Evans et al., 1996; Meerow, 1994). Wood-based materials that have been explored and marketed in Europe for greenhouse production include: Culti-Fiber®, Pietal®, Torbo®, Torbella®, Bio-Culta®, Horti-Fibre®, and Toresa® (Gaches et al., 2010; Gruda and Schnitzler, 2003; Gumy, 2001; Macdonald and Dunn, 1953). In the United States, three wood-based materials, all made from pine trees (*Pinus taeda* L.), have been evaluated for greenhouse use. Clean chip residual, a byproduct produced in field production of clean chips for paper products, contains up to 50% wood, 40% bark, and 10% needles (Boyer, et al., 2008). It was shown in the production of three greenhouse annuals that clean chip residual lacks the high water holding capacity of peat; however, when combined with peat it proved an adequate component (Boyer et al., 2008). Another material, chipped pine logs, consists of 90 to 100% wood, 10% bark, and no needles (Jackson et al., 2010). A study with poinsettia utilized two screen sizes of chipped pine logs (2.38 mm and 4.76 mm), a mixture (75% 4.76 mm wood chips: 25% peat, v:v), and a peat-lite control (80% peat: 20% perlite, v:v). Substrates with chipped pine logs had a comparatively lower water holding capacity; however, when plants were produced with 100 $mg \cdot L^{-1}$ more soluble nitrogen, the plants produced growth comparable to traditional peat (Jackson et al., 2008). A third product, WholeTree, is processed from whole pine trees and consists of wood, bark, needles, cones and other tree parts, resulting in a substrate that contains about 80 percent wood and twenty percent other tree parts (Fain et al., 2008). A study using 50% WholeTree substrate or chipped pine log and 50% peat to grow greenhouse annuals showed that WholeTree and chipped pine log substrate were interchangeable (Gaches et al., 2010).

The use of local materials for greenhouse substrates provides many benefits including a more sustainable supply coupled with decreased shipping costs. One such material that could yield a viable wood-based substrate for the Great Plains is Eastern Redcedar (*Juniperus virginiana* L.). This species is a common and indigenous evergreen tree that is found throughout the Great Plains. It has increased in population and land coverage to the point of becoming a nuisance (Beilmann and Brenner, 1951; Bidwell et al., 1990; Briggs et al., 2002; Dirr, 2009; Drake and Todd, 2002; Hoch, 2000; Hoch and Briggs, 1999; Owensby et al., 1973; van Haverbeke and Read, 1976;). The spread of Eastern Redcedar is largely due to suppression of fire and over-grazing of livestock (Bragg, 1976; Bragg and Hulbert, 1976; Blan, 1970; Briggs and Gibson, 1992; Kucera, 1960; Schmidt and Stubbendieck, 1993). This, in turn, has a negative impact on livestock by reducing grazing areas and increasing livestock handling (Engle, 1985; Engle et al., 1987; Stritzke and Rollins, 1984). Furthermore, the presence of Eastern Redcedar has an adverse effect on native species, decreasing plant and animal diversity (Chapman et al., 2004; Coppedge et al. 2001; Briggs et al., 2002; Gehring and Bragg, 1992; Horncastle et al., 2005; Linneman and Palmer, 2006). As such, the harvest of Eastern Redcedar for use as a substrate component could have a positive effect on the environment of the Great Plains.

The objective of this study was to evaluate Eastern Redcedar as a substrate component for production of three herbaceous ornamental potted crops: vegetative Petunia (*Petunia* x *hybrida* Juss.), New Guinea Impatiens (*Impatiens hawkeri* W. Bull.), and Vinca ((*Catharanthus roseus* L.G. Don). Eastern Redcedar processed to the size of 4.76 mm was used to replace different fractions of peat in a standard peat and perlite substrate.

Materials and Methods

Treatments. Eastern Redcedar chips (JVC) from Queal Enterprises (Pratt, KS) were ground to pass a 4.76 mm screen (C.S. Bell Co., Tiffin, OH Model 30HMBL). On 15 April 2010, the substrate components JVC, perlite (Therm-o-rock East INC, New Eagle, PA), and sphagnum peatmoss (Premier Pro-moss, Quakertown, PA) were combined to create five treatment substrates: 0, 25, 50, 75, and 100% JVC; 25% perlite (except the 100% JVC treatment); and the remainder composed of sphagnum peatmoss (v:v:v).

Physical properties. Substrates were analyzed for particle size distribution by passing a 100 g air-dried sample through a series of sieves. Sieves were shaken for 3 minutes with a Ro-tap (Ro-tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations per minute, 159 taps per minute). Substrate air space, water holding capacity, bulk density, and total porosity were determined by using a NCSU Porometer with 347.5 cubic centimeter samples in a 7.6 cm aluminum cylinder with eight holes for measuring drainage and saturation (Raleigh, NC; Fonteno and Bilderback, 1993).

All substrates were amended pre-plant with: 4.68 $kg \cdot m^{-3}$ controlled release fertilizer (Scotts Osmocote Classic 14N-6.12P-11.62K, 3 to 4 month slow release, Marysville, OH), 0.59 $kg \cdot m^{-3}$ micronutrients (Scotts, Micromax, Marysville, OH), 5.85 $kg \cdot m^{-3}$ lime (Kelly's Green Team, dolomitic lime, Kirksville, MO) 1.17 $kg \cdot m^{-3}$ gypsum (Espoma, organic tradition garden gypsum, Millville, NJ), and 0.29 $kg \cdot m^{-3}$ of wetting agent (OHP, Suffusion granules, Mainland, PA).

Annuals were planted in 10.16 cm-diameter containers with of volume of 480 ml (Dillen Products, 4.00 standard, Middlefield, OH) on April 15, 2010. Three annual bedding plant crops were purchased through Ball Horticultural Co. (Chicago, IL): rooted cuttings of Petunia (*Petunia* x *hybrida* Juss. 'Suncatcher White') and New Guinea Impatiens (*Impatiens hawkeri* W. Bull. 'Celebrette Lavender'), both produced by Tawaga Greenhouses (Centennial, CO); and plugs of annual Vinca (*Catharanthus roseus* L.G. Don 'Pacifica Apricot') produced by C. Raker and Sons, Litchfield, MI). Petunia and New Guinea Impatiens were both transplanted with one liner per container while two plugs of Vinca were transplanted per container. Each plant species was treated as a separate experiment. The experiments took place in greenhouse 106D of the Throckmorton Plant Sciences Center, Kansas State University, Manhattan, KS.

The experiments were arranged in completely random designs (CRD), each with 5 substrate treatments and 12 replications. Data was analyzed with SAS (Ver. 9.1, SAS Institute, Cary, NC) using the Waller-Duncan K-ratio T-test multiple comparison procedure.

Irrigation. Two containers per treatment served as sentinel pots to determine when plants grown in that treatment required watering. One sentinel pot was located in the middle of the experiment and one on the edge of the experiment. Maximum container capacity of each treatment was determined at the start of the study. When the treatment's sentinel pot average dried down to a specific weight (unique to each treatment) indicating that it had dropped to 70% container capacity due to water loss, water was applied to bring the treatment back to container capacity. For the first two weeks after transplant, 150 mL of water was applied when pot weight indicated that watering was required. After this period, the volume of water that was applied to each treatment was varied to maintain a 30% ±5% leaching fraction. Sentinel plants were weighed daily to determine need for water application.

Plant growth. Growth data was collected for all experiments on days 7, 14, 21, 28, 34, and 42 after transplant (DAP). The number of flowers in bloom and the growth indices [(widest width + perpendicular width + height) ÷ 3] were measured, except for New Guinea Impatiens, which did not flower prior to termination of the experiment. At termination (42 DAP), whole above-ground plants shoots were collected, dried for 5 days at 65^{o}C (Isotemp Oven, Fisher Scientific, Pittsburgh, PA), and weighed to determine shoot dry weight.

Substrate analyses, New Guinea Impatiens. Substrate pH and electrical conductivity (EC) were determined at 7, 14, 21, 28, 34, and 42 days after transplant (DAP) using the PourThru technique (Wright, 1986) in the New Guinea Impatiens experiment only. Electrical conductivity and pH was measured using a Accumet® excel XL20 pH and conductivity meter (Fisher Scientific, Pittsburgh, PA).

Results and Discussion

Physical properties. The total porosity of each substrate was statistically similar (Table 3-1). However, container capacity and airspace differed based on substrate: in general, as percent JVC increased, container capacity decreased and air space increased (Table 3-1). Bulk density was greatest in 100% JVC and decreased with each addition of peatmoss (Table 3-1). There was no difference between the 100% JVC and 75% JVC treatments based on total porosity, container capacity, and air space (Table 3-1), suggesting that the 4.76 mm JVC was replacing the functions of perlite in the substrate.

Particle size analysis indicated that both 0% JVC and 75% JVC had the most coarse material (larger than 2.00 mm), with all other substrates having less coarse material and all being similar to each other (Table 3-2). Medium sized material (less than 2.00 and greater than 0.5 mm) was greatest in 100% JVC (61%) and generally decreased with decreasing JVC content until 0% JVC (40%). Fine material (less than 0.5 mm) was similar in each substrate containing peatmoss and was higher in 75% and 100% JVC. Again, the minimal differences between the 100% JVC and 75% JVC treatments suggest that use of the 4.76 mm JVC was replacing the functions of perlite in the substrate.

Plant growth. Growth indices for all three annual species showed a distinct pattern by at least 21 DAP, and the trend began with both Petunia and New Guinea Impatiens as early as 7 DAP. This pattern was reflective of the substrates' JVC content: in general, as JVC content increased, plant growth decreased (Tables 3-4, 3-5, and 3-6; Figs. 3-3, 3-4, and 3-5). Based on growth index and dry weights, the most growth occurred in plants grown in 0% JVC, then decreased with increased JVC at 25% to50%; plants grown in 75% and 100% JVC were smallest. Flowering responses were similar to growth results for Petunia and Vinca (Tables 3-4 and 3-5).

These results differ from the findings of Murphy (2011) in an experiment at Auburn, AL, with seed-propagated Petunia (*Petunia* x *hybrida* Juss. 'Dream Sky Blue'), Vinca (*Catharanthus roseus* (L.) G.Don 'Cooler Peppermint'), and Bedding Impatiens (*Impatiens walleriana* Hook.f. 'Super Elfin Salmon') with 6.35 mm particle size JVC (larger than our 4.76 mm JVC). The treatments in the Auburn experiments included substitution of JVC for perlite (75% peat: 25% 6.35 mm JVC, v:v) and a portion of the peatmoss (50% peat: 50% 6.35 mm JVC, v:v; Murphy, 2011). These treatment mixes resulted in physical properties similar to their 75% peat: 25% perlite control. In their research, plant growth was similar in substrates with 25% JVC and 50% JVC to plants grown in a 75% peat: 25% perlite control mix. Comparisons between the physical properties of treatment substrates used in the Auburn research and the experiments reported here indicate that the Auburn JVC substrates had higher total porosity (92 to 93.5% compared to our 83%) and contributes to the explanation of differences in results between these studies. These results support the use of JVC as a substitute for the substrate component in a mix that contributes air space, not water holding capacity.

Substrate analyses, New Guinea Impatiens experiment. The pH of the 0% JVC treatment was lower than all other treatments throughout the entire experiment (Fig. 3-1 and

Table 3-3). The pH was higher as JVC content of the substrate increased during the first two weeks of the experiment, though 100% JVC had a lower pH than 75% JVC at 7 DAP (Fig. 3-1 and Table 3-3). Substrates containing any amount of JVC resulted in similar pH on 21 to 34 DAP, while at 42 DAP there were minor differences (Fig. 3-1 and Table 3-3). These results indicate that JVC will result in higher substrate pH during production than peatmoss, so pre-plant dolomitic lime amendment may need to be reduced slightly with its use.

Through 14 DAP, electrical conductivity (EC) was highest in the 0% JVC treatment and decreased with increasing JVC content, though 75% and 100% JVC resulted in similar readings (Fig. 3-2 and Table 3-3). By 21 DAP, all JVC-containing substrates had a similar EC of about 1.0 mS/cm, which was lower than the 0% JVC treatment. By 34 DAP through termination of the experiment, all substrates resulted in similar EC readings (Fig. 3-2 and Table 3-3). These results suggest that JVC ties up some fertilizer available early in the production cycle; the mechanism may be microbial or via substrate exchange capacity. However, by 21 DAP and with the same fertilizer applied across treatments, EC was comparable across treatments.

These experiments suggest that 4.76 mm JVC, like perlite, is associated with increasing airspace and decreased container capacity (Murphy, 2011; Starr, 2010a; Starr, 2010b). This increase in airspace and decrease in water holding capacity is associated with wood-based substrates, in general. In a greenhouse study with clean chip residual, a peat component was required in order to produce marketable annual plants (Boyer et al., 2008). Another study evaluating WholeTree substrate hammermilled to 0.64 cm demonstrated that WholeTree could be used as a large portion of the mix; however, peat was still necessary to produce plant growth equal to a standard mix (Fain et al., 2008). Similarly, our research suggests that 4.76 mm JVC cannot replace peat as the primary component in a standard mix, but it could probably be used as a replacement for perlite. Further experimentation would help optimize the ratios of JVC and peat that will result in optimal growth of greenhouse annuals.

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Table 3-1 Physical properties of Eastern Redcedar- and peat-based substrate[z].

Substrates[y]	Total porosity[v]	Container capacity[w]	Air space[x]	Bulk density[u]
		(% Vol)		(g*cm^{-3})
0% JVC: 75% Peat	85.30 [ns]	75.80 a[t]	9.50 c	0.13 e
25% JVC: 50% Peat	84.10	72.00 b	12.10 c	0.15 d
50% JVC: 25% Peat	83.10	66.20 c	16.80 b	0.17 c
75% JVC: 0% Peat	82.83	51.47 d	31.37 a	0.18 b
100% JVC	80.30	50.60 d	29.73 a	0.20 a

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

[y]Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peatmoss. Substrates mixed on v:v:v basis with each treatment containig 25% perlite, the exception of 100% JVC.

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

[w]Container capacity is (wet wt - oven dry wt) / volume of the sample.

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

[u]Bulk density after forced-air drying at 105°C for 48 h.

[t]Percent weight of sample collected on each screen, means within row followed by the same lettter are not significantly different bassed on waller-duncan K ratio t tests at α=0.05 (n=3).

[ns]means not signficantly different

Table 3-2 Particle size analysis of Eastern Redcedar-based substrates.

U.S. Standard sieve no.	Sieve opening (mm)	Substrate[z]				
		0% JVC: 75% Peat	25% JVC: 50% Peat	50% JVC: 25% Peat	75% JVC: 0% Peat	100% JVC: 0% Peat
1/4"	6.30	1.85 a[y]	0.32 b	0.30 b	0.10 b	0.00 b
10	2.00	31.72 a	23.18 b	22.38 b	30.94 a	22.40 b
25	0.71	26.48 d	37.38 c	41.62 b	47.31 a	48.30 a
35	0.50	13.95 ab	14.89 a	13.49 bc	10.91 d	12.67 c
60	0.25	16.78 a	16.12 a	14.84 a	11.03 b	7.79 c
140	0.11	7.79 a	6.58 b	6.06 b	2.47 d	4.67 c
pan	0.00	1.44 a	1.48 a	1.32 a	0.49 c	0.92 b
	Coarse [x]	33.57 a	23.50 b	22.68 b	31.04 a	22.40 b
	Medium	40.43 d	52.27 c	55.11 bc	58.22 ab	60.97 a
	Fine	26.01 a	24.18 a	22.21 a	10.75 c	16.62 b

[z]Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peatmoss. Substrates mixed on v:v:v basis with each treatment containig 25% perlite, the exception of 100% JVC.
[y]Percent weight of sample collected on each screen, means within row followed by the same lettter are not significantly different bassed on waller-duncan K ratio t tests at α=0.05 (n=3).

[x]coarse = 2.00 mm and greater; Medium = less than 2.00 and greater than 0.5 mm; fine = Less than 0.5 mm.

Table 3-3 Changes in pH and electrical conductivity over 42 days in New Guinea impatiens (*Impatiens hawkeri* W. Bull. 'Celebrette Lavender').

	pH					
Substrate[z]	7 DAP[y]	14 DAP	21 DAP	28 DAP	34 DAP	42 DAP
0% JVC: 75% Peat	4.70 e[x]	4.80 d	5.02 b	5.60 b	5.69 c	5.91 d
25% JVC: 50% Peat	5.71 d	6.00 c	6.65 a	6.81 a	6.92 a	6.65 c
50% JVC: 25% Peat	6.19 c	6.54 b	6.63 a	6.82 a	7.11 a	7.19 ab
75% JVC: 0% Peat	7.08 a	6.78 b	6.51 a	6.82 a	7.05 a	7.39 a
100% JVC	6.67 b	7.42 a	6.63 a	6.72 a	6.68 b	7.00 b
	Electrical Conductivity[w]					
0% JVC: 75% Peat	3.14 a[x]	3.15 a	1.52 a	1.32 a	1.04 [ns]	0.76 b
25% JVC: 50% Peat	2.20 b	1.77 b	1.06 b	0.81 c	0.79	0.77 b
50% JVC: 25% Peat	1.35 c	1.24 c	0.97 b	1.04 bc	0.93	0.95 a
75% JVC: 0% Peat	0.69 d	0.80 d	0.96 b	0.99 bc	0.86	0.79 b
100% JVC	0.83 d	1.05 cd	0.97 b	1.20 ab	0.78	0.87 ab

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Peat = peatmoss. Substrates mixed on v:v:v basis with each treatment containig 25% perlite, the exception of 100% JVC.

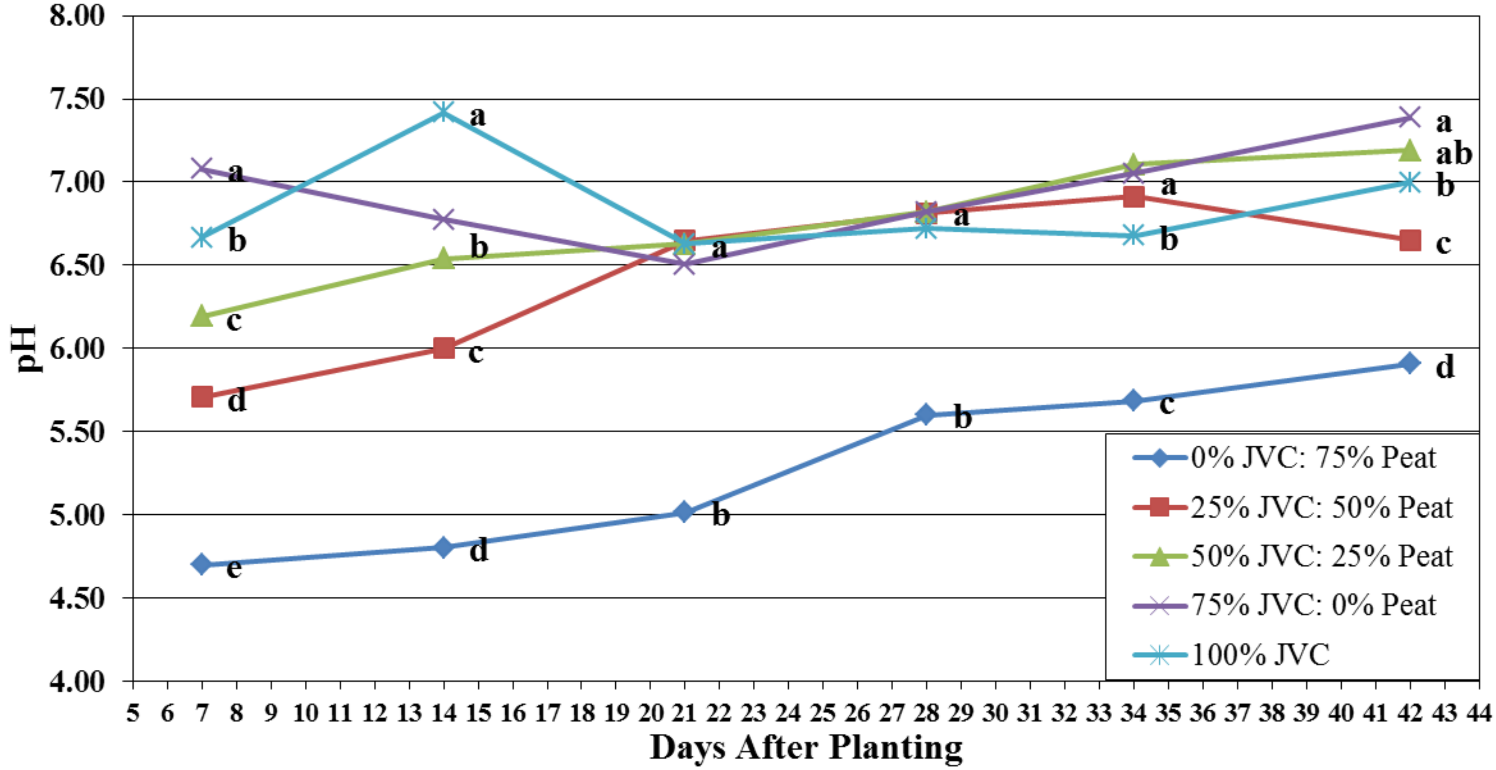
[y]DAP = days after planting.

[x]Means within column and location followed by the same letter are not significantly different based on

[w]valuems measured in mS/cm.

[ns]means not signficantly different.

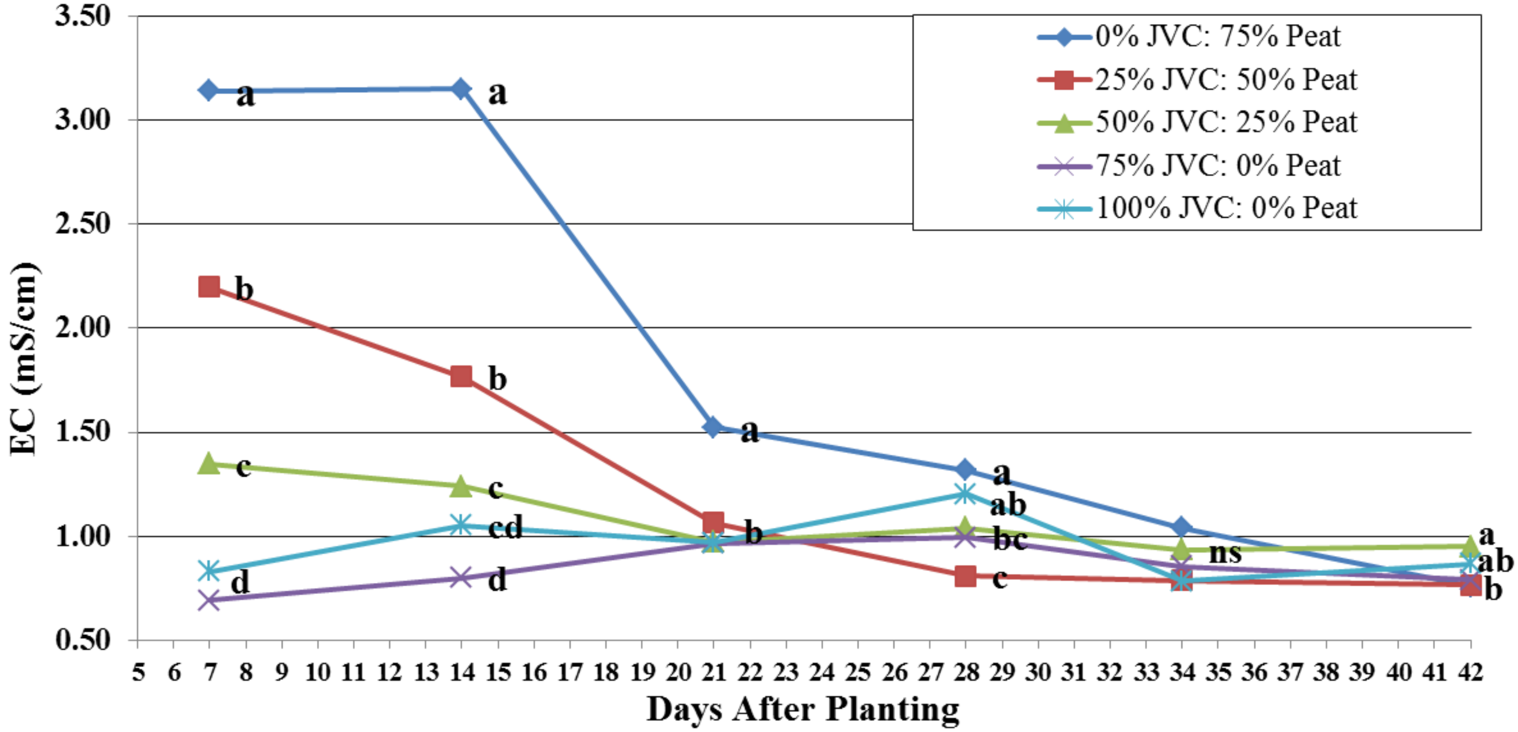
Figure 3-1 Visual Representation of Changes in pH over 42 days in New Guinea impatiens (Impatiens hawkeri W. Bull. 'Celebrette Lavender').



Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peatmoss. Each treatment contained 25% perlite with the exception of 100% JVC.

Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=4).

Figure 3-2 Visual Representation of Changes in EC over 42 days in New Guinea impatiens (*Impatiens hawkeri* W. Bull. 'Celebrette Lavender').



Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peatmoss. Each treatment contained 25% perlite with the exception of 100% JVC.

Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=4).

Means that are not significantly different are labeled ns.

Table 3-4 Effects of Eastern Redcedar-based substrates on the growth indices, shoot dry weight, and flower number of vinca (*Catharanthus roseus* L. G. Don 'Pacifica Apricot XP') over 42 days[z].

	7 DAP[y]	14 DAP	21 DAP	28 DAP	34 DAP	42 DAP
Substrate[z]	Growth Indices[x]					
0% JVC: 75% Peat	4.92 [ns]	5.70 [ns]	8.42 a[w]	11.00 a	13.00 a	15.19 a
25% JVC: 50% Peat	5.00	5.84	6.09 b	7.62 b	10.22 b	13.72 b
50% JVC: 25% Peat	4.94	5.65	5.20 c	5.21 c	6.17 c	8.60 c
75% JVC: 0% Peat	4.91	5.27	4.94 c	4.87 c	5.24 d	5.95 d
100% JVC	4.94	5.64	5.25 c	5.20 c	5.08 d	5.36 d

	14 DAP	21 DAP	28 DAP	34 DAP	42 DAP	Shoot dry
Substrate	Average Number of Flowers[v]					Weight[u]
0% JVC: 75% Peat	0.42 [ns]	1.75 a	2.83 a	3.92 a	4.50 a	2.02 a
25% JVC: 50% Peat	0.75	1.42 a	2.33 a	2.42 b	3.67 a	1.30 b
50% JVC: 25% Peat	0.58	1.33 ab	2.25 a	2.08 b	2.17 b	0.44 c
75% JVC: 0% Peat	0.25	0.50 b	0.92 b	0.92 c	1.25 bc	0.31 cd
100% JVC	0.17	1.08 ab	0.75 b	0.50 c	0.83 c	0.24 d

[z]Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peatmoss. Substrates mixed on v:v:v basis with each treatment containig 25% perlite, the exception of 100% JVC.

[y]DAP = days after planting.

[x]Growth index = (height + width 1 + width 2).

[w]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=12).

[v]Effects of Eastern Redcedar based substrates on Petunia flower number.

[u]Shoots were harvested at the container surface and oven dried at 70˚C for 48 h.

[ns]means not signficantly different.

Table 3-5 Effects of Eastern Redcedar on the growth indices, flower number, and shoot dry weight of petunia (*Petunia* x *hybrida* Juss. 'Suncatcher White') over 42 days.

	7 DAP[y]	14 DAP	21 DAP	28 DAP	34 DAP	42 DAP
Substrate[z]	Growth Indices[x]					
0% JVC: 75% Peat	5.33 a[w]	9.38 a	14.42 a	17.99 a	19.90 a	20.68 a
25% JVC: 50% Peat	5.07 ab	7.39 b	8.92 b	11.20 b	13.62 b	15.71 b
50% JVC: 25% Peat	4.75 bc	5.70 c	5.33 c	6.00 c	8.03 c	10.24 c
75% JVC: 0% Peat	4.41 bc	5.13 cd	4.11 d	4.02 d	4.70 d	5.33 d
100% JVC	4.60 c	4.48 d	3.18 d	3.36 d	3.68 d	3.86 d

	14 DAP	21 DAP	28 DAP	34 DAP	42 DAP	Shoot dry Weight[u]
Substrate	Average Number of Flowers[v]					
0% JVC: 75% Peat	0.42 [ns]	1.67 [ns]	4.67 a	11.75 a	19.67 a	3.76 a
25% JVC: 50% Peat	0.67	1.83	3.17 b	7.75 b	12.42 b	1.79 b
50% JVC: 25% Peat	0.25	1.58	2.17 bc	2.00 c	3.83 c	0.72 c
75% JVC: 0% Peat	0.42	1.08	1.33 cd	0.97 c	0.75 d	0.22 d
100% JVC	0.50	1.17	1.08 d	0.67 c	0.50 d	0.15 d

[z]Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peatmoss. Substrates mixed on v:v:v basis with each treatment containig 25% perlite, the exception of 100% JVC.

[y]DAP = days after planting.

[x]Growth index = (height + width 1 + width 2)

[w]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=12).

[v]Effects of Eastern Redcedar based substrates on Petunia flower number.

[u]Shoots were harvested at the container surface and oven dried at 70˚C. for 48 h.

[ns]means not signficantly different.

Table 3-6 Effects of Eastern Redcedar on the growth indices and shoot dry weight of impatiens (*Impatiens hawker* 'Celebrette Lavender') over 42 days^{z}.

Substrate^{y}	7 DAP^{x}	14 DAP	21 DAP	28 DAP	34 DAP	42 DAP	SDW^{w}
0% JVC: 75% Peat	6.08 a^{v}	7.88 a	8.96 a	10.62 a	11.53 a	13.59 a	1.74 a
25% JVC: 50% Peat	5.51 b	6.77 b	7.06 b	7.96 b	9.26 b	11.96 b	1.13 b
50% JVC: 25% Peat	5.21 bc	6.12 c	6.29 c	6.39 c	7.12 c	8.39 c	0.56 c
75% JVC: 0% Peat	4.83 d	6.93 b	5.56 d	5.56 d	5.85 d	6.53 d	0.27 d
100% JVC	5.09 dc	6.96 b	5.14 d	5.17 d	5.35 d	5.75 d	0.29 d

^{z}Growth index = (height + width 1 + width 2).

^{y}Substrate treatments were: JVC = Juniperus virginiana chips, Peat = peat moss. Substrates mixed on v:v:v basis with each treatment containing 25% perlite, the exception of 100% JVC.

^{x}DAP = days after planting.

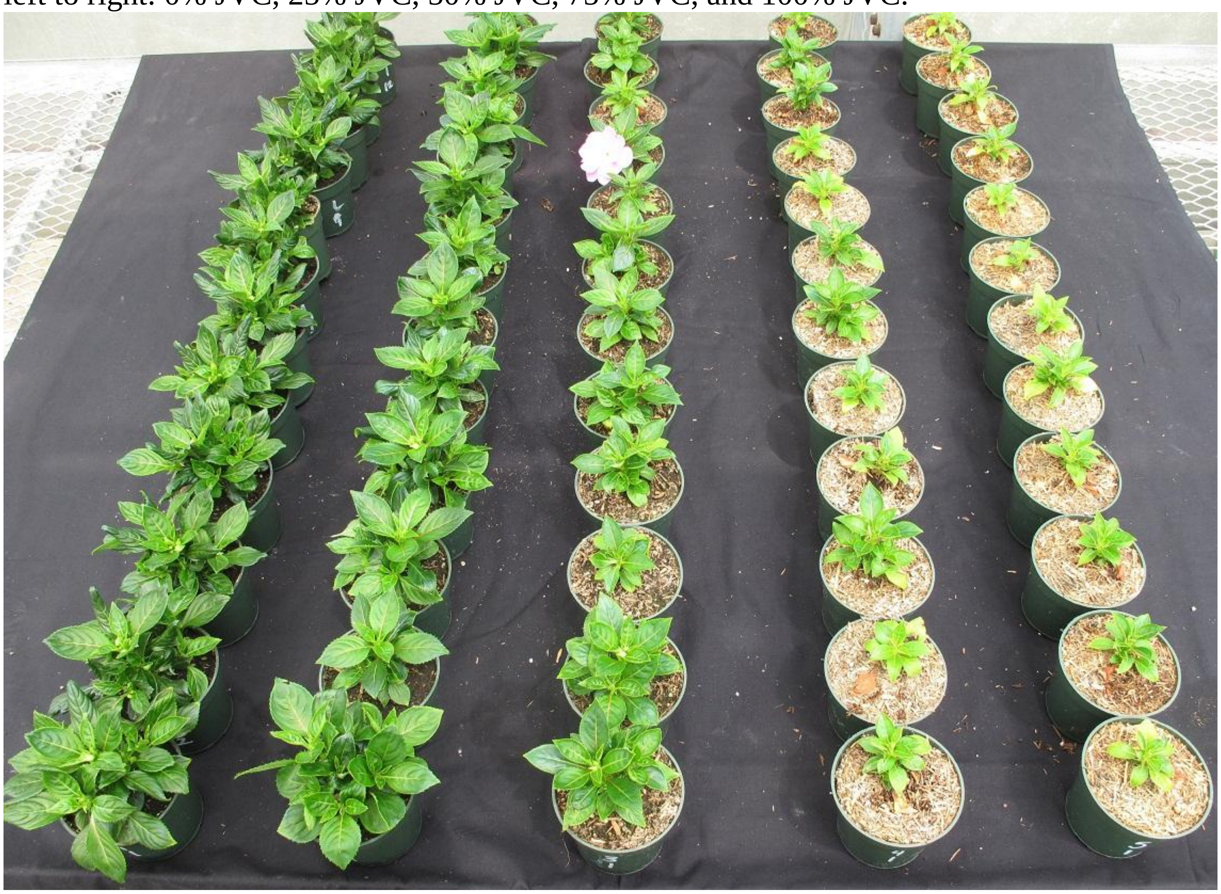
^{w}Shoot Dry Weight, shoots were harvested at the container surface and oven dried at 70˚C for 48 h.

^{v}Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=12).

Figure 3-3 The effects of Eastern Redcedar (JVC)-based substrates on vinca (*Catharanthus roseus* L. G. Don 'Pacifica Apricot XP') at 42 days after planting. Each substrate contained 25% perlite and differing percentages of JVC to Peat with the exception of 100% JVC. Plant columns from left to right: 0% JVC, 25% JVC, 50% JVC, 75% JVC, and 100% JVC.

Figure 3-4 The effects of Eastern Redcedar (JVC)-based substrates on vinca (*Catharanthus roseus* L. G. Don 'Pacifica Apricot XP') at 42 days after planting. Each substrate contained 25% perlite and differing percentages of JVC to Peat with the exception of 100% JVC. Plant columns from left to right: 0% JVC, 25% JVC, 50% JVC, 75% JVC, and 100% JVC.

Figure 3-5 The effects of Eastern Redcedar (JVC)-based substrates on impatiens (*Impatiens hawker* 'Celebrette Lavender') at 42 days after planting. Each substrate contained 25% perlite and differing percentages of JVC to Peat with the exception of 100% JVC. Plant columns from left to right: 0% JVC, 25% JVC, 50% JVC, 75% JVC, and 100% JVC.



Chapter 4 - Eastern Redcedar and Hedge-Apple Substrate Processed to Four Hammermill Screen Sizes Affects Nursery Crop Growth

In many regions of the U.S. the nursery industry increasingly requires greater quantities of substrate material to meet their production needs. One of these primary materials is pine bark (PB). Unfortunately PB is becoming a scarcer resource due to decreased timber production (Yeager et al., 2007; Laiche and Nash, 1986; Lu et al., 2006). This has led to a demand for alternatives to PB that are sustainable, locally available, and adaptable to pre-existing machinery. Eastern Redcedar (*Juniperus virginiana* L.) and Hedge-Apple (*Maclura pomifera* Raf.) also known as Osage-orange are two common trees in the Great Plains that could meet these requirements for substrate material in the containerized nursery industry. Both species are noted for their adaptability to marginal areas and harsh site conditions which has led to their wide scale in growth hedge rows (Bahari et al., 1985; Dirr, 2009; Eggmeyer, 2005; Kramer, 1949; Ormsbee et al., 1976). Unfortunately this adaptability, in the case of Eastern Redcedar, has led to wide scale expansion into native grass lands and cattle ranges which have led to both economic and ecological concerns (Beilmann and Brenner, 1951; Bidwell et al., 1990; Drake and Todd, 2002; Hoch and Briggs, 1999; Hoch, 2000; Owensby et al., 1973). This expansion is due to increased livestock and wild fire suppression or lack of controlled field burning (Bragg, 1976; Bragg and Hulbert, 1976; Blan, 1970; Briggs and Gibson, 1992; Kucera, 1960, Schmidt and Stubbendieck, 1993). Another quality both trees have in common is that their wood is known to be resistant to decay due to anti-fungal chemicals (Barnes and Gerber, 1955; Dunford et al., 2007; Ishikawa et al., 2001; Nuñez et al., 2006; Wang et al., 1976; Wang and Hart 1983). This decay resistance could help substrates avoid shrinkage, which can cause unfavorable changes in substrate physical properties over a production cycle.

A study on Eastern Redcedar as a substrate component replacing increasing portions of PB in a standard nursery mix has shown increased airspace and decreased water holding capacity as Eastern Redcedar content increases (Starr et al., 2010). Manipulation of physical properties by increasing or decreasing screen size of hammermilled material could result in substrates with more suitable airspace and container capacity for containerized production. In 2005, an experiment was conducted to evaluate clean chip residual's effects on woody materials (Boyer et al., 2009). Clean chip residual is a byproduct produced from thinning pine plantations with mobile equipment directly in the field for clean chips, which are used in paper production. It contains both pine bark, wood, and needles (Boyer et al., 2008). Five substrates were used consisting of a pine bark control and four 100% hammermilled clean chip residual to pass a 9.5, 12.7, 19.1, and 31.8 mm screen as well as PB and were used to grow five woody species (Boyer et al., 2009). It was demonstrated that 12.7 and 9.5 mm clean chip residual was similar to the pine bark control and that plants grown in these smaller screen sizes had greater growth compared to plants grown in larger screen sizes (19.1 mm and 31.8 mm). In general, plants grown in clean chip residual were similar to plants grown in PB (Boyer et al., 2009). Adjustment of screen size for Eastern Redcedar substrate (JVC) could increase water holding capacity resulting in increased growth more comparable to PB by altering particle size distribution. This study compares both JVC and *Maclura* to a PB control to determine if *Maclura* could be used as a nursery substrate and to determine at what screen size, if any, JVC and *Maclura* can produce comparable plants to those grown in PB.

Materials and Methods

Eastern Redcedar chips (Queal Enterprises. Pratt, KS) from whole trees harvested in Barber County, KS (aged for six months) were ground in a hammer mill (C.S. Bell Co., Tiffin, OH, Model 30HMBL) to pass a 4.76, 9.53, 12.70, and 19.05 mm screen on 28 April 2010. *Maclura* chips were harvested in the Haysville, KS area by a local power company and ground through the same screen sizes as JVC on the same date. The JVC, *Maclura* and a PB (SunGro, Bellevue, WA) control were then blended with sand to make a series of nine 80% wood : 20% sand (by vol.) substrate mixes. Substrates were pre-plant incorporated with 1.17 kg/m^2 micronutrient package (Scotts, Micromax, Marysville, OH) and controlled release fertilizer at 8.60 kg/m^2 (Scotts, Osmocote Classic, 18 N-2.62 P-9.96 K, 8 to 9 month release, Marysville, OH). Containers holding 7.57 L (Olympian Heavy weight-Classic 1000, Nursery Supplies INC®, Fairless Hills, PA) were then filled and planted with of one liner per container of Blackeyed-susan (*Rudbeckia fulgida* var. *fulgida* L.) (Creek Hill Nursery, Leola, PA), Maiden grass (*Miscanthus sinensis* Anderss. 'Graziella') (Emerald Coast Growers, Pensacola, FL), Crapemyrtle (*Lagerstroemia indica* (L.) Pers. 'Arapaho') (Cedar Valley Nurseries, Ada, OK), and Baldcypress (*Taxodium distichum* L. [Rich.]) (one year old seedlings grown at the John C. Pair Horticulture Research Station, Haysville, KS; seed collected from Ingram, TX). Each plant species grown and both substrate components, JVC or *Maclura,* were treated as separate experiments. Containers were placed on an outdoor gravel container pad and irrigated daily via overhead sprinklers supplying 2.54 cm of water daily. Redbud (*Cercis canadensis* L.)(seedlings grown at the John C. Pair Horticulture Research Station, Haysville, KS; seed collected from station) were planted on the same date but with two seedlings per container that were thinned to one 43 days after planting (DAP). Redbud plants were transferred later to the container pad after they were allowed to harden off in the greenhouse until 15 DAP. Spirea (*Spiraea japonica* L. f. 'Little Princess') (Spring Meadow Nursery, Inc. Grand Haven, MI) were planted on 06 May 2010.

Data collection began on 13 May 2010, 16 days after planting (DAP), and continued once every 4 weeks (43, 71, 106, 127 and 154) until termination on 29 September 2010 except Blackeyed-Susan and Maiden Grass which were harvested earlier on 11 August 2010 (106 DAP). Data collected included pH and electrical conductivity (EC) using the PourThru technique (Wright, 1986). Leaf greenness as measured with a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ), and growth indices [(widest width + perpendicular width + height) ÷ 3] were measured at 16, 43, 71, and 106 DAP. Shoot and root dry weight was recorded at the conclusion of the study by drying in a forced air oven (The Grieve Co. Model SC-400, Round Lake, IL) at 71°C for 7 days. Substrate physical properties were determined using North Carolina State University porometers (Raleigh, NC), which measured substrate air space, water holding capacity, substrate bulk density, and total porosity (Fonteno and Bilderback, 1993). Leaf samples (four replications per substrate treatment) of Maiden Grass, Crapemyrtle, and Redbud were analyzed (Brookside laboratories, New Knoxville, OH) for nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), Magnesium (Mg), sulfur (S), boron (B), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn). Foliar N was determined by combustion analysis using 1500 N analyzer (Carlo Erba, Milan, Italy). Remaining nutrients were determined by microwave digestion with inductively coupled plasma-emission spectromertry (Thermo Jarrel Ash, Offenbach, Germany). Data was analyzed using SAS using the Waller-Duncan K-ratio T Test (Version 9.1 SAS Institute INC. Cary, NC). The experimental design was a randomized complete block and eight single plant replications. Each primary substrate component, JVC or

Maclura, and each plant species grown in these substrates were considered separate experiments for the purpose of analysis and compared to the same species grown in the PB control. As such, there were 12 total experiments each one analyzing the effect of differing screen sizes of either JVC or *Maclura* compared to PB on one of six plant species.

Results and Conclusions

Substrate pH for JVC did not vary based on substrate at 106 DAP and afterwards (Table 4-3). Initially at 16 DAP and at 43 DAP all JVC based substrates were similar to each other and had a higher pH than PB; 71 DAP was generally similar to these dates though there was more variation in pH among JVC treatments. The first three measurement dates PB had a significantly lower pH but over time all substrates increasingly became similar. *Maclura* based substrates started on 16 DAP with no significant differences based on substrate (Table 4-3). However by 43 DAP and onward to 106 DAP 19.05 mm JVC had the highest pH and generally pH decreased with decreasing screen size and the lowest pH was found in PB. At 127 DAP and 154 DAP the difference based on substrate began to decrease and while there was statistical difference substrates were becoming more alike. So similarly to JVC, *Maclura* initially had a higher pH than PB at any given screen size but those differences become minimal over time. Electrical conductivity for JVC based substrates and the PB control did not differ from each other until 154 DAP which exhibited minimal differences (Table 4-4). As such it is reasonable to assume that both PB and JVC, regardless of screen size, have similar properties revolving around EC. *Maclura* based substrates were also similar at 16, 71, 106, and 127 DAP (Table 4-4). At 43 DAP EC was highest in 9.53 and decreased with both increasing and decreasing screen size; the lowest EC was in PB. At 154 DAP, PB was again the lowest EC with all *Maclura* substrates being similar to each other. In general, like JVC, *Maclura* screen sizes have similar properties.

However, it is noteworthy that both when there were significant differences and at times when EC differences were not significant, PB usually had the lowest EC compared to all other treatments.

Pine bark had the highest total porosity followed by all JVC substrates each of which were similar to one another (Table 4-1). All substrates were within the recommended range of 50 to 85% total porosity (Yeager et al., 2007). Container capacity, however, did have differences based on substrate treatment. The highest container capacity was found in PB followed by 4.76 mm JVC and decreased with each increase in screen size (Table 4-1). Only 4.76 mm JVC was within the recommended range of 45 to 65% container capacity, including the PB control at 68.83% (Yeager et al., 2007). Air space was the inverse of container capacity with PB having the lowest in airspace followed by 4.76 mm JVC with an increase in airspace with each decrease in screen size. Again, 4.76 mm JVC was within recommended ranges (10 to 30%) as well as 9.53 mm JVC, but just barely at 29.93% air space (Yeager et al., 2007). Bulk density was highest in PB with all JVC treatments having a lower bulk density that was similar to each other. There was no statistical difference in substrate shrinkage. Particle size analysis of JVC revealed that 9.53 and 19.05 mm JVC had the most coarse (2.00 mm and larger) particles, followed by PB and 12.70 mm JVC, with the least coarse particles found in 4.76 mm JVC (Table 4-2). However 4.76 mm JVC had the most medium sized particles (less than 2.00 mm and larger than 0.5 mm) and the percent of medium particles decreased with increasing particle size up to 19.05 mm JVC and PB which both had the least medium particles. All substrates had similar amounts of fine particles (less than 0.5 mm) except 9.53 which had less than all other substrates.

Total porosity was higher in PB but was followed by 12.70 mm *Maclura*, then 4.76 and 19.05 mm *Maclura*, and finally 9.53 mm *Maclura*; all substrates were within recommended ranges (Yeager et al., 2007) (Table 4-1). Additionally PB had the highest container capacity followed by 4.76 mm and generally decreased with increasing screen size. Only 4.76 mm *Maclura* fell within recommended ranges (Yeager et al., 2007). Airspace was lowest in PB followed by 4.76 mm *Maclura* and increased at 9.53 mm *Maclura* with an additional increase at 12.70 and 19.05 mm *Maclura*, both of which had the highest air space. As with JVC, 4.76 and 9.53 mm *Maclura* were within recommended ranges with 9.53 on the verge at 29.57% airspace (Yeager et al., 2007). Bulk density was similar in PB, 4.76 and 9.53 mm JVC with a decrease in bulk density at 12.70 and 19.05 mm *Maclura*. Shrinkage in *Maclura* was highest in 4.76 mm *Maclura*, followed by all other *Maclura* substrates. This is surprising considering *Maclura* is considered to be decay resistant (Dirr, 2009; U.S. Forest Product Laboratory, 1961); however the highest shrinkage found in 4.76 mm *Maclura* was fairly small at 2.30 mm. The substrate with the most coarse material was 12.70 mm *Maclura* (Table 4-2). This was followed by 9.53, then 19.05 mm *Maclura*, PB, and finally 4.76 mm *Maclura*. However for medium sized particles, 4.76 mm *Maclura* had the highest percentage followed by 9.53 mm *Maclura*, 12.70 mm *Maclura*, and both PB and 19.05 mm *Maclura*. Further 4.76 mm *Maclura*, and PB, had the highest fraction of fine material, followed by 19.05 mm *Maclura*, then 9.53 mm *Maclura*, and finally 12.70 mm *Maclura*. In general both PB and 4.76 mm *Maclura* tended to have more medium and fine particles while both 9.53 and 12.70 tended to have more medium and coarse particles; 19.05 mm *Maclura* had more of a balance between all three particles sizes favoring the medium ones.

Other studies investigating wood-based substrates, specifically pine tree substrate (also known as chipped pine logs) which is a substrate made of pine logs processed for use in containerized plant production, require 10 to 15% fine material to have an acceptable container capacity (Jackson et al., 2010). Both experiments used differing screen sizes, in the case of the pine tree substrate 4.76, 6.35, 9.35, 15.90 mm as well as a un-hammermilled substrate. However, the pine tree substrate experiment also had two substrate components in addition to 100% pine tree substrate: 10% sand and 25% peat (Jackson et al., 2010). Our experiment incorporated at 20% sand component in each treatment. In the pine tree substrate experiment sand greatly increased the percent fine particles in each screen size treatment. However, that addition of sand was not associated with increases in container capacity though it was associated with increased growth in general (Jackson et al., 2010). Possibly due to increased air space or increased water columns (Jackson et al., 2010). Both experiments were fairly comparable within the JVC, *Maclura*, and pine tree substrate both with and without sand at different screen sizes for container capacity and air space (Jackson et al., 2010). However, pine tree substrate had a higher percentage of fine particles at each screen size compared to either JVC or *Maclura* (Jackson et al., 2010). The amount of fine material contributing to container capacity in this experiment could have been obscured by the 20% sand portion. For both JVC and *Maclura* smaller screen sizes were associated with greater container capacity which decreased with increasing screen size. However many of the substrates had similar percentages of fine material with the exception of 9.53 mm JVC and *Maclura* and 12.70 mm *Maclura*. As such, smaller screen sizes may have a greater proportion of fine material which contribute to container capacity but are undetected due to the presence of sand. Even so, increasing container capacity could be useful and a portion of a fine material associated with increased water holding capacity from an additional source such as compost, peatmoss, or pine bark could greatly improve physical properties, allowing for increased growth which has been demonstrated with other wood-based materials (Jackson et al., 2010; Murphy et al., 2010).

Blackeyed-Susan

Growth indices, the average of height, the widest width, and the perpendicular width, was similar for Blackeyed-Susan at 16 DAP, 43 DAP, and 71 DAP though at 71 DAP a trend in decreased growth at 9.53 mm JVC and larger screen sizes began to develop (Table 4-5). Finally at 106 DAP, the termination date, growth was greatest in PB and 4.76 mm JVC with the least in 12.70 mm JVC; 9.53 and 19.05 mm JVC were similar to all other treatments. The dry weight was greatest in PB and the least in 12.70 and 19.05 mm JVC. Both 4.76 and 9.53 mm JVC were similar to all other substrates (Table 4-5; Fig. 4-10).

Growth indices for *Maclura* based substrates followed the same pattern at each measurement date; PB producing the most growth and all *Maclura* based substrates producing plants with less growth compared to PB but similar growth to each other. This same pattern was also found in the dry weight (Table 4-5; Fig. 4-12). Leaf Greenness for both JVC and *Maclura* were generally similar at each measurement date with the exception of 16 DAP for JVC and 43 DAP for *Maclura* (Tables 4-6).

Maiden Grass

Maiden grass grown in JVC substrates had no statistical differences at 16 and 71 DAP for growth index (Table 4-5; Fig. 4-1). At 42 DAP PB produced the larger plants while all JVC substrates produced significantly smaller plants but were all similar to each other. When terminated (106 DAP) PB had produced the most growth and 19.05 produced the least. All other substrates produced growth that ranged between these two substrates. Shoot dry weight was highest in PB followed by 4.76 mm JVC and decreased with each increase in screen size.

Growth index of plants grown in *Maclura* was not initially significant (16 DAP) and were generally similar at 43 DAP (Table 4-5; Fig. 4-2). By 71 DAP PB and 4.76 mm *Maclura* had produced the largest plants while all other *Maclura* substrates had less growth but were similar to one another. There was greater variation in plant growth at termination (106 DAP) with the most growth in PB, followed by 4.76 mm JVC, then 9.53 and 19.05 mm *Maclura*, and finally the least in 12.70 mm *Maclura*. Shoot dry weight was highest in PB followed by 4.76 mm *Maclura*, 19.05 mm JVC produced the third greatest shoot dry weight with 9.53 and 12.70 mm *Maclura* producing the least (Table 4-5).

Both JVC and *Maclura* showed the same trends for nutrient content from foliar analysis (Table 4-7, Table 4-8). There were few differences between N, P, and K content among substrates and all were below recommended ranges (Mills and Jones, 1996). No nutrient was within recommended ranges, they either fell below recommended ranges (Mg, S, and B) or above recommended ranges (Fe, Mn, Cu, Zn, Al) for almost every substrate. The exceptions being fairly random and singular with the except Zn content of 4.76 mm to 12.70 mm *Maclura* which were all within recommended ranges. Despite most nutrients falling outside of recommended ranges Maiden Grass showed no signs of deficiency or toxicity and produced large amounts of growth. Both JVC, *Maclura*, and PB showed the same patterns of being either below or above recommended ranges.

All woody Plants

All woody species were grown for 154 days. Between 106 DAP and 154 DAP a period of high winds and summer heat occurred which resulted in dieback among some woody plant species. This is reflected in decreases in growth indices between 106 and 154 DAP.

Crapemyrtle

While initial growth indices of Crapemyrtle varied between JVC treatments at 16 DAP by 43 DAP until termination at 154 DAP the same pattern was continuously repeated (Table 4-9;

Fig. 4-3). Pine bark produced the greatest growth index and all JVC substrates produced plants that were smaller than PB, and similar to one another. This same pattern was repeated for shoot dry weight of Crapemyrtle while root dry weight showed no statistical difference based on substrate. For analysis of foliar nutrient content of plants grown in JVC substrates N, P, and K all had similar percentages in each substrate and were mostly above recommended ranges but not greatly so (Table 4-10) (Mills and Jones, 1996). Calcium, S, Mn, and Zn were within recommended ranges as was Cu for 4.76 to 12.70 mm JVC while PB and 19.05 mm JVC fell only slightly below recommended ranges. Additionally Mg, B, and Al also were below recommended ranges for each substrate while Fe was higher than recommended ranges for each substrate. There appeared to be no signs of toxicity or deficiency in Crapemyrtle and like the Maiden Grass, PB and JVC substrates had the same instances falling below, above, or within recommended ranges.

Growth index of plants grown in *Maclura* did not vary at 16 DAP and was generally similar up to 71 DAP (Table 4-9; Fig. 4-4). At 106 DAP PB had produced the most growth followed by 4.76 mm *Maclura*, with each increase in screen size associated with a decrease in growth index. However by 127 *Maclura* differences in growth between *Maclura* treatments had diminished so that all *Maclura* treatments were similar to each other; PB still had produced the most growth. Finally though at 154 DAP differences between *Maclura* treatments reemerged with PB once again producing the most growth and 12.70 and 19.05 mm *Maclura* the least with remaining two substrates, 4.76 and 9.53 mm *Maclura* falling in-between these three substrates. Shoot dry weight highest in PB and all JVC substrates were similar to each other and less than PB, except 0.53 mm JVC which was also similar to PB. There was no difference based on root dry weight. *Maclura* foliar content of N was similar in each substrate and above recommended levels but not greatly so (Table 4-11) (Mills and Jones, 1996). Phosphorus was highest in PB and above recommended ranges while *Maclura* substrates were within recommended ranges. Potassium content was the opposite with all *Maclura* substrates above recommended ranges while PB had the least K but was within recommended ranges. As with JVC, *Maclura* was mostly similar to the PB control in regards to being over or under recommended ranges with the notable exception of B. Boron content was below recommended ranges and was the lowest in general in PB, while all Maclura substrates had more B and were within the recommended ranges.

Spirea

Spirea Growth indices for plants grown in JVC were largest in PB while 4.76 mm JVC had the least from 43 to 106 DAP; all other JVC falling between those two substrates (Fig. 4-9). By 127 DAP until 154 DAP all differences in plant growth had disappeared resulting in similar plants; further neither shoot nor root dry weight had significant differences either.

Growth indices of Spirea grown in *Maclura* were similar up to 71 DAP where PB was greater with all other substrates having less growth and were similar to each other (Fig. 4-9). However there was more statistical differences appearing at 106 DAP, with 12.70 mm *Maclura* showing the least growth of any substrate treatment. These statistical differences in growth were lost in the die back caused by experienced by woody plants in this study though 12.70 mm *Maclura* still had the least growth at 127 and 154 DAP. Shoot dry weight was highest in PB, followed by 4.76 mm *Maclura*, then 9.53 and 19.05 mm *Maclura* with the least dry weight in 12.70 mm *Maclura*. Root dry weight on the other hand was higher in 4.76 mm *Maclura* with the least in 12.70 mm *Maclura* with all other treatments falling between these two.

Baldcypress

Growth index for Baldcypress grown in JVC was not significantly different past 43 DAP (Table 4-12; Fig. 4-5). For caliper, all treatments were generally similar though PB at 106 and 127 DAP 4.76 mm JVC generally had thicker trunks. There were no differences in shoot or root dry weight for plants grown in JVC based substrates and PB.

For Baldcypress grown in *Maclura* there were few to no differences based on growth index until 106 DAP (Table 4-12; Fig. 4-7). At 106 DAP growth was highest in PB while all other substrates had less growth but were similar to each other. However by 127 and 154 DAP, probably due to large amounts of dieback, all treatments were similar to one another. Caliper by 71 DAP onwards was highest in PB with all *Maclura* substrates producing thinner trunks but were similar to one another; this same pattern was also found in shoot dry weight. Root dry weight was similar among all treatments.

Redbud

While redbud grown in JVC initially had differences in growth index, favoring PB, those differences began to disappear by 71 DAP, and from 106 DAP to termination there were no significant differences between substrate treatments. This was also true of caliper and there were no differences in shoot and root dry weight at the conclusion of the study (Table 4-13; Fig. 4-9).

Growth index and caliper for plants grown in *Maclura* had no significant differences by 71 DAP nor were there differences based on root dry weight. However there were differences in shoot dry weight with 19.05 mm *Maclura* producing more shoot dry weight and PB the least, with all other treatments being similar to those two treatments (Table 4-13; Fig. 4-11). For both

JVC and Maclura substrates N, P, and K were similar for PB and each particle size and within recommended ranges (Table 4-14, Table 4-15) (Mills and Jones 1996). Further, most nutrient content for Redbud was within recommended ranges. However Fe was above recommended ranges for all substrates as was sulfur in PB and all JVC substrates as well as 9.53 mm Maclura. Manganese was above of recommended ranges for PB as was 12.70 and 19.05 mm Maclura. Leaf greenness for both JVC and *Maclura* at 16 DAP were greater in PB than other treatments, and at 43 DAP both plants grown in PB and both 19.05 mm JVC and *Maclura* were had greater leaf greenness than plants grown in other substrates (Table 4-16). By 71 DAP and until termination there were no significant differences between PB and any *Maclura* treatment. Eastern Redcedar substrate did have differences from 71 to 106 DAP with 9.53 to 19.05 mm JVC having greener leaves compared to 4.76 mm JVC and PB, though often these differences were not great.

In general for crops evaluated in this study at both 106 and 154 DAP for woody and herbaceous species certain trends appear. When looking at both growth index and shoot dry weight, growth measurements were higher in PB than JVC or *Maclura* substrates. Within JVC or *Maclura* the screen sizes were often similar to each other or had less growth at 12.70 and 19.05 mm screen sizes, when differences occurred. Additionally, nutritional differences from foliar analysis show that PB, Maclura, and JVC have similar trends and as such are not associated with toxicity or deficiencies of any given nutrient compared to PB. These results are similar to the findings of other experiments with wood-based substrates with differing screen sizes. Boyer et al. (2009) working with clean chip residual ground to pass 9.5, 12.7, 19.1, and 31.8 mm screens which were compared to PB found that for most growth measurements those substrates and PB were comparable (Boyer et al., 2009). However when differences did occur it was found in the larger screen sizes and was probably due to physical properties (Boyer et al., 2009). In the previously mentioned study by Jackson et al. (2010) pine tree substrate was passed through 4.76, 6.35, 9.35, and 15.90 mm screen and used alone, or with an additional 10% sand or 25% peatmoss component (Jackson et al., 2010). It was found that plant growth decreased with increasing screen size regardless of additional components but that 4.76 mm pine tree substrate with additional components produced plants equal to or exceeding growth in a PB and peat-lite control. These additional components were associated with increased container capacity (Jackson et al., 2010). Data in this study concurs, demonstrating that container capacity decreased with increasing screen size for both JVC and *Maclura*. Only 4.76 mm of either JVC or *Maclura* was within recommended ranges for container capacity and container capacity decreased with increasing screen size. Furthermore, PB had a higher total porosity in general compared to either JVC or *Maclura*. Studies comparing WholeTree substrate (whole pine trees ground for use as substrate) and clean chip residual in combination with PB found that the addition of PB helped to improve these substrates (Murphy et al., 2010). Substrates were composed of hammermilled pine processed through a 9.53 mm screen were used to make 0%, 25%, 50%, 75% or 100% clean chip residual or WholeTree (Substrate made from whole, ground pine trees) substrate with the remaining composed of PB. It was shown that plants grown in up to 75% wood-based substrate, either WholeTree or clean chip residual, and 25% PB were comparable to 100% pine bark (Murphy et al., 2010). While this study showed that different screen sizes of JVC or *Maclura* were fairly equivocal to each other screen size, and often similar to PB, in general PB out performed JVC and *Maclura*. Other studies on JVC used JVC ground to pass a 19.05 screen to make substrates containing both PB and JVC at different proportions with each incorporating 20% Sand to grow Baldcypress (Starr et al., 2010). It was determined that there was no difference based on height and shoot dry weight in substrates containing up to 20% JVC compared to PB. At higher levels of JVC plants put on less shoot dry weight, but not height (Starr et al., 2010). This study used 19.05 mm JVC, use of a smaller screen size of JVC could allow for a decreased portion of PB and an increased portion of JVC while maintain an adequate container capacity.

Eastern Redcedar and *Maclura* can both be used as primary substrate components. While these substrates were generally similar growth 4.76 mm and to a lesser extent 9.53 mm both have physical properties closer to the industry standard PB. Further, while JVC and *Maclura* both often had similar patterns of growth compared to PB overall JVC tended to have fewer significant differences when compared to PB. Use of these materials as a substrate component could alleviate some of the shipping costs and availability issues associated with PB as a primary substrate component. The financial savings from use of JVC or *Maclura* could offset the decrease in growth associated with them compared to PB. Additionally the incorporation of a PB or peatmoss fraction and a smaller screen size of JVC or *Maclura* could result in a substrate with comparable growth and container capacity to a standard PB substrate.

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Table 4-1 Physical properties of Eastern Redcedar, *Maclura*, and PB substrates[z].

Substrates[y]	Total porosity[x] (% Vol)	Container capacity[w] (% Vol)	Air space[v] (% Vol)	Bulk density[u] ($g*cm^{-3}$)	Shrinkage[t] mm
			JVC		
Pine Bark	73.50 a[s]	68.83 a	4.70 e	0.52 a	0.43 [ns]
4.76 mm JVC	70.23 b	50.07 b	20.17 d	0.45 b	0.81
9.53 mm JVC	70.07 b	40.10 c	29.93 c	0.46 b	0.20
12.70 mm JVC	69.97 b	35.17 d	33.87 b	0.45 b	0.33
19.05 mm JVC	69.00 b	29.90 e	40.10 a	0.47 b	0.49
			Maclura		
Pine Bark	73.50 a	68.83 a	4.70 d	0.52 a	0.43 c
4.76 mm *Maclura*	68.33 c	52.30 b	16.03 c	0.51 a	2.30 a
9.53 mm *Maclura*	66.27 d	36.73 c	29.57 b	0.50 a	1.24 b
12.70 mm *Maclura*	71.47 b	36.57 c	34.90 a	0.43 b	1.58 b
19.05 mm *Maclura*	68.27 c	33.33 d	34.90 a	0.46 b	1.35 b
Recommended[r]:	50-85	45 to 65	10 to 30	0.19-0.70	

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

[y]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera*. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

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

[w]Container capacity is (wet wt - oven dry wt) / volume of the sample.

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

[u]Bulk density after forced-air drying at 105°C for 48 h.

[t]Difference between final substrate level and initial substrate level measured from the top the container.

[s]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on waller-duncan K ratio t tests at α=0.05 (n=3).

[r]Recommended ranges as reported by Yeager et al., (2007).

[ns]Means not significantly different.

Table 4-2 Particle size analysis of Eastern Redcedar and *Maclura* substrates compared to pine bark.

U.S. Standard sieve no.	Sieve opening (mm)	Substrate[z]				
		Pine Bark	JVC			
			4.76 mm	9.53 mm	12.70 mm	19.05 mm
1/4"	6.30	4.43 b[y]	1.25 b	0.94 b	1.91 b	9.37 a
10	2.00	22.83 bc	18.83 c	32.83 a	25.57 b	24.41 b
25	0.71	27.85 d	38.23 a	35.21 b	32.29 c	23.40 e
35	0.50	12.21 ab	12.54 a	10.31 c	12.14 ab	11.08 bc
60	0.25	23.03 a	19.83 a	14.99 b	21.03 a	23.62 a
140	0.11	8.56 a	7.46 a	4.57 b	6.24 ab	7.73 a
pan	0.00	1.08 b	1.86 a	1.15 b	0.81 c	0.38 d
	Coarse[x]	27.26 b	20.09 c	33.76 a	27.48 b	33.78 a
	Medium	40.06 c	50.76 a	45.52 b	44.44 b	34.50 d
	Fine	32.68 a	29.15 a	20.71 b	28.09 a	31.72 a
		Pine Bark	*Maclura*			
			4.76 mm	9.53 mm	12.70 mm	19.05 mm
1/4"	6.30	4.43 a[y]	0.77 b	1.76 b	2.83 ab	4.20 a
10	2.00	22.83 c	14.73 d	35.32 ab	41.37 a	29.45 bc
25	0.71	27.85 c	37.81 a	34.20 b	32.28 b	28.71 c
35	0.50	12.21 ab	13.54 a	9.54 cd	8.37 d	11.21 bc
60	0.25	23.03 a	24.27 a	14.31 b	11.48 b	20.25 a
140	0.11	8.56 a	8.02 a	4.48 bc	3.38 c	5.86 b
pan	0.00	1.08 a	0.85 b	0.39 c	0.29 c	0.32 c
	Coarse[x]	27.26 c	15.49 d	37.08 ab	44.20 a	33.65 bc
	Medium	40.06 c	51.35 a	43.74 b	40.65 bc	39.91 c
	Fine	32.68 a	33.16 a	19.18 bc	15.15 c	26.43 ab

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on waller-duncan K ratio t tests at α=0.05 (n=3).

[x]Coarse = 2.00 mm and greater; Medium = less than 2.00 and greater than 0.5 mm; fine = Less than 0.5 mm.

Table 4-3 Changes in pH for Eastern Redcedar, *Maclura*, and Pine Bark substrates.

Substrates[z,v]	16 DAP[y]	43 DAP	71 DAP	106 DAP	127 DAP	154 DAP
Pine Bark[u]	6.02 b[x]	6.06 b	6.28 c	6.80 [ns]	6.59 [ns]	7.25 [ns]
4.76 mm JVC	6.89 a	7.28 a	6.80 b	6.84	6.90	7.18
9.53 mm JVC	6.94 a	7.18 a	7.22 ab	7.03	6.94	7.17
12.70 mm JVC	6.92 a	7.24 a	7.04 ab	6.95	6.68	7.11
19.05 mm JVC	7.05 a	7.39 a	7.34 a	7.22	6.80	7.48
Pine Bark	6.02 b	6.06 c	6.28 c	6.80 c	6.59 b	7.25 b
4.76 mm *Maclura*	6.77 a	6.87 b	6.66 b	7.28 b	7.08 ab	7.41 b
9.53 mm *Maclura*	6.95 a	6.96 b	6.72 ab	7.31 b	7.15 a	7.64 ab
12.70 mm *Maclura*	6.99 a	7.14 ab	6.93 ab	7.57 a	7.40 a	7.65 ab
19.05 mm *Maclura*	7.02 a	7.37 a	7.07 a	7.62 ab	7.17 a	7.88 a

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera*. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]DAP = days after planting

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=4).

[w]Irrigation water collected for comparison, not statistically analyzed.

[v]JVC and Maclura are considered separate experiments.

[u]Pine bark control is identical and repeated for comparison for both substrates.

[t]average irrigation pH was 7.50.

[s]Average pH of irrigation water is 7.50.

[ns]Means not significantly different.

Table 4-4 Changes in electrical conductivity (mS/cm) for Eastern Redcedar and Pine Bark Based substrates.

Substrates[z]	16 DAP[y]	43 DAP	71 DAP	106 DAP	127 DAP	154 DAP
Pine Bark	1.16 [v,ns]	0.64 [ns]	0.96 [ns]	1.09 [ns]	0.85 [ns]	0.73 b[x]
4.76 mm JVC	1.10	0.83	0.73	1.26	1.03	0.80 ab
9.53 mm JVC	1.02	0.67	1.00	1.31	0.96	0.81 ab
12.70 mm JVC	1.02	0.75	0.96	1.37	0.99	0.89 a
19.05 mm JVC	1.01	0.64	0.94	1.30	1.13	0.83 ab
Pine Bark	1.16 [ns]	0.64 c	0.96 [ns]	1.09 [ns]	0.85 [ns]	0.73 b
4.76 mm *Maclura*	1.39	0.99 abc	1.36	1.39	1.14	0.90 a
9.53 mm *Maclura*	1.11	1.43 a	1.43	1.22	1.00	0.93 a
12.70 mm *Maclura*	1.05	1.15 ab	1.03	1.11	1.10	0.93 a
19.05 mm *Maclura*	1.08	0.85 bc	1.06	1.28	1.00	0.98 a

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]DAP = days after planting

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests $\alpha=0.05$ (n=4).

[w]Average EC of irrigation water is 0.77.

[ns]Means not significantly different.

Table 4-5 Growth of Blackeyed-Susan (*Rudbeckia fulgida* var. *fulgida* L.) and Maiden Grass (*Miscanthus sinensis* Anderss. 'Graziella')over 106 days in Eastern Redcedar, *Maclura* or Pine Bark substrates.

Substrate[z]	16 DAP[w]	43 DAP	71 DAP	106 DAP	Shoot dry weight[x]
	Blackeyed-Susan growth index in JVC[y]				
Pine Bark	16.62 a[v]	28.29 [ns]	41.67 ab	49.42 a	70.70 a[w]
4.76 mm JVC	15.67 ab	27.17	42.38 a	49.67 a	65.18 ab
9.53 mm JVC	14.44 b	26.83	38.10 bc	44.71 ab	60.16 ab
12.70 mm JVC	15.06 ab	24.71	36.77 c	41.00 b	52.31 b
19.05 mm JVC	16.46 a	26.79	39.81 abc	46.75 ab	54.94 b
	Blackeyed-Susan growth index in *Maclura*				
Pine Bark	16.62 a	28.29 a	41.67 a	49.42 a	70.70 a
4.76 mm *Maclura*	14.53 b	21.88 b	36.92 b	40.79 b	57.11 b
9.53 mm *Maclura*	15.11 ab	22.79 b	34.08 b	37.54 b	53.55 b
12.70 mm *Maclura*	14.92 ab	22.88 b	33.33 b	35.42 b	46.04 b
19.05 mm *Maclura*	14.94 ab	23.42 b	35.15 b	40.54 b	55.71 b
	Maiden Grass growth index in JVC				
Pine Bark	28.38 [ns]	42.08 a	91.29 [ns]	108.50 a	142.65 a
4.76 mm JVC	25.13	25.71 b	81.92	105.46 ab	100.58 b
9.53 mm JVC	28.17	28.88 b	83.79	97.37 bc	85.88 bc
12.70 mm JVC	30.17	31.00 b	81.25	100.83 abc	76.43 c
19.05 mm JVC	28.50	29.92 b	78.92	92.88 c	70.75 c
	Maiden Grass growth index in *Maclura*				
Pine Bark	28.38 [ns]	42.08 a	91.29 a	108.50 a	142.65 a
4.76 mm *Maclura*	27.52	29.46 b	95.71 a	100.54 ab	113.15 b
9.53 mm *Maclura*	31.75	35.37 ab	79.50 b	94.21 b	75.33 dc
12.70 mm *Maclura*	27.17	34.29 ab	76.46 b	81.62 c	68.55 dc
19.05 mm *Maclura*	26.63	41.00 a	77.46 b	93.21 b	89.55 c

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates each contained 80% wood to 20% Sand.

[y]Growth index = [(height + width 1 + width 2)/3].

[x]Shoots were harvested at the container surface and oven dried at 70˚C for 48 h. Weight is measured in grams.

[w]DAP = days after planting.

[v]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[ns]Means not significantly different.

Table 4-6 Leaf greenness of Blackeyed-Susan (*Rudbeckia fulgida* var. *fulgida* L.) grown in Eastern Redcedar, *Maclura*, or pine bark over 106 Days.

Substrate[y]	16 DAP[x]	43 DAP	71 DAP	106 DAP
	Leaf Greenness of Blackeyed-Susan Grown in JVC[z]			
Pine Bark	44.03 a[w]	39.55 [ns]	41.98 [ns]	52.30 [ns]
4.76 mm JVC	40.81 ab	38.41	46.29	51.25
9.53 mm JVC	42.30 a	37.11	46.70	51.03
12.70 mm JVC	37.33 b	36.79	46.33	49.53
19.05 mm JVC	42.14 a	36.71	44.61	52.61
	Leaf Greenness of Blackeyed-Susan Grown in *Maclura*			
Pine Bark	44.03 [ns]	39.55 a	41.98 [ns]	52.30 [ns]
4.76 mm *Maclura*	43.15	32.96 b	42.89	48.19
9.53 mm *Maclura*	43.10	39.01 ab	45.19	54.14
12.70 mm *Maclura*	42.83	40.76 a	41.89	53.65
19.05 mm *Maclura*	44.70	37.38 ab	41.24	54.94

[z]A measure of leaf chlorophyll content using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ).

[y]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[x]DAP = days after planting

[w]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[ns]Means not significantly different.

Table 4-7 Nutrient Content of Maiden Grass (*Miscanthus sinensis* Anderss. 'Graziella') grown in Eastern Redcedar or Pine bark 106 days after planting.

	Tissue Content[y]					
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
Substrates[z]						
Pine Bark	1.23 [ns]	0.24 a[x]	1.48 b	0.54 ab	0.22 a	0.15 a
4.76 mm JVC	1.09	0.16 b	1.55 ab	0.64 ab	0.13 b	0.11 bc
9.53 mm JVC	1.18	0.17 b	1.77 a	0.51 b	0.13 b	0.10 c
12.70 mm JVC	1.18	0.19 ab	1.77 a	0.56 ab	0.14 b	0.11 bc
19.05 mm JVC	1.30	0.17 b	1.54 b	0.69 a	0.12 b	0.12 b
Sufficiency range[v]:	1.61	0.18	0.60	0.53	0.11	0.14
	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)
Substrates						
Pine Bark	4.55 a	191.75 a	211.00 a	14.40 [ns]	64.90 a	255.00 ab
4.76 mm JVC	4.28 ab	168.75 ab	104.85 b	12.20	48.03 ab	291.75 ab
9.53 mm JVC	3.53 ab	156.00 ab	107.13 b	12.75	51.55 ab	229.75 b
12.70 mm JVC	2.75 b	141.25 b	143.38 b	14.50	46.73 ab	346.50 a
19.05 mm JVC	4.25 ab	177.25 ab	97.75 b	13.58	39.83 b	303.50 ab
Sufficiency range:	8	55	209	2	20	46

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera*. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg×kg.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[v]Sufficiency range published by Mills and Jones (1996) based on Miscanthus sinensis 'Zebrinus'.

[ns]Means not significantly different.

Table 4-8 Nutrient Content of Maiden Grass (*Miscanthus sinensis* Anderss. 'Graziella') grown in *Maclura* or Pine bark 106 days after planting.

	Tissue Content[y]					
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
Substrates[z]						
Pine Bark	1.23 a	0.24 a	1.48 [ns]	0.54 ab	0.22 a	0.15 a
4.76 mm *Maclura*	1.01 b	0.14 c	1.65	0.46 b	0.11 c	0.09 c
9.53 mm *Maclura*	1.29 a	0.18 b	1.70	0.66 a	0.14 b	0.14 ab
12.70 mm *Maclura*	1.28 a	0.20 b	1.54	0.65 a	0.11 c	0.12 b
19.05 mm *Maclura*	1.30 a	0.20 b	1.82	0.59 ab	0.13 bc	0.12 b
Sufficiency range[w]:	1.61	0.18	0.60	0.53	0.11	0.14
	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)
Substrates						
Pine Bark	4.55 [ns]	191.75 a	211.00 a	14.40 a	64.90 a	255.00 [ns]
4.76 mm *Maclura*	3.73	127.50 b	45.48 c	10.63 c	35.35 bc	183.00
9.53 mm *Maclura*	4.70	176.75 a	106.50 b	12.30 bc	38.50 bc	221.25
12.70 mm *Maclura*	3.88	182.75 a	109.18 b	12.68 ab	26.93 c	251.00
19.05 mm *Maclura*	4.08	157.50 ab	115.20 b	12.75 ab	47.23 b	194.00
Sufficiency range:	8	55	209	2	20	46

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg×kg.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[w]Sufficiency range published by Mills and Jones (1996) based on Miscanthus sinensis 'Zebrinus'.

[ns]Means not significantly different.

Table 4-9 Growth of Crapemyrtle (*Lagerstroemia indica* (L.) Pers. 'Arapaho') and Spirea Spirea (*Spiraea japonica* L. f. 'Little Princess') over 154 days in Eastern Redcedar, *Maclura*, or Pine bark based substrates.

	Crapemyrtle Growth Index in JVC[y]						Shoot dry	Root dry
Substrate[z]	16 DAP[v]	43 DAP	71 DAP	106 DAP	127 DAP	154 DAP	weight[x]	weight[w]
Pine Bark	27.75 a[u]	35.58 a	50.83 a	53.75 a	49.25 a	47.13 a	42.10 a	12.33 [ns]
4.76 mm JVC	24.65 ab	28.44 b	41.46 b	41.44 b	43.29 b	41.13 b	26.76 b	9.98
9.53 mm JVC	23.10 b	26.67 b	43.08 b	44.83 b	44.25 b	41.87 b	30.64 b	11.78
12.70 mm JVC	22.98 b	27.33 b	40.17 b	44.50 b	42.50 b	42.54 b	24.65 b	12.73
19.05 mm JVC	25.46 ab	29.79 b	40.12 b	42.67 b	40.83 b	40.42 b	24.06 b	10.68
	Crapemyrtle Growth Index in *Maclura*							
Pine Bark	27.75 [ns]	35.58 a	50.83 a	53.75 a	49.25 a	47.13 a	42.10 a	12.33 [ns]
4.76 mm *Maclura*	26.08	31.17 ab	44.63 b	44.96 b	40.83 b	42.29 bc	26.39 b	10.63
9.53 mm *Maclura*	25.98	31.13 ab	46.17 ab	44.29 bc	44.08 b	46.08 ab	35.23 ab	17.78
12.70 mm *Maclura*	25.02	32.04 ab	44.12 b	42.54 bc	41.13 b	40.21 c	25.59 b	14.08
19.05 mm *Maclura*	24.06	28.79 b	41.29 b	41.08 c	42.17 b	41.63 c	27.01 b	13.35
	Spirea Growth Index in JVC							
Pine Bark	8.27 [ns]	18.25 a	25.56 a	31.46 a	29.42 [ns]	30.58 [ns]	26.45 [ns]	13.73 [ns]
4.76 mm JVC	9.94	14.38 c	19.25 c	24.75 c	27.25	27.88	23.91	16.93
9.53 mm JVC	10.31	15.57 bc	21.17 b	26.71 bc	27.25	27.13	19.14	24.10
12.70 mm JVC	10.36	16.25 b	22.23 b	29.00 ab	26.96	29.10	24.86	21.58
19.05 mm JVC	8.63	15.13 bc	20.72 bc	27.46 bc	27.42	28.04	21.14	17.20
	Spirea Growth Index in *Maclura*							
Pine Bark	8.27 [ns]	18.25 a	25.56 a	31.46 a	29.42 a	30.58 a	26.45 a	13.73 ab
4.76 mm *Maclura*	7.88	14.25 ab	17.06 b	20.92 b	19.88 b	19.67 b	11.33 b	19.25 a
9.53 mm *Maclura*	9.71	16.38 b	18.38 b	20.33 bc	17.79 b	17.50 b	8.46 bc	10.98 ab
12.70 mm *Maclura*	9.44	15.94 ab	16.98 b	17.84 c	15.76 b	16.67 b	4.96 c	5.20 b
19.05 mm *Maclura*	9.75	16.63 ab	18.19 b	20.92 b	17.96 b	16.63 b	8.73 bc	13.48 ab

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates each contained 80% wood to 20% Sand.

[y]Growth index = [(height + width 1 + width 2)/3].

[x]Shoots were harvested at the container surface and oven dried at 70°C for 48 h. Weight is measured in grams.

[w]Roots were washed of substrate and oven dried at 70°C for 48 h. Weight is measured in grams.

[v]DAP = days after planting.

[u]Means within column and location followed by the same letter

[ns]Means not significantly different.

Table 4-10 Nutrient Content of Crapemyrtle (*Lagerstroemia indica* (L.) Pers. 'Arapaho') in Eastern Redcedar or Pine bark 154 days after planting.

	Tissue Content[y]					
	N (%)	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**S (%)**
Substrates[z]						
Pine Bark	2.83 [ns]	0.25 b	1.45 b	1.29 [ns]	0.26 a	0.26 [ns]
4.76 mm JVC	3.00	0.35 a	1.50 ab	1.15	0.21 ab	0.26
9.53 mm JVC	3.03	0.34 a	1.56 ab	1.22	0.20 ab	0.26
12.70 mm JVC	3.17	0.27 ab	1.57 ab	1.27	0.19 b	0.27
19.05 mm JVC	3.07	0.27 ab	1.63 a	1.60	0.17 b	0.26
Sufficiency range[v]:	1.56 to 2.06%	0.11 to 0.23%	0.45 to 1.53%	1.12 to 2.10%	0.43 to 0.72%	0.14 to 0.27%
	B (ppm)	**Fe (ppm)**	**Mn (ppm)**	**Cu (ppm)**	**Zn (ppm)**	**Al (ppm)**
Substrates						
Pine Bark	23.23 c	336.50 [ns]	539.80 a	6.43 b	106.43 a	59.25 a
4.76 mm JVC	24.55 c	304.25	138.70 b	10.70 a	66.35 b	27.48 b
9.53 mm JVC	26.45 bc	304.00	295.50 ab	11.53 a	61.33 b	26.73 b
12.70 mm JVC	32.10 ab	325.67	386.00 ab	10.13 a	62.00 b	25.63 b
19.05 mm JVC	28.73 a	380.25	416.30 ab	6.83 b	73.65 b	32.20 b
Sufficiency range:	37 to 65	43 to 109	105 to 708	7 to 25	35 to 194	124 to 190

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg×kg.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[v]Sufficiency range published by Mills and Jones (1996) based on common Crapemyrtle.

[ns]Means not significantly different.

Table 4-11 Nutrient content of Crapemyrtle (*Lagerstroemia indica* (L.) Pers. 'Arapaho') in *Maclura* or Pine bark 154 days after planting.

	Tissue Content[y]					
	N (%)	**P (%)**	**K (%)**	**Ca (%)**	**Mg (%)**	**S (%)**
Substrates[z]						
Pine Bark	2.83 ab	0.25 a	1.45 b	1.29 b	0.26 ns	0.26 ab
4.76 mm *Maclura*	2.86 a	0.22 b	1.83 a	2.09 a	0.23	0.27 a
9.53 mm *Maclura*	2.67 ab	0.19 bc	1.95 a	2.10 a	0.20	0.24 bc
12.70 mm *Maclura*	2.75 ab	0.20 bc	1.94 a	1.91 a	0.22	0.25 abc
19.05 mm *Maclura*	2.51 b	0.18 c	1.82 a	1.74 a	0.21	0.23 c
Sufficiency range[w]:	1.56 to 2.06%	0.11 to 0.23%	0.45 to 1.53%	1.12 to 2.10%	0.43 to 0.72%	0.14 to 0.27%
	B (ppm)	**Fe (ppm)**	**Mn (ppm)**	**Cu (ppm)**	**Zn (ppm)**	**Al (ppm)**
Substrates						
Pine Bark	23.23 c	336.50 c	539.80 ns	6.43 ns	106.43 a	59.25 a
4.76 mm *Maclura*	44.63 a	525.75 ab	304.80	6.65	44.83 b	47.88 ab
9.53 mm *Maclura*	38.70 b	630.75 a	550.80	5.68	35.25 b	47.55 ab
12.70 mm *Maclura*	42.55 ab	526.50 ab	415.80	6.25	32.35 b	38.40 b
19.05 mm *Maclura*	42.38 ab	464.75 b	260.40	5.25	29.73 b	36.83 b
Sufficiency range:	37 to 65	43 to 109	105 to 708	7 to 25	35 to 194	124 to 190

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg×kg.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[w]Sufficiency range published by Mills and Jones (1996) based on common Crapemyrtle.

[ns]Means not significantly different.

Table 4-12 Growth and Caliper of Baldcypress (*Taxodium distichum* L. [Rich.]) over 154 days in Eastern Redcedar, *Maclura*, or Pine bark based substrates.

Substrate[z]	16 DAP[x]	43 DAP	71 DAP	106 DAP	127 DAP	154 DAP	SDW[w]
	Growth Index of Baldcypress in JVC[y]						
Pine Bark	36.52 ns	46.08 a[u]	57.88 ns	78.11 ns	70.79 ns	54.96 ns	68.89 ns
4.76 mm JVC	34.63	41.79 ab	54.00	75.23	68.78	60.67	67.01
9.53 mm JVC	32.90	41.29 ab	57.63	73.77	67.83	61.75	69.24
12.70 mm JVC	33.77	40.50 b	54.04	74.13	66.92	59.75	66.46
19.05 mm JVC	36.27	44.79 ab	58.00	73.60	69.46	63.17	64.53
	Growth Index of Baldcypress in *Maclura*						SDW
Pine Bark	36.52 ns	46.08 a	57.88 ns	78.11 a	70.79 ns	54.96 ns	68.89 a
4.76 mm *Maclura*	33.29	40.46 b	55.13	66.29 b	66.88	55.54	51.76 b
9.53 mm *Maclura*	36.75	44.38 ab	59.92	64.54 b	63.92	57.67	47.21 b
12.70 mm *Maclura*	33.75	41.83 ab	56.33	67.63 b	66.25	59.29	47.25 b
19.05 mm *Maclura*	34.81	43.08 ab	57.96	67.96 b	62.05	56.92	45.33 b
	Caliper of Baldcypress in JVC[t]						RDW[v]
Pine Bark	7.35 ns	8.78 ns	11.27 ns	14.77 a	15.82 a	16.97 ns	80.75 ns
4.76 mm JVC	6.60	7.55	10.33	13.86 ab	14.90 ab	15.43	87.90
9.53 mm JVC	7.10	7.53	10.16	13.30 b	14.28 b	15.08	69.03
12.70 mm JVC	6.66	7.51	9.99	12.73 b	13.87 b	14.60	77.23
19.05 mm JVC	7.23	8.58	10.74	13.67 ab	14.07 b	14.98	96.50
	Caliper of Baldcypress in *Maclura*						RDW
Pine Bark	7.35 ns	8.78 ns	11.27 a	14.77 a	18.82 a	16.97 a	80.75 ns
4.76 mm *Maclura*	7.02	8.32	10.09 b	13.45 b	14.46 b	15.24 b	52.53
9.53 mm *Maclura*	7.50	8.56	10.33 ab	13.45 b	14.07 b	14.5 b	60.85
12.70 mm *Maclura*	6.75	8.01	9.81 b	13.00 b	13.43 b	13.95 b	88.05
19.05 mm *Maclura*	6.97	8.25	9.85 b	12.94 b	13.66 b	14.18 b	79.90

[z]Substrate treatments were: JVC = Juniperus virginiana chips, Pine Bark, or Maclura pomifera. Substrates each contained 80% wood to 20% Sand.

[y]Growth index = [(height + width 1 + width 2)/3].

[x]DAP = days after planting.

[w]Shoot dry weight, was harvested at the container surface and oven dried at 70°C for 48 h. Weight is measured in grams.

[v]Root dry weight, was washed of substrate and oven dried at 70°C for 48 h. Weight is measured in grams.

[u]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[t]Plants were measure six inches from the top of the substrate.

[ns]Means not significantly different.

Table 4-13 Growth and Caliper of Redbud (*Cercis canadensis* L.) over 154 days in Eastern Redcedar, *Maclura*, or Pine bark based substrates.

Substrate[z]	16 DAP[x]	43 DAP	71 DAP	106 DAP	127 DAP	154 DAP	SDW[w]
			Growth Index of Redbud in JVC[y]				
Pine Bark	10.40 a[u]	15.88 a	23.88 a	37.96 [ns]	40.61 [ns]	40.46 [ns]	24.63 [ns]
4.76 mm JVC	8.79 bc	10.85 b	16.29 b	36.88	40.71	46.53	35.73
9.53 mm JVC	9.35 ab	11.56 b	20.42 ab	46.50	37.08	38.13	26.17
12.70 mm JVC	7.75 c	11.52 b	24.75 a	41.67	44.50	55.29	27.24
19.05 mm JVC	9.31 abc	11.96 b	23.17 a	38.92	40.88	39.75	24.34
			Growth Index of Redbud in *Maclura*				SDW
Pine Bark	10.40 [ns]	15.88 a	23.88 [ns]	37.96 [ns]	40.61 [ns]	40.46 [ns]	24.63 b
4.76 mm *Maclura*	9.42	13.38 b	24.75	45.04	48.92	48.71	35.24 ab
9.53 mm *Maclura*	8.42	11.42 b	21.96	38.38	41.00	39.62	26.35 ab
12.70 mm *Maclura*	9.25	13.56 ab	24.58	41.71	44.04	41.58	29.36 ab
19.05 mm *Maclura*	8.44	11.10 b	26.48	44.33	47.57	48.86	42.31 a
			Caliper of Redbud in JVC[t]				
Pine Bark		2.17 a	3.14 a	6.12 [ns]	7.83 [ns]	8.72 [ns]	RDW[v]
4.76 mm JVC		1.68 b	1.70 c	5.08	6.36	7.21	39.70 [ns]
9.53 mm JVC		1.83 b	2.26 bc	6.03	6.88	7.16	37.20
12.70 mm JVC		1.54 b	2.57 abc	6.17	7.18	7.79	28.35
19.05 mm JVC		1.86 ab	2.70 ab	6.00	7.42	8.40	43.40
			Caliper of Redbud in *Maclura*				45.93
Pine Bark		2.17 a	3.14 [ns]	6.12 [ns]	7.83 [ns]	8.72 [ns]	39.70 [ns]
4.76 mm *Maclura*		1.70 b	2.70	6.26	8.78	8.61	32.05
9.53 mm *Maclura*		1.66 b	2.43	5.84	7.47	7.84	31.75
12.70 mm *Maclura*		1.88 ab	2.85	6.26	7.78	8.74	36.55
19.05 mm *Maclura*		1.71 b	2.92	6.82	8.75	9.49	33.57

[z]Substrate treatments were: JVC = Juniperus virginiana chips, Pine Bark, or Maclura pomifera. Substrates each contained 80% wood to 20% Sand.

[y]Growth index = [(height + width 1 + width 2)/3].

[x]DAP = days after planting.

[w]Shoot dry weight, was harvested at the container surface and oven dried at 70˚C for 48 h. Weight is measured in grams.

[v]Root dry weight, was washed of substrate and oven dried at 70˚C for 48 h. Weight is measured in grams.

[u]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[t]Plants were measure six inches from the top of the substrate, caliper for Redbud was not measured at 16 DAP

[ns]Means not significantly different.

Table 4-14 Nutrient content of Redbud (*Cercis canadensis* L.) grown in Eastern Redcedar or Pine bark 154 days after planting.

	Tissue Content[y]					
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
Substrates[z]						
Pine Bark	2.42 [ns]	0.41 a[x]	1.21 [ns]	1.08 [ns]	0.17 a	0.26 [ns]
4.76 mm JVC	1.90	0.26 ab	1.18	1.23	0.13 ab	0.25
9.53 mm JVC	2.55	0.35 a	1.23	1.19	0.10 b	0.23
12.70 mm JVC	2.17	0.20 b	1.16	1.09	0.10 b	0.25
19.05 mm JVC	2.77	0.39 a	1.17	1.26	0.12 b	0.28
Sufficiency range[u]:	1.14 to 2.86%	0.09 to 0.82%	0.76 to 1.43%	0.72 to 2.67%	0.12 to 0.36%	0.16 to 0.22%
	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)
Pine Bark	23.38 [ns]	207.25 [ns]	100.73 [ns]	4.18 b	19.08 [ns]	26.80 [ns]
4.76 mm JVC	22.15	202.00	65.65	6.33 a	16.73	30.80
9.53 mm JVC	22.13	207.00	91.28	7.08 a	15.23	23.43
12.70 mm JVC	16.83	207.25	68.58	6.10 ab	10.78	37.68
19.05 mm JVC	25.10	255.00	74.60	7.40 a	19.43	22.93
Sufficiency range:	10 to 67	20 to 56	7 to 76	2 to 8	7 to 30	11 to 48

[z]Substrate treatments were: JVC = *Juniperus virginiana* chips or pine bark substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg×kg.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[u]Sufficiency range published by Mills and Jones (1996) based on Redbud.

[ns]Means not significantly different.

Table 4-15 Nutrient Content of Redbud (*Cercis canadensis* L.) Grown in *Maclura* or Pine bark 154 days after planting.

	Tissue Content[y]					
	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)
Substrates[z]						
Pine Bark	2.42 ns	0.41 ns	1.21 ns	1.08 ns	0.17 ns	0.26 ns
4.76 mm *Maclura*	2.01	0.29	1.15	1.25	0.14	0.21
9.53 mm *Maclura*	2.74	0.53	1.45	1.54	0.16	0.30
12.70 mm *Maclura*	2.09	0.35	1.29	1.10	0.11	0.19
19.05 mm *Maclura*	2.46	0.27	1.26	1.00	0.12	0.23
Sufficiency range[w]:	1.14 to 2.86%	0.09 to 0.82%	0.76 to 1.43%	0.72 to 2.67%	0.12 to 0.36%	0.16 to 0.22%
	B (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Al (ppm)
Pine Bark	23.38 ab[x]	207.25 ns	100.73 ns	4.18 b	19.08 a	26.80 a
4.76 mm *Maclura*	35.35 ab	213.00	60.18	4.68 ab	11.43 b	22.98 ab
9.53 mm *Maclura*	35.05 a	220.75	101.70	6.13 a	14.65 ab	23.53 a
12.70 mm *Maclura*	23.15 ab	199.25	57.10	5.85 a	11.63 b	16.50 c
19.05 mm *Maclura*	19.65 b	197.50	79.60	5.88 a	13.23 ab	17.50 bc
Sufficiency range:	10 to 67	20 to 56	7 to 76	2 to 8	7 to 30	11 to 48

[z]Substrate treatments were: *Maclura* or Pine bark. Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[y]Tissue analysis performed on the most recently mature leaves. N = nitrogen, P = phosphorous, K = potassium, Ca = calcium, Mg = magnesium, S =sulfur, B = boron, Fe = iron, Mn = manganese, Cu = copper, Zn = zinc, Al = Aluminum, 1ppm = 1mg ×kg.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[w]Sufficiency range published by Mills and Jones (1996) based on Redbud.

[ns]Means not significantly different.

Table 4-16 Leaf greenness of Redbud (*Cercis canadensis* L.) grown in Eastern Redcedar, *Maclura*, or Pine bark over 106 Days

	Leaf Greenness of Redbud in JVC[z]					
Substrate[y]	16 DAP[x]	43 DAP	71 DAP	106 DAP	127 DAP	154 DAP
Pine Bark	33.04 a[w]	34.04 a	33.84 a	35.16 ab	33.82 b	38.94 b
4.76 mm JVC	27.00 c	22.88 c	26.64 b	32.74 b	35.03 b	38.69 b
9.53 mm JVC	26.84 c	24.28 cb	37.71 a	34.94 ab	37.31 ab	40.86 ab
12.70 mm JVC	25.61 c	24.00 c	37.85 a	34.91 ab	36.48 ab	38.51 b
19.05 mm JVC	29.34 b	29.54 ab	36.39 a	38.78 a	40.55 ab	46.68 a
	Leaf Greenness of Redbud in *Maclura*					
Pine Bark	33.04 a	34.04 a	33.84 [ns]	35.16 [ns]	33.81 [ns]	38.94 [ns]
4.76 mm *Maclura*	28.24 b	26.48 b	31.33	33.38	33.16	38.44
9.53 mm *Maclura*	27.31 b	27.29 b	34.64	35.49	34.94	42.05
12.70 mm *Maclura*	27.20 b	28.66 b	33.68	35.20	36.64	40.08
19.05 mm *Maclura*	27.58 b	30.66 ab	35.40	35.17	36.29	41.78

[z]A measure of leaf chlorophyll content using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ).

[x]DAP = days after planting.

[y]Substrate treatments were: JVC = *Juniperus virginiana* chips, Pine Bark, or *Maclura pomifera* . Substrates mixed on v:v basis with each treatment containing 80% wood to 20% Sand.

[w]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=8).

[ns]Means not significantly different.

Figure 4-1 Appearance of Maiden Grass grown in JVC 106 DAP. Differences in Maiden Grass growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm JVC, 9.53 mm JVC, 12.70 mm JVC, and 19.05 mm JVC.

Figure 4-2 Appearance of Maiden Grass grown in *Maclura* 106 DAP. Differences in Maiden Grass growth based on substrates containing different particle sizes of *Maclura* and compared to PB. From left to right: PB, 4.76 mm *Maclura*, 9.53 mm *Maclura*, 12.70 mm *Maclura*, and 19.05 mm *Maclura*.

Figure 4-3 Appearance of Crapemyrtle grown in JVC 154 DAP. Differences in Crapemyrtle growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm JVC, 9.53 mm JVC, 12.70 mm JVC, and 19.05 mm JVC.

Figure 4-4 Appearance of Crapemyrtle grown in *Maclura* 154 DAP. Differences in Crapemyrtle growth based on substrates containing different particle sizes of *Maclura* and compared to PB. From left to right: PB, 4.76 mm *Maclura*, 9.53 mm *Maclura*, 12.70 mm *Maclura*, and 19.05 mm *Maclura*.

Figure 4-5 Appearance of Baldcypress grown in JVC 154 DAP. Differences in Baldcypress growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm JVC, 9.53 mm JVC, 12.70 mm JVC, and 19.05 mm JVC.

Figure 4-6 Appearance of Spirea grown in JVC 154 DAP. Differences in Spirea growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm JVC, 9.53 mm JVC, 12.70 mm JVC, and 19.05 mm JVC.

Figure 4-7 Appearance of Baldcypress grown in *Maclura* 154 DAP. Differences in Baldcypress growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm *Maclura*, 9.53 mm *Maclura*, 12.70 mm *Maclura*, and 19.05 mm *Maclura*.

Figure 4-8 Appearance of Spirea grown in *Maclura* 154 DAP. Differences in Spirea growth based on substrates containing different particle sizes of *Maclura* and compared to PB. From left to right: PB, 4.76 mm *Maclura*, 9.53 mm *Maclura*, 12.70 mm *Maclura*, and 19.05 mm *Maclura*.

Figure 4-9 Appearance of Redbud grown in JVC 154 DAP. Differences in Redbud growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm JVC, 9.53 mm JVC, 12.70 mm JVC, and 19.05 mm JVC.

Figure 4-10 Appearance of Black-eye Susan grown in JVC 106 DAP. Differences in Black-eye Susan growth based on substrates containing different particle sizes of JVC and compared to PB. From left to right: PB, 4.76 mm JVC, 9.53 mm JVC, 12.70 mm JVC, and 19.05 mm JVC.

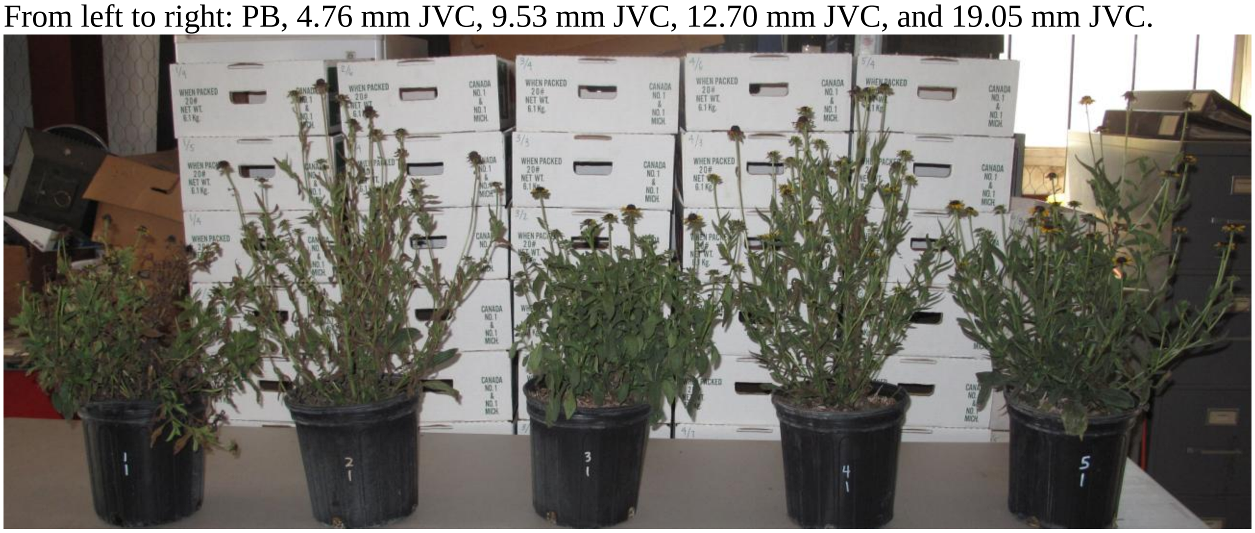

Figure 4-11 Appearance of Redbud grown in *Maclura* 154 DAP. Differences in Redbud growth based on substrates containing different particle sizes of *Maclura* and compared to PB. From left to right: PB, 4.76 mm *Maclura*, 9.53 mm *Maclura*, 12.70 mm *Maclura*, and 19.05 mm *Maclura*.

Figure 4-12 Appearance of Black-eye Susan grown in *Maclura* 106 DAP. Differences in Black-eye Susan growth based on substrates containing different particle sizes of *Maclura* and compared to PB. From left to right: PB, 4.76 mm *Maclura*, 9.53 mm *Maclura*, 12.70 mm *Maclura*, and 19.05 mm.

Chapter 5 - Adventitious Rooting of Herbaceous and Woody Plants in an Eastern Redcedar Substrate

Plant propagation by cuttings is a subject mostly unexplored for alternative substrates. One material commonly used in plant propagation is perlite (Dole and Gibson, 2006). Perlite is an inorganic material made of super-heated (982°C), ground pieces of alumino-silicate rock that resemble small, white spheres. It is used frequently in propagation substrates because it is sterile, provides aeration, retains moisture, is practically neutral, and is lightweight. However, the cost of perlite has increased in response to fuel and production costs (Landis and Morgan, 2009). Additionally, perlite dust is an irritant of the eyes and lungs. So much so that the Occupational Safety and Health Administration recommends that perlite dust be kept under a certain level and that respirators be used when the dust is present (EaglePicher Filtration and Minerals, 2004). Regular exposure to recommended levels and lower of perlite dust is not associated with long term health problems (Cooper and Sargent, 1986; Cooper, 1975; Polatli et al., 2001). However, there is evidence that high levels of exposure does have detrimental, long term effects to lungs (Du et al., 2010; McMichael et al., 1983). Because of the irritation caused by perlite and perlite's increasing cost, an alternative material for propagation of nursery crops would be ideal.

Eastern Redcedar (*Juniperus virginiana* L.) is indigenous to every state in the U.S. east of the 100th meridian, and grows in USDA Hardiness Zones 3 to 9 (Dirr, 2009; Van Haverbeke and Read, 1976). Eastern Redcedar is an increasingly common and invasive species in the Great Plains where it aggressively colonizes grasslands and former fields due to the disruption of its natural control; fire (Bragg, 1976; Bragg and Hulbert, 1976; Blan, 1970; Briggs and Gibson, 1992; Kucera, 1960). Eastern Redcedar is also associated with significant decreases in plant species richness, and changes in animal diversity and abundance on grassland mammals and birds (Briggs et al., 2002; Chapman et al., 2004; Coppedge et al., 2001; Horncastle et al., 2004; Horncastle et al., 2005). Recent research has demonstrated that Eastern Redcedar trees that are chipped and processed (JVC) may be a suitable container substrate component (Murphy, 2011; Starr et al., 2010; Griffin et al., 1998). JVC has been shown to successfully replace perlite in greenhouse production of annuals (Murphy, 2011). Substrates derived from JVC are generally associated with increased airspace, similar to perlite (Murphy, 2011). Use of Eastern Redcedar as a substrate and propagation substrate could provide a local, sustainable, and affordable alternative to perlite while also contributing to a positive effect on local ecosystems after removal.

One concern regarding JVC as a propagation substrate is that Eastern Redcedar is known to have allelopathic properties which hinder seed germination in some native grassland species when its leaves and leaf cover the forest floor (Stipe and Bragg, 1989; Smith, 1986). There is concern that such properties could negatively impact adventitious rooting of stem cuttings. Additionally, Eastern Redcedar is well known for its aromatic oils (Dunford et al., 2007; Eller and Taylor, 2004; Semen and Hiziroglu, 2005). Two of which have antibacterial (cuparene) and antifungal (widdrol) properties and derivatives (Ishikawa et al., 2001; Nuñez et al., 2006). Pervious experiments with Eastern Redcedar substrates have not shown any apparent signs of allelopathic effects on containerized crops (Murphy, 2011; Starr et al., 2010). However, cutting propagation could be an area where such effects could be more evident. Constant exposure to high moisture levels and bottom heat could result in the leaching of alleopathic chemicals and oils out of the JVC into the substrate solution where they can influence root production. These chemicals could result in delayed rooting, root necrosis, and death of the cuttings. Conversely, the antibacterial and anti-fungal properties of the chemicals could enhance rooting of cuttings and survival rates.

The objective of this study was to evaluate the potential of JVC as a propagation substrate for woody and herbaceous cuttings compared to perlite. Cuttings of herbaceous plants are usually rooted in peatmoss-based substrates and in trays with smaller cell volumes than used in this experiment and it is not uncommon for some herbaceous species to be rooted directly in their final containers. Rooting herbaceous crops directly into a substrate containing a high amount of Eastern Redcedar would determine what effect, if any, JVC has on rooting of herbaceous plants. This information then expands on applicableness of Eastern Redcedar as a substrate component for herbaceous crops.

Materials and Methods

Eastern Redcedar chips (JVC) (Queal Enterprises. Pratt, KS) from whole trees harvested in Barber County, KS (logs aged for six months) were ground in a hammer mill (C.S. Bell Co., Tiffin, OH, Model 30HMBL) to pass a 4.76 mm screen. Perlite (Therm-O-Rock East INC, New Eagle, PA) and JVC were mixed to form five substrates consisting of 100% JVC, 75% JVC, 50% JVC, 25% JVC, and 0% JVC (by vol.) with the remaining volume composed of perlite. Substrates were then placed in propagation trays with 36 cells. Each cell had a volume of 220 ml and a depth of 13 cm (IP220. Stuewe and Sons inc. Tangent, OR.). Trays were placed in a greenhouse until cutting were treated and inserted into the substrates.

Chrysanthemum (*Chrysanthemum x morifolium* ’Abelle’) tip cuttings approximately 6 cm in length were treated with 1500 ppm potassium salt of indole-3-butyric acid (K-IBA) dissolved in deionized water on 13 January 2011 and harvested 7 February 2011 or 26 days after planting (DAP). Ivy Gerainum (*Pelargonium peltatum* (L.) L'Hér. ex Aiton ‘Colorcade Cherry

Red') tip cuttings approximately 8 cm in length were directly inserted in to the substrate without K-IBA treatment on 14 January 2011 and harvested 33 DAP. Hibiscus (*Hibiscus rosa-sinensis* L.; unknown cultivar) tip cuttings approximately 10 cm in length were collected from stock plants in the Kansas State University greenhouses, treated with 1,000 ppm K-IBA, inserted into the substrate on 14 January 2011 and harvested 39 DAP. Hardwood cuttings of privet (*Ligustrum x vicaryi* Rehd. 'Golden Vicary') approximately 15 cm in length were collected from plants on the Kansas State University campus and treated with 2,500 ppm K-IBA on Jan 24 and harvested 61 DAP. 'Green Giant' arborvitae (*Thuja* L. x 'Green Giant') tip cuttings approximately 20 cm in length were collected on 17 January 2011 at the John C. Pair Horticultural Research station (Haysville, KS) and treated with 5,000 ppm K-IBA and harvested 54 DAP. For each species, the basal 2 cm of each cutting was dipped in the K-IBA treatment for 5 sec and allowed to air dry for 10 min prior to inserting into the substrate. Three fallow pots were prepared to measure pH and EC with the pour through technique (Wright, 1986) starting on 31 January 2011 and ending on 28 March 2011. Substrate shrinkage was also determined from the fallow pots measuring the change from the container top to the media surface from 31 January 2011 and ending on 28 March 2011.

A mist system operating for 15 seconds every 10 minutes from 8:00 am to 11:00 pm was employed to keep the cuttings moist. On 14 March 2011 the mist schedule was changed to run for 20 seconds every 10 minutes 24 hours a day to ensure adequate substrate moisture. Bottom heat was employed using a heated propagation mat (Redi-Heat™ Propagation Mat. Model RHM2110 Phytotronic Inc. Earth City, MO) which kept substrate temperature constant at 21°C while ambient temperature was maintained at 27°C. On Jan 25 artificial lighting was added from 7:00 am to 11:00 pm (High pressure Sodium Lamps, USD 400, Hummert Int., Earth City, MO).

For statistical analysis each species was treated as a separate experiment. The experimental design was a completely random design (CRD) with five substrate treatments and six cutting subsamples per treatment. Data was analyzed with SAS (Ver. 9.1, SAS Institute,Cary, NC) using the Waller-Duncan K-ratio T-test multiple comparison procedure.

Substrate samples were evaluated for physical properties through porometer analysis (NC State University, Raleigh, NC) to determine water holding capacity, air space, bulk density, total porosity, and plant available water (Fonteno and Bilderback, 1993). Substrates were analyzed for particle size distribution by passing a 100 g air-dried sample through a series of sieves. Sieves were shaken for 3 minutes with a Ro-tap (Ro-tap RX-29, W.S. Tyler, Mentor, OH) sieve shaker (278 oscillations per minute, 159 taps per minute). At termination, cuttings were harvested and data collected, which included percent rooting, root number per rooted cutting (excluding Chrysanthemum and Ivy Geranium) and root dry weight by drying in a forced air oven (The Grieve Co. Model SC-400, Round Lake, IL) at 71°C for 7 days.

Results and Conclusions

Substrate pH in the fallow pots was fairly erratic over the 56 days with no clear pattern emerging. Generally pH was high ranging from 6.19 (100% JVC, 49 DAP) to 7.95 (100% Perlite, 7 DAP) which is higher than the recommended range of 5.5 to 6.5 (Table 5-1) (Hartmann et al., 2002). The water supply used for misting has a pH of 8.13 and may account for the elevated pour through pH. However EC was more consistent. Electrical conductivity was fairly similar for the first 7 DAP. However after 7 DAP until termination, 100% JVC typically had the highest EC (Table 5-1). Total porosity was highest in 100% JVC, 75% JVC, and 50% JVC (Table 5-2). Lowest total porosity was found in 100% perlite. Container capacity was also higher in substrates that contained JVC. Nonetheless all substrate were within the recommended range of 20 to 60% container capacity (Hartmann et al., 2002). The impact of JVC content on airspace was erratic and no clear pattern developed. However, all substrates were within the recommended range of 15 to 40% air space, except 50% JVC. (Hartmann et al., 2002). Bulk density was highest in 100% JVC and decreased with increasing perlite content. This result was expected given the nature of perlite. All substrates had statistically similar shrinkage, which was also expected given the nature of perlite and the decay resistance of JVC.

The high container capacity of JVC compared to perlite is probably due to particle distribution. The coarsest material (2.00 mm and larger) was 0% JVC which made up 73% of all the particle and the least was 100% JVC made up of 21% coarse material with all other substrates falling between these two substrates (Table 5-3). This was reversed for medium sized particles (less than 2.00 mm and larger than 0.5 mm) with 100% JVC having the most particles of this size 60% while 0% JVC was made up of 19% medium particles. All other substrates fell between these two substrates. Lastly the fine particles (less than 0.5 mm) was highest in 50% JVC (24%) and lowest in 75% JVC (7%) with all other substrates falling between the two. Overall, substrates contained mostly particles that were 0.5 mm or larger.

All the cuttings of chrysanthemum and ivy geranium rooted regardless of substrate treatment (Table 5-4). Additionally, substrate JVC content did not influence root dry weight either (chrysanthemum 9.56 g; ivy geranium 3.34 g) (Figs. 5-1 and 5-2). Percent rooting of the woody plants (hibiscus 54%, privet 85%, and ‘Green Giant’ arborvitae 48%) was unaffected by substrate JVC content (Table 5-4). The overall poor rooting of the woody cuttings was surprising and may suggest other unforeseen issues related to the propagation environment. For example ‘Green Giant’ arborvitae is known as a cultivar that roots easily from stem cuttings. Previous work has demonstrated 96% rooting in a 2 perlite : 1 peat (by vol) substrate regardless of hormone treatment (Griffin et al., 1998). Similar to rooting percent, there was no effect of substrate treatment on root dry weight or root number per rooted cutting (Table 5-4; Figs. 5-3 and 5-4). Based on this data perlite and JVC appear interchangeable with no effect of rooting based on the content of JVC or perlite.

The results of this study suggest that JVC can be used similarly to perlite as a substrate component for rooting cuttings. Additionally, despite speculated potential positive or negative effects from allelopathic chemicals in Eastern Redcedar wood there appears to be no effect based on the results of this study. Each species, herbaceous or woody, produced similar results regarding percent rooting, root number per rooted cutting, and root dry weight regardless of substrate JVC or perlite content. The antifungal and antibacterial properties of JVC were not fully explored in this paper and could be a beneficial factor (Ishikawa et al., 2001; Nuñez et al., 2006). It is known that some organic substrates do have the ability to suppress disease. Hardwood bark compost for example can suppress flax fusarium and chrysanthemum wilt as well as Rhizoctonia damping-off (Chef et al. 1983; Nelson and Hoitink, 1983). Another study using coconut coir found that tomato seedling experienced a reduction of incidents of dampening off from 90 to 41% depending of the pathogen species (Candole and Evans, 2004). This property, however, is due in part because of microorganisms associated with coconut coir (Hyder et al., 2009). The ability to ward off pathogens found in Eastern Redcedar could translate to increased resistance to plant die off during propagation in JVC. Therefore, further investigations are warranted.

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Table 5-1. Changes in pH and electrical conductivity (µS/cm) in fallow containers over 56 days.

Substrates[z]	0 DAP[y]	7 DAP	14 DAP	21 DAP	28 DAP	35 DAP	42 DAP	49 DAP	56 DAP
					pH				
100% JVC: 0% Perlite	6.94 ab[x]	7.34 b	7.24 b	7.59 [ns]	7.77	6.39 c	7.50 ab	6.19 c	6.96 [ns]
75% JVC: 25% Perlite	6.82 b	7.30 b	7.39 ab	7.67	7.86	7.08 a	7.12 b	7.28 a	6.96
50% JVC: 50% Perlite	6.93 ab	7.17 b	7.22 b	7.58	7.98	6.73 b	6.57 c	7.23 ab	6.48
25% JVC: 75% Perlite	7.15 ab	7.34 b	7.53 ab	7.20	8.13	6.88 ab	7.49 ab	7.25 ab	6.99
0% JVC: 100% Perlite	7.41 a	7.95 a	7.74 ab	8.00	8.09	6.25 c	7.63 a	6.89 b	7.10
					Electrical Conductivity[v]				
100% JVC: 0% Perlite	564.79 ab	573.20 a	715.20 a	637.67 a	818.30 [ns]	692.57 [ns]	1027.97 a	661.00 a	544.03 a
75% JVC: 25% Perlite	550.13 ab	567.97 a	615.47 b	553.97 b	493.30	715.33	605.43 c	527.80 ab	440.67 b
50% JVC: 50% Perlite	510.70 b	531.70 ab	592.40 b	530.87 b	606.40	687.47	658.50 c	507.40 b	411.40 b
25% JVC: 75% Perlite	521.30 ab	530.33 ab	580.60 b	520.03 b	581.30	697.63	680.50 c	460.83 b	428.60 b
0% JVC: 100% Perlite	574.73 a	509.23 b	657.13 ab	550.47 b	698.00	759.80	845.43 b	474.00 b	456.07 b

[z]Substrate treatments were: Perlite and JVC = *Juniperus virginiana* chips. Substrates mixed on v:v basis.

[y]DAP = days after planting.

[x]Means within column and location followed by the same letter are not significantly different based on Waller-Duncan k ratio t tests α=0.05 (n=3).

[ns]Means not significantly different.

Table 5-2. Physical properties of Eastern Redcedar- and perlite-based substrates.[z]

Substrates[y]	Total porosity[x]	Container capacity[w]	Air space[v]	Bulk density (g/cm^3)	Shrinkage[u] (mm)
		(% Vol)			
100% JVC: 0% Perlite	73.70 a[t]	58.61 a	15.09 ab	0.183 a	0.77 [ns]
75% JVC: 25% Perlite	75.71 a	51.09 a	24.62 a	0.153 b	0.63
50% JVC: 50% Perlite	70.13 a	56.49 a	13.64 b	0.150 bc	0.70
25% JVC: 75% Perlite	68.20 ab	51.82 a	16.38 ab	0.133 cd	0.73
0% JVC: 100% Perlite	60.45 b	36.28 b	24.18 a	0.123 d	0.57
Recommended Ranges[s]		20 to 60%	15% to 40%	0.3-0.8	

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

[y]Substrate treatments were: Perlite and JVC = *Juniperus virginiana* chips. Substrates mixed on v:v basis.

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

[w]Container capacity is (wet wt - oven dry wt) / volume of the sample.

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

[u]Shrinkage is the difference in substrate from the top of the container to the media surface at the beginning of the experiment and at termination.

[t]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on waller-duncan K ratio t tests at α=0.05 (n=3).

[s]Recommended ranges as reported by Hartmann et al., (2002).

[ns]Means not significantly different at P<0.5.

Table 5-3 Percent particle size distribution of Eastern Redcedar- and perlite-based substrates.

U.S. Standard sieve no.	Sieve opening (mm)	Substrate[z] 100% JVC: 0% Perlite	75% JVC: 25% Perlite	50% JVC: 50% Perlite	25% JVC: 75% Perlite	0% JVC: 100% Perlite
1/2"	12.50	0.06 ab[y]	0.59 a	0.03 ab	0.00 b	0.00 b
3/8"	9.50	0.10 [ns]	4.10 [ns]	0.10 [ns]	0.00 [ns]	0.00 [ns]
1/4"	6.30	19.93 a	15.37 b	13.86 b	14.73 b	8.52 c
6	3.65	1.09 c	14.23 b	9.96 bc	14.84 b	34.41 a
8	2.36	6.05 d	11.58 c	11.48 c	16.62 b	21.96 a
10	2.00	9.08 [ns]	11.95 [ns]	7.14 [ns]	7.65 [ns]	11.30 [ns]
14	1.40	19.93 a	15.37 b	13.86 b	14.73 b	8.52 c
18	1.00	13.31 a	11.35 b	9.98 b	8.71 b	3.78 c
35	0.50	15.22 a	8.74 bc	12.89 ab	10.32 abc	4.77 c
60	0.25	7.95 a	3.36 b	8.30 a	5.28 ab	2.46 b
140	0.11	5.05 ab	2.14 b	7.96 a	4.58 ab	2.61 b
270	0.05	1.71 ab	0.89 b	3.47 a	2.06 ab	1.38 b
pan	0.00	0.51 a	0.34 a	0.97 a	0.47 a	0.31 a
	Coarse [x]	20.79 c	54.84 ab	33.67 bc	46.52 b	73.04 a
	Medium	60.27 a	37.95 b	42.41 b	39.12 b	19.32 c
	Fine	18.95 ab	7.21 c	23.91 a	14.37 abc	7.64 bc

[z]Substrate treatments were: Perlite and JVC = Juniperus virginiana chips. Substrates mixed on v:v basis.

[y]Percent weight of sample collected on each screen, means within row followed by the same letter are not significantly different based on waller-duncan K ratio t tests at α=0.05 (n=3).

[x]Coarse = 2.00 mm and greater; Medium = less than 2.00 and greater than 0.5 mm; fine = Less than 0.5 mm.

[ns]Means not significantly different at P<0.5.

Table 5-4. The effect of Eastern Redcedar and perlite on percent rooting, root number, and root dry weight on Chrysanthemum (*Chrysanthemum x morifolium* ’Abelle’), Ivy Gerainum (*Pelargonium peltatum* (L.) L'Hér. ex Aiton ‘Colorcade Cherry Red’), Hibiscus (*Hibiscus rosa-sinensis* L.; unknown cultivar), Privet (*Ligustrum x vicaryi* Rehd. ‘Golden Vicary’), and ‘Green Giant’ arborvitae (*Thuja* L. x ‘Green Giant’).

	Ivy Geranium		Chrysanthemum		Privet			Hibiscus			'Green Giant' arborvitae		
JVC : Perlite[z]	% Rooted	RDW[y]	% Rooted	RDW	% Rooted	Root no.[x]	RDW	% Rooted	Root no.	RDW	% Rooted	Root no.	RDW
100:0	100 [ns]	3.33 [ns]	100 [ns]	10.83 [ns]	86.67 [ns]	7.75 [ns]	4.67 [ns]	60.00 [ns]	3.10 [ns]	2.40 [ns]	60.00 [ns]	7.70 [ns]	9.72 [ns]
75:25	100	2.80	100	9.17	86.11	4.92	2.58	61.11	4.47	3.06	41.67	3.92	7.39
50:50	100	3.89	100	8.06	77.78	4.36	4.22	52.78	4.23	3.76	41.67	3.42	9.17
25:75	100	3.61	100	10.28	88.89	5.11	3.36	41.67	1.60	2.20	44.44	4.53	10.53
0:100	100	3.06	100	9.45	86.11	4.89	5.11	55.56	1.77	2.26	52.78	4.67	7.43
Average:	100	3.34	100	9.56	85.11	5.41	3.99	54.22	3.03	2.74	48.11	4.85	8.85

[z]Substrate treatments were: Perlite and JVC = Juniperus virginiana chips. Substrates mixed on v:v basis.

[y]RDW = Root dry weight (mg).

[x]The average number of roots per cutting.

[ns]Means not significantly different at $P<0.5$.

Figure 5-1 Rooted cuttings of Ivy Geranium rooted in JVC substrates 33 DAP. Ivy Geranium rooted in five substrates containing different ratios of JVC:Perlite. From left to right 100% JVC, 75% JVC, 50% JVC, 25% JVC, 0% JVC.

Figure 5-2 Rooted cuttings of Chrysanthemum in JVC substrates 26 DAP. Chrysanthemum rooted in five substrates containing different ratios of JVC:Perlite. From left to right 100% JVC, 75% JVC, 50% JVC, 25% JVC, 0% JVC.

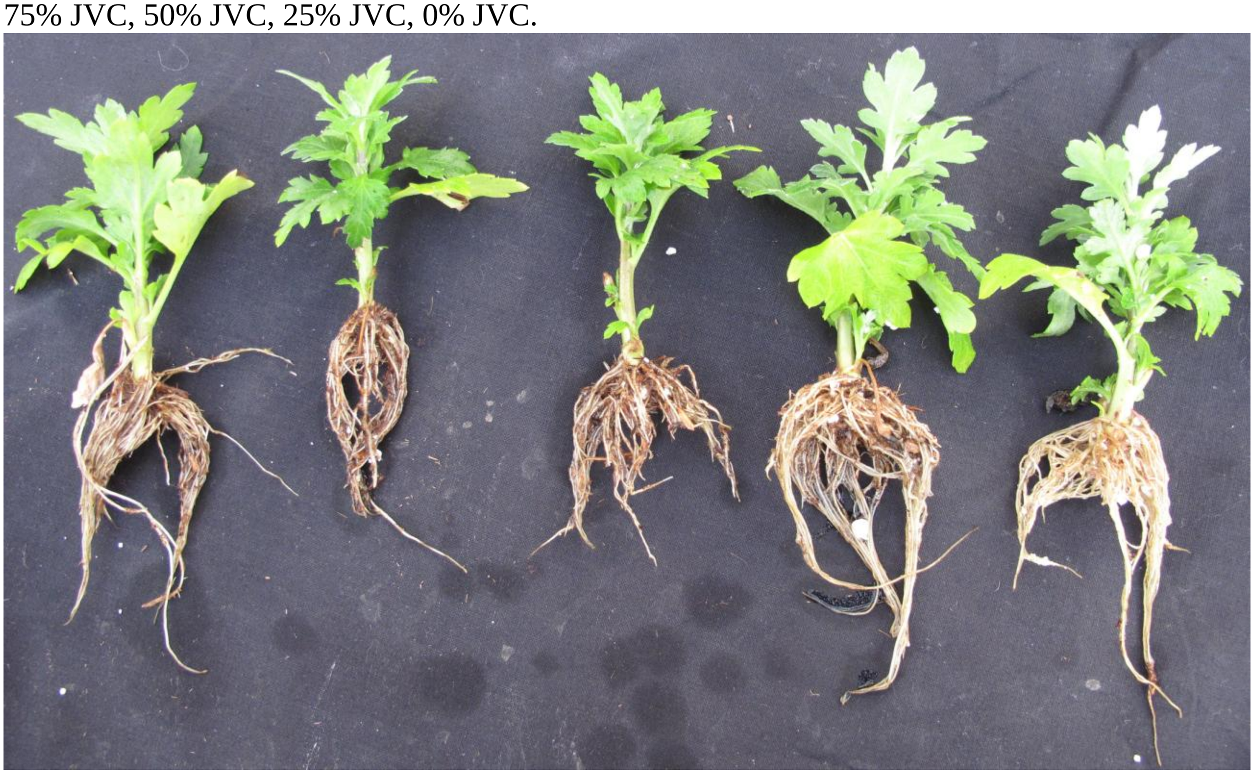

Figure 5-3 Rooted cuttings of Hibiscus in JVC substrates 39 DAP. Hibiscus rooted in five substrates containing different ratios of JVC:Perlite. From left to right 100% JVC, 75% JVC, 50% JVC, 25% JVC, 0% JVC.

Figure 5-4 Rooted cuttings of Privet in JVC substrates 61 DAP. Privet rooted in five substrates containing different ratios of JVC:Perlite. From left to right 100% JVC, 75% JVC, 50% JVC, 25% JVC, 0% JVC.

Chapter 6 - Conclusion

The primary objective of this work was to explore the utilization of Eastern Redcedar (*Juniperus virginiana* L.) as a substrate for container-grown plant production. This project is part of a larger effort to find alternative substrates for both nursery and greenhouse production across the U.S. These alternative products for container-grown plant production need to be locally available, sustainable, economical, versatile enough for use as a substrate with a broad range of species, and adaptable to pre-existing technology and machinery. Eastern Redcedar could fulfill many of these requirements and was the subject of this thesis. Additionally, Hedge-Apple (*Maclura pomifera* Raf.) was also evaluated as a substrate in one nursery production experiment and may also serve as a viable alternative to pine bark.

Generally, it was demonstrated that Eastern Redcedar chips (JVC) used in substrates resulted in increased air space and decreased water holding capacity. In the first nursery crop experiment (Chapter 2) 19.05 mm JVC was used to grow four woody plants. Eastern Redcedar chips where either used as the entire substrate material or combined with pine bark (PB) in a 5:75, 10:70, 20:60, 40:40 (by volume) JVC to PB mixes, and compared to a PB control treatment; all treatments contained 20% Sand. Each substrate type either had a low or high fertilizer treatment. Higher fertilizer rates did result in larger plants, however there were general trends within each fertilizer treatment caused by the JVC treatments. In most cases both a low and high fertilizer treatment followed similar trends, only differing in total plant size. This trend was that plants performed similarly up to 20% JVC then decreased at 40% and further at 80%. This is most likely due to physical properties, as 80% JVC has a high air space and a low container capacity compared to all other substrates tested with 40% JVC. Eastern Redcedar can successfully replace up to 20% of PB in container substrates for the species tested. Species tolerant of drier conditions could possibly thrive in up to 40% JVC. However JVC ground to 19.05 mm, based on this data, cannot be a complete replacement for PB. In spite of this, plants grown in all levels of JVC appeared marketable. Use of high levels of JVC, 40 to 80%, could decrease production costs which might offset the decrease in growth. Other studies on wood-based artificial substrates showed that decreasing the materials particle size increased water holding capacity and plant growth when compared to larger particle sizes (Boyer et al, 2008; Jackson et al, 2008). Alteration of JVC to include more fine particles could help to increase water-holding capacity.

The following year another nursery experiment was conducted examining a variety of JVC sizes (Chapter 4.). Eastern Redcedar chips were ground to 4.76 mm, 9.53 mm, 12.70 mm, and 19.05 mm and combined with 20% Sand, and compared to a PB control. Hedge-Apple (*Maclura*) was also tested with the same particle sizes and control. The results showed that PB, for many of the species tested, out-performed both substrates regardless of how coarsely or finely ground the wood material was. In many cases growth within the wood-based substrates was similar to each other regardless of particle size. However for both JVC and *Maclura* physical properties appear to be more in line with recommended ranges at lower particle sizes (Yeager et al., 2007). Surprisingly, *Maclura* substrates had more shrinkage than pine bark and JVC despite being known as decay resistant. However, this shrinkage was at most 2.30 mm in 4.76 mm *Maclura* substrate. This small amount of shrinkage over 154 days probably would not adversely affect plant production. Additionally, both JVC and *Maclura* in many cases could be interchangeable, since both substrates showing fairly analogous growth at each date. While many plants showed decreased growth compared to PB, both 4.63 and 9.53 mm JVC and *Maclura* showed fair amount of growth, and very often 12.70 and 19.05 had equal or greater growth than the smaller particle sizes.

The second experiment evaluated JVC as a replacement for peat in a standard greenhouse container substrate mix (Chapter 3.). Eastern Redcedar chips and peat were combined to make four different substrates: 0:75, 25:50, 50:50, and 75:25 by volume. Each of these substrates contained an additional 25% perlite, further there was a fifth treatment that consisted of 100% (JVC). This experiment demonstrated that 4.76 mm JVC is a poor substitute for peat in a traditional greenhouse substrate mix. Each plant species suffered decreased growth, dry weight, and flower numbers as JVC content increased. This was most likely due to the decreased container capacity associated with increasing JVC content in addition to the observation that the water held in containers usually sat in the bottom half of containers with higher percentages of JVC. This meant that liner establishment was slowed as roots struggled to survive the dry upper parts of the container before getting to the section of the container that held water. However plants grown in up to 25% JVC, while still showing decreased growth, still were in marketable condition. Other studies using Eastern Redcedar do show positive results with plants grown in 25:75 to 50:50 by volume, 6.35 mm JVC to Peatmoss (Murphy, 2011). In that study JVC was utilized more as a perlite substitute rather than a peat substitute. Perlite, like JVC, is associated with increased airspace. As such, for the final experiment (Chapter 5.) JVC was utilized as a perlite replacement in the media used to propagate both herbaceous and woody cuttings. In this experiment both perlite and JVC were used alone or combined in rations of 25:75, 50:50, and 25:75 JVC to perlite. In this experiment both perlite and JVC were used alone or combined in rations of 75:25, 50:50, and 25:75 JVC to perlite. The plants were grown in greenhouse conditions with overhead lighting and bottom heat. All species were unaffected by any substrate growing equally well in the presence of either material. The percent of cuttings that produced roots based on substrate did not differ statistically for any species represented in this study. The herbaceous plants both rooted easily with 100% rooting. Rooting was high in Privet (*Ligustrum x vicaryi* Rehd. 'Golden Vicary'), and decreased in Hibiscus (*Hibiscus rosa-sinensis* L.; unknown cultivar) and 'Green Giant' arborvitae (*Thuja* L. x 'Green Giant').

These four studies show that JVC can successfully be utilized in a variety of applications within the container-grown plant industry. Eastern Redcedar chips can successfully be used as a nursery substrate replacing 20% PB for coarser JVC and a 100% with finer JVC. While use of JVC does result in decreased growth compared to PB, JVC still produces viable, saleable plants. While not successful in being a replacement for peat, JVC can be used as a component of a greenhouse substrate to reduce input costs. Additionally, JVC can be used for the production of plant cuttings without any significant differences between it and perlite. Use of JVC could be less expensive than using PB as a substrate, resulting in larger profits for plant producers. Eastern Redcedar meets all the requirements of being locally available, sustainable, economical, versatile enough for use with a broad range of species, and adaptable to pre-existing technology and machinery. These studies show that JVC is a viable resource for containerized plant production in regions where large numbers of Eastern Redcedar grow. Further experimentation on watering techniques, combinations of finer JVC particle size and PB for nursery production, differing combinations of JVC and peat for greenhouse production, testing composted and aged JVC, and if JVC could provide protection from soil borne pathogens could help refine JVC use to be a better substrate component. However, at this point, JVC can be used as an alternative substrate to supplement pine bark supplies. While it does show decreases in growth compared to PB, most plants grown in JVC were still marketable and in many cases were visually indistinguishable from PB. Even using JVC as a small part of a substrate mix could help decrease production costs and help to increase profits for nursery growers. Further JVC is versatile, and can be used as a component in addition to peat, and as a propagation material. Eastern Redcedar could be a new material for nursery and greenhouse production operations throughout much of the United States. It is a sustainable substrate that’s harvest can be beneficial to the environment and the wallets of growers.

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