LANDSCAPE ESTABLISHMENT AND IRRIGATION MANAGEMENT OF ORNAMENTAL PLANTS GROWN IN EASTERN REDCEDAR SUBSTRATE

by

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Abstract

Pine bark (PB) has been the principal component of nursery crop substrates in the United States for more than 60 years. Substrate material used for the purpose of growing ornamental plants in the Great Plains is generally shipped a great distance, primarily from the Southeastern U.S., due to a lack of pine plantations in this region. Eastern redcedar (*Juniperus virginiana* L.; ERC), an aggressively weedy tree species, has been identified as a possible alternative to PB for nursery substrates. The objective of this thesis was to evaluate the establishment of *Miscanthus sinensis* N.J. 'Little Kitten' (dwarf maiden grass), *Rosa* (L.) 'Radtkopink' (Knockout® rose), *Ilex glabra* (L.) A. Gray 'Compacta' (holly), *Ulmus parvifolia* Jacq. 'Emer II' (Allee® lacebark elm), *Sedum telphium* L. 'Autumn Joy' (sedum), *Hosta* Tratt. 'Sum and Substance' (hosta), and *Hemerocallis* L. 'Charles Johnston' (daylily) in three substrate mixes. These substrate mixes consisted of 80% PB: 20% sand, 80% ERC: 20% sand, and 40% PB: 40% ERC: 20% sand. At the end of the production phase differences in growth were observed in maiden grass, holly, lacebark elm, and sedum. At the end of the landscape establishment phase, no differences in growth were observed in any species except holly and hosta.

To attempt to overcome the sub-optimal physical properties of ERC (high air space and low container capacity), cyclic irrigation was used to evaluate growth of *Sedum spectabile* Boreau 'Autumn Fire' (sedum), *Rudbeckia fulgida* Aiton 'Goldstrum' (black-eyed susan), and *Hibiscus moscheutos* L. 'Luna White' (hibiscus) in the same 3 substrates. The objective of this study was to evaluate the effect of irrigation frequency (1x, 2x, 3x, or 6x per day) and substrate ERC content on plant growth. Sedum had the greatest growth index (GI) shoot dry weight in PB and when irrigated 1x and 2x per day had the greatest root dry weight regardless of substrate. Irrigation frequency had no significant difference for GI and shoot dry weight Black-eyed susan had the greatest GI and shoot dry weight when grown in PB. Irrigation frequency only had an impact on shoot dry weight of black-eyed susan; plants irrigated 1x, 2x, and 3x per day had the greatest growth. Hibiscus had greatest growth in PB: ERC mix. Irrigation frequency had no impact on growth of hibiscus. Cyclic irrigation does not overcome low water holding capacities in these three species. Overall, ERC can be used as a partial replacement to PB (up to 50%). However, further research evaluating effects of different fertility regimes on ERC substrate is warranted.

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Dedication

I would like to dedicate this thesis to my family and especially to my grandparents Rex and Anna Mae Carmichael. Not a day goes by that I don’t think of the both of you and I wish you were here to see everything that I have and will accomplish. I know that you are looking down on me each and everyday.

Chapter 1 - Introduction and Literature Review

Background of Horticultural Substrates

Since the 1940's container substrates have been an important aspect of the ornamental plant production industry. Before the 1940's substrates were composed of a loam soil, sharp (clean) sand, and sphagnum peat moss (Davidson et al., 2000). Problems with these mixtures included lack of uniformity, small pore space, and variability of plant performance. In the late 1940's and early 1950's the University of California, Los Angeles developed the "U.C. System" for production container-grown plants (Chandler et al., 1957). These substrate blends were composed primarily of sand and sphagnum peat moss. In these blends, redwood shavings, sawdust or rice hulls could be substituted for part or all of the sphagnum peat moss (Chandler et al., 1957). In the early 1970's, pine bark (PB) began to be used as a potting material and has continued to be the primary component of nursery substrates since (Lu et al., 2006). However, Brown and Pokorny (1975) stated that although PB use in container substrates was increasing, but more research was needed to fully understand the physical properties of the material.

Since 1975, PB has become the industry standard for growing plants in a container production system and demand is high throughout the country. In 1980, Penick noted that by 2020, PB use in horticultural industries would become a desired resource and thus demand for PB would double. Penick was also concerned with high PB shipping costs and the industry, as a whole should begin buying local products to help with shipping costs. Recently PB has become increasingly difficult to obtain due to increases in demand for alternative uses, (such as fuel) and due to reduced domestic timber production (Lu et al., 2006; Murphy et al., 2010).

A nursery production problem in the Great Plains region of the U.S. is that all PB used to grow nursery crops is shipped from the Southeastern United States (U.S.), resulting in high import costs (Altland, 2010). The U.S. Department of Agriculture Forestry Service has projected that consumer use of forestry products will increase 40% by 2050 (Haynes, 2003). With the combined increases in shipping costs, competition with the biofuel industry, and the projected increase in consumption of forestry products, research has been and is currently being conducted to find alternatives to PB for use in nursery crop production.

"Good" substrates need to have "ideal" physical and chemical properties for plant growth (Yeager et al., 2007). Substrate physical properties of a substrate include total porosity (TP), air space (AS), container capacity (CC), and bulk density (BD). Total porosity refers to the volume of total pore space. The recommended range for TP is 50-85% (Yeager et al., 2007). Air space is the amount of air-filled pores, also known as macropores, after free water has drained following an irrigation event. The recommended AS range for a substrate is 10-30%. Container capacity, also known as water holding capacity, is the maximum amount of water a substrate can hold after free water has drained following an irrigation event. The recommended range of CC is 45-65%. Bulk density (BD) is the weight per unit volume of the substrate particles. The recommended BD range is 0.19-0.24 g/cc (12.0-15.0 lbs./ ft^3.). Bulk density is important because it affects production (too light= blow over in wind) and shipping (heavy containers cost more to ship). Electrical conductivity (EC) and pH are two chemical properties that are monitored in nursery substrates. Electrical conductivity (EC) refers to the level of salts (fertilizer) within the substrate solution. If EC levels are above the recommended range it could indicate over application of fertilizer and/or insufficient irrigation of plants. Low EC levels could indicate over-irrigation and extreme leaching of nutrients. The recommended EC range is 0.5 to 1.0 mmhos/cm (dS/m). The pH of a substrate can influence nutrient availability for plant uptake. The recommended pH range is 4.5 to 6.5.

Previous substrate studies have evaluated PB availability issues from two perspectives. Research has evaluated either complete PB substrate replacements or possible amendments for use in conjunction with PB. Amendments are intended to improve physical properties of substrates and are used in smaller amounts than complete replacement materials (Davis and Wilson, 2005). As a substrate component, amendments generally make up less than 30% of the substrate (varies with material used). A few alternative amendments that have been evaluated in the last 60 years are: parboiled rice hulls (40%; Gómez and Robbins, 2011), recycled waste/household garbage (20-30%; Kahtz and Gawel, 2003; Croxton et al., 2004), paper sludge (15-30%; Tripepi et al., 1996; Chong and Cline, 1993) and ground automobile tires (20 %, high zinc content; Bowman et al., 1994; Johnson and Tatum, 1996, and Newman et al., 1997).

Wood-based substrates were once thought to tie-up nitrogen and suffer from substrate shrink/swell due to decomposition, have now been proven to be viable substrate components. Wood-based substrates can consist of wood obtained from residuals left behind by the forest harvest process or from using tree species that are considered “low-value” and unusable by processing industries.

For the purpose of this literature review, only substrate replacements to PB will be discussed since this is the greatest need in the Great Plains region. Some of the most viable alternatives currently being evaluated on a national level include: pine tree substrate, *WholeTree*, and clean chip residual. Alternatives being evaluated on a regional level (Midwest and Great Plains) include: Hedge-Apple [*Maclura pomifera* (Raf.) C.K. Schneid.], switchgrass (*Panicum virgatum* L.), corn stover, and Eastern redcedar (*Juniperus virginiana*).

Pine Tree Substrate and WholeTree

In 1986 Laiche and Nash were the first to evaluate pine tree chips (PTC) as a substrate component for nursery production. Pine tree chips are a product normally used by the lumber industry to manufacture hardboard. Pine tree chips consist of the needles, twigs, bark and wood. Laiche and Nash (1986) compared PTC and PB when growing *Rhododendron indicum* (L.) Sweet 'President Clay' (azalea), *Ligustrum sinense* Lour. 'Variegata' (privot) and *Ilex crenata* Thunb. 'Compacta' (holly) in a nursery setting. At the conclusion of the study, the authors found that substrates containing large amounts of wood could be used as a container substrate, though plant performance in PTC was not comparable to plant growth in PB. With the high wood content in PTC substrate, the authors noted there was a greater potential for nutrient leaching during irrigation (Laiche and Nash, 1986). Microorganisms (that help decompose the wood) could also compete with the plant for available nitrogen in the substrate, leading to potential chlorosis and reduced plant growth (Laiche and Nash, 1986).

Nineteen years later, researchers at Virginia Polytechnic Institute and State University (Virginia Tech) continued evaluating PTC (except pine logs used by Virginia Tech did not include limbs). Chipped pine logs or pine tree substrate (PTS) were first evaluated at Virginia Tech by Wright and Browder (2005). At this time the substrate was referred to as chipped pine logs (CPL). Wright and Browder (2005) used loblolly pine

(*Pinus taeda* L.) logs (including bark) and ground them into wood chips. These wood chips were then processed further to produce appropriate particle sizes for container substrates. In this study, *Ilex crenata* Thunb. 'Chesapeake' (Japanese holly), *Rhododendron obtusum* (Lindl.) Planch. 'Karen' (azalea), and *Tagetes erecta* L.'Inca Gold' (marigold) were planted into containers containing either 100% PB, 100% CPL, or 75% CPL: 25% PB and then grown in a greenhouse. These three substrates were analyzed for chemical and physical properties. The authors reported that overall visual quality of plants produced in CPL was acceptable and visual observation of the roots of *Tagetes* and *Rhododendron* roots grown in CPL were comparable to those grown in PB. They concluded that growing plants in a substrate containing CPL was possible for both nursery and greenhouse plants. Future research on irrigation and fertilizer practices was recommended (Wright R.D. and J.F. Browder, 2005; Jackson et al., 2008; Wright et al., 2008; and Wright et al., 2009).

Advantages of using PTS as a container substrate are: 1) production of PTS can be done where abundant growth of pine trees occur and in close proximity to nursery crop growers and substrate companies reducing transportation costs; 2) PTS does not need to be composted or aged, allowing it to be used immediately after the milling process; 3) and container capacity (CC) and air space (AS) can be altered during the processing phase by reducing particle size to meet the requirements of physical properties either by the plant or the grower (Jackson et al., 2010). All of these advantages could make PTS a potential substitute for PB since it is becoming more expensive to ship across the United States (Lu et al., 2006).

Further PTS research was conducted by Fain et al., (2008a), with a type of PTS known as *WholeTree* (WT) substrate. Unlike other wood fiber products that use bark and wood, WT uses the entire above ground portion of the tree (wood, bark, needles, cones, etc.; Fain et al., 2008a, Wright and Browder, 2005). *WholeTree* is harvested from loblolly pine on plantations that are at the thinning stage (~8-12 years old; Fain et al., 2008c). Pine logs are chipped using an industrial tree chipper and then are processed further using a hammer mill. *WholeTree* differs from PTS in that PTS is chipped after the pine log has been de-limbed (Fain et al., 2008a; Gaches et al., 2010; and Marble et al., 2010). Gaches (2010) noted that PTS and WT could be used interchangeably as plants grown in both substrates grew similarly to one another.

Fain et al., (2008a) planted annual vinca 'Little Blanche' [*Catharanthus roseus* (L.) G. Don] and 'Raspberry Red Cooler' [*C. roseus* (L.) G. Don] into three WT substrates and one substrate containing 100% PB. One-gallon (3.8 L) containers were filled with four substrates and then received one liner of annual vinca. It was reported that WT had double the AS and a 14% decline in CC compared to PB on average. With WT having a higher AS and a lower CC, the substrate appeared to not have an effect on the vinca. The authors reported WT substrate pH was higher than the recommended range for vinca, but no visual nutrient deficiencies were observed. Electrical conductivity (EC) was reported to be in the recommended range among all four substrates. Similar results were seen in two greenhouse studies conducted with WT, with all studies indicating WT had the potential to be used as an alternative substrate for horticultural crops (Fain et al., 2008a, Fain et al., 2008b, Fain et al., 2008c)

A greenhouse study by Gaches et al. (2010), compared WT to CPL. As noted above CPL is similar to PTS in that both are composed of pine logs that have been delimbed prior to chipping and then being ground for use as a horticultural substrate. Two experiments were conducted, both using vinca [*C. roseus* (L.) G. Don 'Grape Cooler'] and impatiens (*Impatiens walleriana* Hook. f. 'Dazzler Apricot'). *WholeTree* and CPL were mixed 1:1 (by vol.) with peat moss before planting vinca and impatiens into 0.95 L (1 qt) containers. Results of experiment #1 reported that substrate pH, EC, shrinkage, plant growth index, root rating, and bloom count all showed similarities. The authors noted that vinca grown in CPL plus peat moss showed a 6.5% greater shoot dry weight as compared to vinca grown in WT plus peat moss. In experiment #2, impatiens exhibited higher bloom count and root rating when grown in WT plus peat moss than bloom count and root rating of impatiens grown in CPL plus peat moss. At the conclusion of this study, the authors support previous research conducted by Fain et al., (2008a, 2008b, 2008c) and by Jackson et al., (2008, and 2010) and Wright and Browder (2005, 2008, 2009) in that substrates composed of whole pine trees can be used in ornamental plant production. Studies using PTS, CPL, and WT have been conducted primarily in greenhouses using annual bedding plants as experimental species. Only a few studies using WT have been conducted with woody ornamental crops in a nursery setting.

Clean Chip Residual

Harvesting pine trees by using a mobile in-field chipping process is a newer trend in forest harvesting. The process produces "clean chips" or pulp, which are used for making paper products (Boyer et al., 2008a, and 2012a). Clean Chip Residual (CCR) is a forest by-product consisting of about 50% wood, 40% bark and 10% needles (Boyer et al., 2012b). Which can be used as boiler fuel, or more often, spread back across the recently harvested area (Boyer et al., 2008a, and 2012a). Clean Chip Residual substrates could save nursery growers money, due to the amount currently left behind and for a steady supply of material caused by the in-field processing (Boyer et al., 2012b).

A study by Boyer et al., (2008b) evaluated the growth of perennial nursery crops grown in CCR. Two screen sizes of CCR were used alone or mixed with peat moss and were then compared to a standard mix of PB or PB mixed with peat moss. Nine perennial crops consisting of: *Buddleja davidii* Franch.'Pink Delight' (butterfly bush), *Gaura lindheimeri* Engelm. & A. Gray 'Siskiyou Pink' (beeblossom), *Coreopsis grandiflora* Hogg ex Sweet 'Early Sunrise' (tickseed), *Coreopsis rosea* Nutt. 'Sweet Dreams' (tickseed), *Verbena canadensis* (L.) Britton 'Homestead Purple' (verbena), *Scabiosa columbaria* L. 'Butterfly Blue' (dove pincushions), *Dianthus gratianopolitanus* Vill. 'Firewitch' (dianthus), *Rosmarinus officinalis* L. 'Irene' (rosemary) and *Salvia guaranitica* A. St.-Hil. Ex Benth. 'Black and Blue' (sage) were transplanted into 3.8L (1 gal) containers (Boyer et al., 2008b). Overall, plants grown in CCR had less growth than plants grown in the other treatments, however, plants grown in CCR had caught up by the end of the production cycle. The authors noted that reduced growth could be the result of nitrogen (N) tie-up in the early stages of production.

A similar study using four different screen sizes of CCR alone was compared with PB (Boyer et al., 2009). Growth of five woody ornamentals *Loropetalum chinensis* var. *rubrum* Yieh (Chinese fringe flower), *Buddleja davidii* Franch. 'Black Knight' (butterfly bush), *Lagerstroemia indica* L. 'Hopi' (crapemertle), *Lagerstroemia* x *fauriei* L. 'Natchez' (crapemertle), and *Rhododendron indicum* (L.) Sweet 'Mrs. G.G. Gerbing' (azalea) was evaluated. These liners were planted into 3.8 L (1 gal) nursery containers. Plants grown in CCR were comparable to plants grown in PB; with the plants grown in smaller particle size CCR having greater root growth.

Boyer et al., (2008b) noted that low plant growth of plants grown CCR could be due to N tie-up, which was supported by Wright et al., (2008) showing that wood-based substrates would need increased N to produce plants comparable to those grown in a traditional substrate. Boyer et al., (2012a) studied N-immobilization of CCR when compared to PB and peat moss. Clean Chip Residual had greater microbial respiration when compared to peat moss regardless of the N rate, but was comparable to PB. At the conclusion of the N-immobilization study the authors noted that N-immobilization in CCR was similar to PB.

Douglas-Fir and Biofuel Crops

Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco] bark is commonly used in the Pacific Northwest as a container substrate component (Svenson et al., 2001; Buamscha et al., 2007; Owen and Altland, 2008; and Gabriel et al., 2009). Douglas fir bark used in container substrates is either fresh bark or aged bark (aged for seven months before use) (Buamscha et al., 2007). Buamscha et al., (2007) studied fresh and aged douglas-fir bark substrate influence on container-grown plants. At the conclusion of the study, aged douglas-fir bark lowered pH and AS while increasing CC. They noted that the consistency of the chemical properties of douglas-fir bark depended more on physical properties than bark aging with a coarse particle size being more consistent.

Because of the need to ship PB from Southeastern U.S. to the Midwest and Great Plains due to the lack of local pine plantations, alternatives to PB in these regions have been explored (Altland, 2010; Altland and Krause, 2009). With abundant farmland, biofuel crops have been studied as alternatives (Altland, 2010). Crops classified as biofuel are: switchgrass (*Panicum virgatum* L.), willow (*Salix* spp. L.), corn (*Zea mays* L.) stover, and giant miscanthus (*Miscanthus* x *giganteus* J.M. Greef & Deuter ex Hodkinson & Renvoize). These crops are classified as biofuels because of the large amount of biomass they generate (Altland, 2010). Altland and Krause (2009) evaluated switchgrass as a substrate component. Data showed that switchgrass, as a substrate, could be processed and modified to be suitable for woody crop production. Physical properties of switchgrass depend on whether it was processed as a coarse or fine particle size (Altland and Krause, 2009). The authors noted that switchgrass processed through a 0.47 cm (0.18 in) screen had ideal physical properties. Research conducted by Altland (2010) evaluated substrates consisting of either 100% switchgrass, miscanthus, willow chip, corn stover, and PB or biofuels mixed with 20% peat moss for the first experiment and a second experiment was conducted using a mix of biofuels with 10% municipal solid waste compost, and 20% peat moss (Altland, 2010). The study concluded that when used alone, biofuel-based substrates do not provide ideal physical properties to sustain plant growth, because AS was higher and CC was lower than the recommended ranges (Altland, 2010).

Hardwood-based PB alternatives

Trees considered low-value or as "trash trees" were studied to determine whether these trees had potential to be viable amendments in greenhouse substrates (Murphy et al., 2011). Three low-value tree species including sweetgum (*Liquidambar styraciflua* L.), hickory (*Carya sp.* Nutt.), and eastern redcedar were evaluated along with WT as potential amendments to a standard peat/perlite mix. Three bedding plant species including 'Dreams Sky Blue' petunia (*Petunia* x *hybrida* Vilm. 'Dreams Sky Blue'), 'Cooler Peppermint' vinca (*C. roseus* L. 'Cooler Peppermint'), and 'Super Elfin Salmon' impatiens (*I. walleriana* Hook.f. 'Super Elfin Salmon') were planted into substrate mixes of 75:25 (v:v) and 50:50 (v:v) peat mixed with either sweetgum, hickory, or eastern redcedar (Murphy et al., 2011). Results of this study indicate that eastern redcedar-amended substrates performed comparably to the standard peat/perlite mix. Eastern redcedar substrates performed better than substrates amended with WT. The authors did not recommend using sweetgum or hickory as amendments in annual bedding plant production (Murphy et al., 2011).

The only issue with the PB alternatives listed above (PTS, WT, CCR, douglas-fir, and biofuel crops) is that while they are all viable alternatives to PB, none of them are readily available for the Great Plains region. Some may argue that biofuel crops are available and suited for the Great Plains, but more research is needed on the use of these biofuels before they can become viable for use in nursery crops.

Eastern redcedar

Eastern redcedar (ERC) is native to the east and central parts of North America and has become aggressively weedy throughout many parts of the Great Plains (Figure 1.1; Dirr, 2009; Griffin, 2009; and Stritzke and Rollins, 1984). Advancement of ERC into fields and grasslands was once hindered by livestock grazing and wildfires that occurred at intervals of 5 to 15 years (Starr et al., 2012; Stritzke and Rollins, 1984). Due to the lack of natural controls (wildfires and livestock grazing), it is estimated that 762 acres per day are lost to ERC invasion in Oklahoma alone (Drake and Todd, 2002). With this rapid encroachment of ERC into fields and grasslands, an industry to help combat the invasion of ERC has grown (Griffin, 2009). Once harvested, ERC is allowed to dry in the field for up to one year before grinding occurs (Figure 1.2). Eastern redcedar chips that are produced from the grinding process can be used as mulch for landscapes (Figure 1.3). A study by Maggard et al., (2012) demonstrated that using wood-based mulches such as ERC, helps maintain soil moisture and temperature levels along with the suppression of weeds.

Research conducted by Griffin (2009), evaluated ERC ground to pass through a 2.0 cm (3/4 inch) screen and incorporated at 0%, 5%, 10%, 20%, 40%, and 80% into a PB: sand mixture. Chinese pistache (*Pistacia chinensis* Bunge) and Indian-cherry [*Frangula caroliniana* (Walter) A. Gray] were planted into the substrate combinations. Chinese pistache exhibited shorter plants when grown in 10% and 80% ERC when compared to 0%. At the conclusion of the study, no visible signs of nutrient deficiencies were observed in either species.

Starr et al., (2012, 2013) continued research with ERC as a potential alternative substrate by studying the growth of baldcypress [*Taxodium distichum* (L.) Rich.] in ERC and the affect of substrate particle size on the growth of black-eyed susan (*Rudbeckia fulgida* Aiton). Starr et al. (2012) evaluated the growth of baldcypress in six different substrates, similar to the previous study conducted by Griffin (2009). Starr et al. (2012) concluded that ERC could be a potential replacement for PB. Due to poor substrate physical properties, baldcypress planted in 80% ERC had plant dry weight less than other treatments. This study demonstrated that physical properties of ERC, such as high AS and low CC, can limit the use of ERC as a full replacement for PB (Starr et al., 2013; Carmichael et al., 2012).

Landscape Establishment

Few articles have been published about landscape establishment of plants grown in wood-based substrates. In general, landscape establishment studies have explored the as effects of irrigation frequency, planting depth, container types, groundcovers, and mulches on landscape plant establishment (Marshall and Gilman, 1998; Gilman, 2001; Scheiber et al., 2007; Arnold and McDonald, 2009; and Bryan et al., 2010). Two articles discussed landscape establishment in wood-based substrates. One discussed the affects of growing annual bedding plants in pine tree substrate (PTS) followed by planting in a landscape (Wright et al., 2009). The authors stated that plants grown either in PB or PTS were acceptable for the landscape, with the caveat that increased fertilization was needed to overcome N immobilization in wood-based substrates. They also noted that N-immobilization would only occur in the original rootball and not in mineral soil because it was not amended with PTS and by quick exploration into the mineral soil by the roots. Results of this study indicated that plants grown in PB and PTS, have equal appeal in the landscape (Wright et al., 2009).

Marble et al., (2012) evaluated landscape establishment of ‘Acoma crapemyrtle (*Lagerstormia indica* L. x *faurei* ‘Acoma’), ‘D.D. Blanchard’ magnolia (*Magnolia grandiflora* L. ‘D.D. Blanchard’) and shumard oak (*Quercus shumardii* Buckley) that were initially grown in WT or CCR. Clean chip residual and WT were chosen for this study because CCR and WT had not been evaluated in a landscape setting (Marble et al., 2012). Plants that were grown in CCR and WT were also compared with plants grown in

PB. Plants were grown for two growing seasons before being destructively harvested by cutting the shoots off 15.3 cm (6 in.) above the soil level and extracting roots from the soil. The authors concluded that regardless of the substrate, all three species performed similarly once in the landscape.

Several studies have been conducted using ERC as a container substrate either in the greenhouse or a nursery setting. No studies have been conducted looking at the landscape establishment of plants grown in ERC. It is important to discern any plant growth differences that my occur after consumers plant into the landscape in order to ensure high plant quality for nursery crop growers and retailers.

Cyclic Irrigation

In the horticultural industry (primarily the container-grown nursery crop production industry) PB-based substrates are known for having low moisture retention properties; necessitating daily watering during the growing season (Warren and Bilderback, 2002; Yeager et al., 2007). Surveys conducted in the Southeastern U.S. note that producers tend to follow best management practices of irrigating plants before 10:00 am. Many nurseries irrigate for one hour, applying about 1 in/hr (2.45 cm/hr) (Fain et al., 2000). Once these nurseries were monitored for one year it was noted that the nurseries were actually under-applying water by 40% or only appling an average of 0.6 in/hr (1.6 cm/hr). According to the Best Management Practices: Guide for Producing Nursery Crops (Yeager et al., 2007) the amount of water applied during irrigation cycles should be based on the crop. Nurseries should check the water content of the substrates to monitor irrigation for effectiveness and efficiency (Yeager et al., 2007; Fain et al., 2000).

Warren and Bilderback (2002) noted that previous research had been conducted that showed plants respond to split irrigation (or cyclic irrigation). Splitting irrigation into two applications increased shoot and root growth and decreased canopy and substrate temperatures. Irrigating plants during the day when plants are more actively transpiring and taking up water has been shown to increase growth and reduce water stress (Warren and Bilderback, 2002). Cyclic irrigation is the splitting of the prescribed amount of water per day, among a series of cycles that consist of intervals of rest and irrigation. These series of cycles help improve irrigation efficiency and nutrient retention (Warren and Bilderback, 2002; Tyler et al., 1996). By allowing rest periods between irrigation cycles, water has time to move from the macropore system to the micropore system of the container substrate (Tyler et al., 1996). These resting periods reduce the amount of run-off/leachate and also help retain nutrients in the container substrate (Tyler et al., 1996; Warren and Bilderback, 2002).

Eastern redcedar, similar to other wood-based substrates, has problems with water retention. Since ERC is known for having high AS and low CC compared to PB, this could subject substrates to drying out faster than traditional mixes. Using cyclic irrigation could help maintain constant moisture in the substrate. To date, there has been no research conducted with ERC as an alternative substrate using cyclic irrigation to help overcome these poor physical properties.

Objectives

Based on previous studies with ERC as a substrate component, we know that ERC can perform well as a substrate for some ornamental nursery crops. Eastern redcedar is known to have high AS and low CC resulting in limited use as a complete replacement for PB. The first objective of this research was to expand the list of plants that can be successfully grown in ERC and to evaluate the affects ERC has on ornamental crops once planted into the landscape over time. The second and final objective of this research was to determine if cyclic irrigation could overcome the poor physical properties (high AS and low CC) of ERC in order to render ERC more suitable as a replacement for PB.

Literature Cited

Altland, J. 2010. Use of processed biofuel crops for nursery substrates. J. Environ. Hort. 28:129-134.

Altland, J. and C. Krause. 2009. Use of switchgrass as a nursery container substrate. HortScience. 44:1861-1865.

Arnold, M.A. and G.V. McDonald. 2009. Groundcovers, organic and inorganic mulches, and masonry surfaces differentially affect establishment and root zone characteristics of urban trees. Arbor. and Urban For. 35:232-240.

Brown, E.F., F.A. Pokorny. 1975. Physical and chemical properties of media composed of milled pine bark and sand. J. Amer. Soc. Hort. Sci. 100:119-121.

Bowman, D.C., R.Y. Evans, and L.L. Dodge. 1994. Growth of chrysanthemum with ground automobile tires used as a container soil amendment. HortScience. 29: 774-776.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L Sibley. 2008a. Clean chip residual: A substrate component for growing annuals. HortTechnology. 18:423-431.

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

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

Boyer, C.R., H.A. Torbert, C.H. Gilliam, G.B. Fain, T.V. Gallagher, and J.L Sibley. 2012a. Nitrogen immobilization in plant growth substrates: Clean chip residual, pine bark, and peatmoss. Intern. Journ. of Agr. Vol 2012. <http://www.hindawi.com/journals/ija/2012/978528/>

Boyer, C.R., T.V. Gallagher, C.H. Gilliam, G.B. Fain, H.A. Torbert, and J.L. Sibley. 2012b. Description of clean chip residual forest harvest and its availability for horticultural uses in the southeastern United States. HortTechnology. 22:381-387.

Bryan, D.L., M.A. Arnold, A. Volder, W.T. Watson, L. Lombardini, J.J. Sloan, L.A. Valdes-Aguilar, and A.D. Cartmill. 2010. Planting depth during container production and landscape establishment affects growth of *Ulmus parvifolia*. HortScience 45:54-60.

Buamscha, M.G, J.E. Altland, D.M. Sullivan, D.A. Horneck, and J. Cassidy. 2007. Chemical and physical properties of douglas fir bark relevant to the production of container plants. HortScience 42:1281-1286.

Carmichael, T.R., C.R. Boyer, S.L. Warren, and J.J. Griffin. 2012. Effect of irrigation frequency on sedum grown in alternative substrates. Proc. South. Nurs. Assn. Res. Conf. 57:2-5.

Chandler, P.A., R.D. Durbin, J. Ferguson, J.W. Huffman, O.A. Matkin, D.E. Munnecke, C.N. Roistacher, W.R. Schoonover, and R.H. Sciaroni. 1957. The U.C. system for producing healthy container-grown plants through the use of clean soil, clean stock, and sanitation. Univ. of California Div. of Agr. Sci.: Agr. experimentation station – ext. service.

Chong, C. and R.A. Cline. 1993. Response of four ornamental shrubs to container substrate amended with two sources of raw paper mill sludge. HortScience 28: 807-809.

Croxton, S.D., J.L. Sibley, W. Lu, and M. Schaefer. 2004. Evaluation of composted household garbage as a horticultural substrate. Proc. Southern. Nurs. Assn. Res. Conf. 49: 296-298.

Daniel, T.C., P.A. Moore, Jr., A.N. Sharpley, and C.W. Wood. 1995. Poultry manure management: Environmentally sound options. J. of Soil and Water Conserv. 50:321.

Davidson, H., R. Mechlenburg, C. Peterson. 2000. Nursery management administration and culture, Fourth Edition. Prentice Hall. Upper Saddle River, NJ.

Davis, J.G. and C.R. Wilson. 2005. Choosing a soil amendment. Colorado State University Extension. Factsheet 7.235. <http://www.ext.colostate.edu/pubs/garden/07235.html>.

Dirr, M.A. 2009. Manual of woody landscape plants: Their identification, ornamental characteristics, culture, propagation, and uses, Sixth Edition. Stipes Publishing L.L.C.. Champaign, Il.

Drake, B., and P. Todd. 2002. A strategy for control and utilization of invasive juniper species in Oklahoma: Final report of the “Redcedar Task Force”. Oklahoma Dept of Ag, Food, and For. 17 July 2012. http://www.forestry.ok.gov/websites/forestry/images/rcstf.pdf

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008a. *WholeTree* substrates derived from three species of pine in production of annual vinca. HortTechnnology18:13-17.

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008b. Establishment of greenhouse-grown *Tagetes patula* and *Petunia* x *hybrida* in '*WholeTree'* substrates. Acta Hort. 782:387-393.

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

Fain, G.B., C.H. Gilliam, K.M. Tilt, J.W. Olive, B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18: 142-144.

Gabriel, M.Z., J.E. Altland, and J.S. Owen Jr. 2009. The effect of physical and hydraulic properties of peatmoss and pumice on douglas fir bark based soilless substrates. HortScience 44:874-878.

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

Gilman, E.F. 2001. Effect of nursery production method, irrigation, and inoculation with mycorrhizae-forming fungi on establishment of *Quercus virginiana*. J. Arboriculture 27:30-39.

Gómez, C. and J. Robbins. 2011. Pine bark substrates amended with parboiled rice hulls: Physical properties and growth of container-grown spirea during long-term nursery production. HortScience 46: 784-790

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

Haynes, R. W., tech. coord. 2003. An analysis of the timber situation in United States: 1952-2050. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-560.

Jackson, B.E., R.D. Wright, J.F. Browder, J.R. Harris, and A.X. Niemiera. 2008. Effect of fertilizer rate on growth of azalea and holly in pine bark and pine tree substrates. HortScience 43:1561-1568.

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

Johnson, P. and D. Tatum. 1996. The use of crumb rubber amendment in the production of poinsettias. Proc. Southern Nurs. Assn. Res. Conf. 41: 111-115

Kahtz, A.W. and N.J. Gawel. 2003. Use of recycled waste as an amendment in container production media. Proc. Southern Nurs. Assn. Res. Conf. 48: 71-73.

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

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

Maggard, A.O., R.E. Will, T.C. Hennessey, C.R. McKinley, and J.C. Cole. 2012. Tree-based mulches influence soil properties and plant growth. HortTechnology 22: 353-361.

Marble, S.C., G.B. Fain, C.H. Gilliam, G. B. Runion, S.A. Prior, H.A. Torbert, and D.E. Wells. 2012. Landscape establishment of woody ornamentals grown in alternative wood-based container substrates. J. Environ. Hort. 30:13-16.

Marble, S.C., C.H. Gilliam, J.L. Sibley, G.B. Fain, H.A. Torbert, T.V. Gallagher, and J.W. Olive. 2010. Evaluation of composted poultry litter as a substrate amendment for *WholeTree*, clean chip residual, and pine bark for container grown woody nursery crops. J. Environ. Hort. 28:107-116.

Marshall, M.D. and E.F. Gilman. 1998. Effects of nursery container type on root growth and landscape establishment of *Acer rubrum* L. J. Environ. Hort. 16:55-59.

Murphy, A.M., C.H. Gilliam, G.B. Fain, H.A. Torbert, T. V. Gallagher, J. L. Sibley, S. C. Marble, and A. L. Witcher. 2010. Extending pine bark supplies with wholetree and clean chip residual substrates. J. Environ. Hort. 28:217-223.

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

Newman, S.E., K.L. Panter, M.J. Roll, and R.O. Miller. 1997. Growth and nutrition of geraniums grown in media developed from waste tire components. HortScience 32: 674-676.

Owen, J.S. Jr., J.E. Altland. 2008. Container height and douglas fir bark texture affect substrate physical properties. HortScience 43:505-508.

Penick, E. B. 1980. Future of the horticultural bark industry in the United States. p. 2-3. *In*: R. C. Allison. Organic and Fuel Uses for Bark and Wood Residues. Proceedings No. P-80-27, Forest Products Research Society, Madison, WI.

Scheiber, S.M., E.F. Gilman, M. Paz, and K.A. Moore. 2007. Irrigation affects landscape establishment of burford holy, pittosporum, and sweet viburnum. HortScience. 42:344-348.

Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2012. Eastern redcedar (*Juniperus virginiana*) as a substrate component effects growth of three tree species. J. Environ. Hort. 30: 189-194.

Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2013. Post harvest processing of eastern redcedar and hedge-apple substrates affect nursery crop growth. J. Environ. Hort. 31: 7-13.

Stritzke, J.F. and D. Rollins. 1984. Eastern redcedar and its control. Weeds Today. 7-8.

Svenson, S.E., J. Bukelew, B. Becker, and J. Paxson. 2001. Growth of nursery crops in compost-amended douglas-fir bark. Proc. Southern Nurs. Assn. Res. Conf. 46: 123-125.

Tripepi, R.R., M.W. George, A.G. Campbell, and B. Shafii. 1996. Evaluating pulp and paper sludge as a substrate for peat moss in container media. J. Environ. Hort. 14: 91-96.

Tyler, H.H., S.L. Warren, T.E. Bilderback. 1996. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14: 194-198.

Warren, S.L. and T.E. Bilderback. 2002. Timing of low pressure irrigation affects plant growth and water utilization efficiency. J. Environ. Hort. 20: 184-188.

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

Wright, R.D., B.E. Jackson, J.F. Browder, and J.G. Latimer. 2008. Growth of chrysanthemum in a pine tree substrate requires additional fertilizer. HortTechnology 18:111-115.

Wright, R.D., B.E. Jackson, M.C. Barnes, and J.F. Browder. 2009. The landscape performance of annual bedding plants grown in pine tree substrate. HortTechnology 19:78-82.

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best management practices guide for production nursery crops. Southern Nurs. Assn., Atlanta, GA.

Figure 1.1 Eastern redcedar invasion in Barber County, KS.

Figure 1.2 Grinding of 1-year old eastern redcedar.

Figure 1.3 Ground eastern redcedar.

Chapter 2 - Production and Landscape Establishment of Nursery Crops in Eastern Redcedar-Amended Substrates

Abstract

Pine bark (PB) has been the principal component of nursery crop substrates in the United States for more than 60 years. Substrate material used for the purpose of growing ornamental plants in the Great Plains is generally shipped a great distance, primarily from the Southeastern U.S., due to a lack of pine plantations in the region. Eastern redcedar (*Juniperus virginiana* L.; ERC), an aggressively weedy tree species, has been identified as a possible alternative to PB for nursery substrates. The objective of this study was to evaluate the landscape establishment of *Miscanthus sinensis* N.J. 'Little Kitten' (dwarf maiden grass), *Rosa* (L.) 'Radtkopink' (Double Pink Knockout™ rose), *Ilex glabra* (L.) A. Gray 'Compacta' (holly), *Ulmus parvifolia* Jacq. 'Emer II' (Allee™ lacebark elm), *Sedum telphium* L. 'Autumn Joy' (sedum), *Hosta* Tratt. 'Sum and Substance' (hosta), and *Hemerocallis* L. 'Charles Johnston' (daylily) in three substrate mixes. These substrate mixes consisted of 80% PB: 20% sand, 80% ERC: 20% sand, and 40% PB: 40% ERC: 20% sand. This study was split into two phases, production and landscape. During the production phase pH, EC, growth index (GI), SPAD, caliper (Allee™ lacebark elm) and shoot and root dry weight were measured. Growth index, SPAD, caliper (Allee™ lacebark elm only), along with shoot and root dry weights were collected during the landscape phase. At the end of the production phase differences in growth were observed in maiden grass, holly, lacebark elm, and sedum among the different substrates. At the end of the landscape establishment phase, no differences in growth were observed in

species except holly and hosta indicating that nursery growers should consider using ERC as a substrate component.

Significance to the Industry

With pine bark (PB) availability becoming more inconsistent because of environmental factors increased shipping costs and competition by other industries, more local and sustainable alternatives have become needed. A local and sustainable alternative to PB in the Great Plains region of the United States is eastern redcedar (*Juniperus virginiana* L.; ERC). Eastern redcedar is a native of the Great Plains and has become known as a "weedy species" due to the lack of natural controls. Using ERC as a substrate, nursery growers can reduce substrate costs and increase local sustainability. In this study, ERC as a substrate component was evaluated for effects on eight plant species after being planted into the landscape. At the conclusion of the study, all plant species that were first grown in ERC grew similarly to plants grown in PB after field planting.

Introduction

Pine bark (PB) has been used for many years as a substrate component for nursery crop production. Since the 1970's, PB has become the industry standard for growing plants in containers, however Penick (1980) noted that by the year 2020 PB could become a desired resource by two main industries: horticulture and fuel. Due to increased shipping costs and demand from other industries (Lu et al., 2006), PB is becoming more difficult to locate, particularly in the Great Plains region of the U.S. (Murphy et al., 2010; Boyer et al., 2012). These issues have accelerated the need to find alternative substrates for nursery crop production.

Several studies have evaluated wood-based substrate component alternatives for PB such as: clean chip residual (CCR) and pine tree substrates (Boyer et al., 2012; Jackson et al., 2008; Murphy et al., 2010). In a study by Murphy et al. (2010) CCR and *WholeTree* (WT) substrates were evaluated as alternatives to PB for woody nursery crops. *WholeTree* and CCR used in the study were processed to pass through a 0.95 cm (3/8 in) screen. Substrate blends consisted of 100% PB, WT, and CCR, 75:25 PB:CCR and PB:WT, 50:50 PB:CCR and PB:WT, or 25:75 PB:CCR and PB:WT (v:v). All substrate blends were then amended 6 substrate: 1 sand (by vol.) The authors reported no difference in growth for six different ornamental taxa when PB was amended with up to 75% alternative substrate. The need to find alternatives is particularly important in the Great Plains region where no native pine stands are available for bark harvest so PB supplies must be shipped long distances, raising costs for growers.

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

A study conducted by Griffin (2009) suggested that ERC could be used as an alternative substrate. Eastern redcedar was mixed with PB and 20% sand at six different ratios 0%, 5%, 10%, 20%, 40%, and 80%. Seedlings of Chinese pistache (*Pistacia chinensis* Bunge) and Indian-cherry [*Frangula caroliniana* (Walter) A. Gray] were planted and after 20 weeks, growth data was collected. Plants grown in 10% and 80% ERC had less growth then plants grown in other treatments, which displayed no growth differences. Work with ERC continued in a study by Starr et al. (2013) where 100% ERC and 100% hedge-apple [*Maclura pomifera* (Raf.) C.K. Schneid.] substrates were evaluated as alternatives to PB when growing black-eyed susan (*Rudbeckia fulgida* Aiton var. *fulgida*), ‘Graziella’ maiden grass (*Miscanthus sinensis* Andersson ‘Graziella’), ‘Arapaho’ crapemyrtle (*Lagerstroemia* L. x ‘Arapaho’), baldcypress [*Taxodium distichum* (L.) Rich.], and redbud (*Cercis Canadensis* L.). In this study, shoot dry weight and plant growth indices decreased as ERC particle size increased. This result was attributed to low container capacity (CC) and high air space (AS). The authors noted that all plants grown in ERC were marketable, except for crapemyrtle. Mixing either ERC or hedge-apple with PB could help adjust CC into recommended ranges.

A study evaluating the potential of three tree species considered low-value or “trash trees” as viable amendments in greenhouse substrates demonstrated that ERC-based substrates performed well (Murphy et al., 2011). Three low-value tree species including sweetgum (*Liquidambar styraciflua* L.), hickory (*Carya* Nutt. *sp.*), and eastern redcedar were evaluated along with WT as potential amendments to a standard peat/perlite mix. Three bedding plant species including ‘Dreams Sky Blue’ petunia (*Petunia* x *hybrida* Vilm. ‘Dreams Sky Blue’), ‘Cooler Peppermint’ vinca [*Cathanranthus roseus* (L.) G. Don ‘Cooler Peppermint’], and ‘Super Elfin Salmon’ impatiens (*Impatiens walleriana* Hook. f. ‘Super Elfin Salmon’) were planted into substrate mixes of 75:25 and 50:50 (v:v) peat mixed with either sweetgum, hickory, or eastern redcedar. At the conclusion of the study, the authors noted that ERC-amended substrates performed comparably to the standard peat/perlite mix. Eastern redcedar also performed better than substrates amended with WT. The authors did not recommend using sweetgum or hickory as amendments in annual plant production due to reduced plant growth, flower count and plant dry weights.

It has not been determined whether growing plants in ERC has an impact on their growth in the landscape. However, Marble et al. (2012) evaluated the landscape establishment of three woody ornamental species that were grown in WT or CCR. Plants grown in 6:1 (v:v) CCR: sand and WT: sand were compared to plants grown in PB. In that study plants were grown in the landscape for two growing seasons. The authors concluded that regardless of production substrate, all three species grew similarly once in the landscape. Similarly, plants grown in ERC have not been evaluated in a landscape setting either. The purpose of this study was to evaluate the affects of ERC substrates on the growth of a wide range of container-grown nursery crops (trees, shrubs, and herbaceous perennials), then observe the affects of ERC on these plants after planting into the landscape.

Materials and Methods

Production study

Eastern redcedar chips were obtained from Queal Enterprises (Pratt, KS) and processed through a hammer mill (C. S. Bell Co., Tiffin, OH, Model 30HMBL; Figure 2.3) with a 3.18mm (3/8-inch) screen on May 19, 2011. On June 2, 2011, 3 substrate treatments consisting of 80% PB: 20% sand, 80% ERC: 20% sand, and 40% PB: 40% ERC: 20% sand (Figure 2.4) were mixed and amended with Osmocote (The Scotts Co. Maryville, OH) 18N-6P-12K nine month controlled release fertilizer and Micromax (The Scotts Co. Maryville, OH). Liners of eight species (Table 2.1), *Sedum telphium* L. 'Autumn Joy' ('Autumn Joy' sedum), *Miscanthus sinensis* N.J. 'Little Kitten' ('Little Kitten' maiden grass), *Gaillardia x grandiflora* Van Houtte (blanket flower), *Rosa* L. 'Radtkopink' (Double Pink Knockout® rose), *Ilex glabra* (L.) A. Gray 'Compacta' (inkberry holly), *Ulmus parvifolia* Jacq. 'Emer II' (Allee® lacebark elm), *Hosta* Tratt. 'Sum and Substance' (hosta) and *Hemerocallis* L. 'Charles Johnston' (daylily). Particle size distribution analysis was conducted with a Ro-Tap sieve shaker (W.S. Tyler, Mentor, OH) by passing 250 g (0.55 lb.) or dried substrate through 12.5, 9.5, 6.3, 3.35, 2.36, 2.0, 1.4, 1.0, 0.5, 0.25, 0.11, and 0.05 mm sieves. Particles that passed through the 0.05 mm sieve were collected in the pan. Substrate physical properties were determined with methods set forth by Fonteno and Harden (2003), North Carolina State University, Horticultural Substrate Laboratory (Raleigh, NC) for the NC State porometer.

On June 2, 2011, all plants except Allee® lacebark elm (June 9, 2011) were potted and placed on the container pad at the Kansas State University John C. Pair Horticulture Center (Haysville, KS) in a randomized complete block design with 14 replications except for hosta and daylily (8 reps) and sedum (10 reps). All plants were planted into trade 3-gallon (11.4 L) containers (Classic C1200, Nursery Supply Inc., Chambersburg, PA) except sedum, daylily and hosta, which were planted into 1-gallon (3.8 L) containers (Classic C400, Nursery Supply Inc., Chambersburg, PA). Hosta plants were placed in a shade structure and irrigated with 200 ml of water per day (by hand). Plants on the container pad were irrigated by overhead sprinklers with a total of 2.54 cm (1 in.) of water per day. Substrate pH and electrical conductivity (EC) were collected with the pour through method (Wright, 1986) on a monthly basis. Leachate was measured with a pH/conductivity meter (XL20 Fisher Scientific, Pittsburgh, PA) at 7, 28, 75, 96, and 120 days after potting (DAP). Growth indices (GI) [(height + width + perpendicular width) ÷ 3] and stem diameter [measured at 10.16 cm (4 in.) above soil surface] were measured at 120 DAP, except daylily fan count was recorded. Since Allee® lacebark elm was potted later, GI and stem diameter were measured at potting and 113 DAP. Leaf greenness was measured at 71 DAP using a SPAD-502 Chlorophyll Meter (Konica Minolta, Ramsey, NJ) by taking the average of leaf greenness of four recently mature leaves on Double Pink Knockout™ rose, inkberry holly, blanket flower, and Allee™ lacebark elm. On Oct. 5, 2011 (125 DAP) 4 reps from each species were harvested. Plants were cut at the substrate surface to separate roots from shoots. Substrate was removed from roots with high-pressure water stream. Shoots and roots were dried in a forced-air oven (Grieve SC-350 Electric Shelf Oven, Round Lake, IL) at 160°F (71°C) until dry weight stabilized (13d). All data were analyzed using SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) and means were separated by using Waller-Duncan Multiple Range Test (α=0.05).

Landscape Establishment study

On Oct 5, 2011 the remaining 10 reps of the same five species (Allee® lacebark elm, Double Pink Knockout® rose, inkberry holly, ‘Little Kitten’ maiden grass, and blanket flower) were planted into a Canadian-Waldeck fine sandy loam soil with a pH of 5.9 located at the Kansas State University John C. Pair Horticulture Center (JCPHC; Haysville, KS). Plants were transplanted into six rows with 1.5 m (5.0 ft.) in-row spacing and 3.1 m (10 ft.) between-row spacing. All plants were planted by hand and were watered immediately after planting. Each plant was fertilized after planting with 14.2 g (0.5 oz.) of N of Urea 46N-0P-0K per plant. Soil moisture was maintained by drip irrigation [Netafim Typhoon series 0.95 LPM•100 m^{-1} (0.25 GPM•100 ft^{-1}); Tel Aviv, Israel). Irrigation occurred weekly for 6 hr to achieve 18.0 liters•m^{-1} (4.75 gal•3.2 ft^{-1}) of water when rainfall was insufficient. Weed control was achieved using oryzalin (United Phosphorous Inc., Trenton, NJ) applied after planting at a rate of 9.45 liters•ha^{-1} (4 qt•ac^{-1}) with hand hoeing occurring thereafter. Annual ryegrass (*Lolium* multiflorum Lam.; Tillage RootMax, Cover Crop Solutions, Robesonia, PA) was used as a cover crop between rows. On April 9, 2012 eight reps of ‘Charles Johnston’ daylily and 10 reps of ‘Autumn Joy’ sedum were planted into the same field at the JCPHC. On the same date 10 reps of hosta were planted into a shade structure located at the JCPHC. During the landscape establishment phase GI were measured at 230, 292, and 329 days after planting (DAPL). Leaf greenness was measured at 329 DAPL using a SPAD-502 Chlorophyll Meter by taking the average of leaf greenness of four recently mature leaves. On Sept. 5, 2012, plants were harvested by undercutting with a U-blade mounted (Bobcat 671975 0.91 m (36 in) Digger, Bobcat Co. West Fargo, ND) on a skid-steer (Bobcat S185, Bobcat Co. West Fargo, ND). Allee® lacebark elm also required the additional use of a tree spade [Bobcat TS34T (truncated spade set to 0.86 m (34 in) diameter) Bobcat Co. West Fargo, ND]. Plants were cut at the soil interface to separate roots from shoots. Roots were washed of soil with a high-pressure water stream. Shoots and roots were dried in a forced-air oven (Grieve SC-350 Electric Shelf Oven, Round Lake, IL) at 160°F (71°C) until dry weight stabilized (1 week). At the conclusion of the study relative grow rate was calculated [(Ln. GI at field planting – Ln. GI at end of study) x 100]. Blanket flower, inkberry holly and 'Autumn Joy' sedum sustained deer damage prior to planting in the landscape therefore these plants were arranged in a randomized complete block design by amount of deer damage with 10 reps, three substrate treatments and 2 single plant subsamples per treatment [except for hosta and daylily (8 reps)]. All data were analyzed using SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) and means were separated by using Waller-Duncan Multiple Range Test (α=0.05).

Results and Discussion

Production

Physical Properties

Only ERC had greater air space (AS) than the recommended range (Yeager et al., 2007; Table 2.2). Container capacity of PB was within the recommended range, while both ERC and PB:ERC mix were below the recommended range. Total porosity (TP) of all three substrates were similar and within the recommended range. Pine bark had greater bulk density (BD) than ERC and the PB:ERC mix, but all three substrates were within the recommended range. Pine bark and PB:ERC mix had similar particles sizes, ERC had equal coarse to PB and less medium and fine particles than the other treatments

(Table 2.3). Based one previous work (Starr et al., 2013) there findings were not surprising. The greater proportion of coarse particles in ERC explains these findings.

EC and pH

Electrical conductivity was similar among substrates at all three measurement dates (Figure 2.1; Table 2.4). At 7 and 120 DAP pH was lowest in PB (5.62), followed by the PB:ERC mix (6.48) and ERC (7.55). At 75 DAP pH was higher in ERC (6.10) and PB:ERC (6.00) mix then PB (5.78).

Allee® lacebark elm

Shoot and root dry weights were significantly decreased when grown in ERC compared to PB and PB:ERC substrates(Table 2.5). Differences in GI were observed among substrates. Plants grown in PB:ERC were larger than plants grown in ERC. Plants grown in PB were similar to all others. However, there were no significant differences in SPAD measurements among substrates. Caliper was greatest in plants grown in PB:ERC, while plants grown in PB and ERC had smaller caliper at 113 DAP. These results suggest that plants produced in 50% ERC are similar in growth to the industry standard substrate.

Double Pink Knockout® rose

Shoot dry weight, root dry weight and GI were unaffected by substrates (Table 2.5). In contrast, plants grown in ERC had the greatest leaf greenness, whereas plants in PB:ERC had the lowest.

Inkberry holly

Differences in GI were observed. Plants growing in PB and PB:ERC had greater GI than plants growing in 80% ERC (Table 2.5). In addition, plants grown in ERC exhibited greater leaf greenness (SPAD) when compared to plants in PB. Plants growing in PB:ERC had similar SPAD readings to the others. Shoot dry weight of inkberry holly grown in PB was greater than plants grown in ERC. However, PB:ERC was similar to the others, whereas, root dry weight was unaffected by substrates.

Maiden grass

Growth index and shoot dry weight produced by plants grown in PB was greater than that of plants grown in ERC (Table 2.5). Plants growing in PB:ERC were similar to the others. Root dry weight was unaffected by substrate.

Blanket flower

Growth index, SPAD, shoot, and root dry weights were unaffected by substrate (Appendix, Table A.1). Data was recorded prior to deer damage.

Sedum

Growth index of sedum grown in PB:ERC was greater than sedum grown in PB (Table 2.5). Shoot and root dry weight not collected due to deer damage.

Landscape Establishment

Allee® lacebark elm

At the end of the study, there were no differences among substrates for GI or caliper at 230, 292, or 329 DAPL (Appendix, Table A.2). There were also no differences for SPAD, shoot or root dry weights. Growth index of Allee® lacebark elm increased an average of 42% after planting (Appendix, Table A.3).

Double Pink Knockout® rose

Growth indices at 230, 292, and 329 DAPL showed no significant difference among the substrates (Appendix, Table A.2). In addition, SPAD, shoot and root dry weight showed no significant differences between any substrate. Double pink Knockout® rose had no significant difference among substrates in percent growth increased 36% over the 209 days in the field (Figure 2.6; Appendix, Table A.3).

Inkberry holly

Growth index at every measurement date and shoot dry weight of plants grown in PB were greater than plants grown in ERC (Table 2.6) Root dry weight and SPAD were unaffected by substrate. Holly grew an average of 24% over the course of the landscape establishment study and there were no significant differences for percent growth among substrates (Figure 2.7; Appendix, Table A.3).

Maiden grass

At every date GI, shoot and root dry weights showed no significant differences among substrates (Appendix, Table A.2). Plants grew on average an additional 46% after planting in the landscape, though no significant difference among substrates were observed in percent growth (Figure 2.8; Appendix Table A.3).

Blanket flower

Deer damage was too extensive for plant survival so data was not collected.

Sedum

No differences in GI were observed among plants grown in the three substrates at any measurement date (Appendix, Table A.2). No differences among substrates were observed for shoot or root dry weights. Sedum grew an average of 40%, while no significant difference in percent growth among substrates were measured (Figure 2.9; Appendix, Table A.3)

Hosta

Growth indices showed differences among substrates at 230, 292, and 329 DAPL(Table 2.6). By 329 DAPL plants grown in PB were larger than plants grown in ERC. Plants in PB:ERC were similar to both. Shoot dry weight was greatest in PB, and least in ERC. Shoot dry weight in PB:ERC was similar to both. Root dry weight of hosta grown in PB was greater than the other treatments. Hosta had a negative percent growth (-33%) due to extreme weather conditions of 30 days of +100°F (37.8°C) and extensive damage by blister beetles [*Epicauta pennsylvanica* (De Geer)] (personal observation), but still showed no significant difference among substrates (Figure 2.10; Appendix, Table A.3)

Daylily

There were no differences in fan counts among plants grown in the various substrates at any measurement date (Appendix, Table A.2). There were also no differences observed among substrates for shoot or root dry weights (Figure 2.11; Appendix, Table A.3).

Discussion

Growth of plants evaluated during the production phase were similar to a pervious study (Starr et al., 2012), where baldcypress grown in a PB:ERC mixture grew similarly to baldcypress grown in PB. Root dry weight for blanket flower, inkberry holly, maiden grass, and double pink Knockout® rose showed that the roots grew equally well in any of the three substrates. Growth index and shoot dry weight data suggest plants grown in substrates amended with ERC may require a higher fertilizer rate or different irrigation schedule than plants grown in PB. Jackson et al. (2008) suggested that wood-based substrates may need additional fertilization in addition to the slow-release fertilizer incorporated at time of mixing due to higher levels of microbial activity as the wood substrates decompose. All species demonstrated that under extreme Great Plains weather conditions, which ranged from a wet spring to 53 days of +100°F (37.8°C) in the summer, could be grown in a PB: ERC mix with similar size and marketability (personal observation) to plants grown in a PB control.

In conclusion, all species in the landscape establishment phase, except inkberry holly and hosta, performed similarly regardless of the container substrate that was used during the production phase. Plants grown in ERC that were smaller at the end of the production phase caught up to plants grown in PB and PB:ERC substrates by the end of the landscape study. Results observed in this study are similar to a study by Marble et al. (2012). The authors studied the performance of 'Acoma' crapemyrtle (*Lagerstroemia indica* x *faurei* 'Acoma'), ' D.D. Blanchard' magnolia (*Magnolia grandiflora* L. 'D.D. Blanchard'), and shumard oak (*Quercus shumardii* Buckley) that were container-grown in WT, CCR, and PB then planted into the landscape. The authors noted that all species performed similarly regardless of the container substrate. Data herein suggest that ERC is an acceptable amendment (up to 50%) for PB-based substrates. Most plants in this study were marketable and grew well in the landscape regardless of the substrate in which they were grown. Nursery growers in the Great Plains should consider supplementing their substrates with ERC in order to reduce costs and increase sustainability efforts.

Literature Cited

Boyer, C.R., T.V. Gallagher, C.H. Gilliam, G.B. Fain, H.A. Torbert, and J.L. Sibley. 2012. Description of clean chip residual forest harvest and its availability for horticultural uses in the southeastern United States. HortTechnology 22: 381-387.

Drake, B., and P. Todd. 2002. A strategy for control and utilization of invasive juniper species in Oklahoma: Final report of the “Redcedar Task Force”. Oklahoma Dept of Ag, Food, and For. 17 July 2012. <http://www.forestry.ok.gov/websites/forestry/images/rcstf.pdf>

Fonteno, W.C. and C.T. Harden. 2003. Procedures for determining physical properties of horticultural substrates using the NCSU porometer. Horticultural Substrates Laboratory. North Carolina State University. <http://www.ncsu.edu/project/hortsublab/pdf/porometer_manual.pdf>

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

Jackson, B.E., R.D. Wright, J.F. Browder, J.R. Harris, and A.X. Niemiera. 2008. Effect of fertilizer rate on growth of azalea and holly in pine bark and pine tree substrates. HortScience 43:1561-1568.

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

Marble, S.C., G.B. Fain, C.H. Gilliam, G.B. Runion, S.A Prior, H.A. Torbert, and D.E. Wells. 2012. Landscape establishment of woody ornamentals grown in alternative wood-based container substrates. J. Environ. Hort. 30:13-16.

Murphy, A. M., C. H. Gilliam, G. B. Fain, H. A. Torbert, T. V. Gallagher, J. L. Sibley, S. C. Marble, and A. L. Witcher. 2010. Extending pine bark supplies with wholetree and clean chip residual substrates. J. Environ. Hort. 28: 217-223.

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

Penick, E. B. 1980. Future of the horticultural bark industry in the United States. p. 2-3. *In*: R. C. Allison. Organic and Fuel Uses for Bark and Wood Residues. Proceedings No. P-80-27, Forest Products Research Society, Madison, WI.

Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2012. Eastern redcedar (*Juniperus virginiana*) as a substrate component effects growth of three tree species. J. Environ. Hort. 30: 189-194.

Starr, Z.W., C.R. Boyer, and J.J. Griffin, 2013. Post harvest processing of eastern redcedar and hedge-apple substrates affect nursery crop growth. J. Environ. Hort. 31: 7-13.

Stritzke, J.F. and D. Rollins. 1984. Eastern redcedar and its control. Weeds Today. 7-8.

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

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best management practices guide for production nursery crops. Southern Nurs. Assn., Atlanta, GA.

Figure 2.1 Substrate electrical conductivity levels for plants grown in 80% PB: 20% sand, 40%PB: 40%ERC: 20% sand, and 80% ERC: 20% sand (by vol.) measured on double pink Knockout® rose over time (black box indicates recommended ranges).

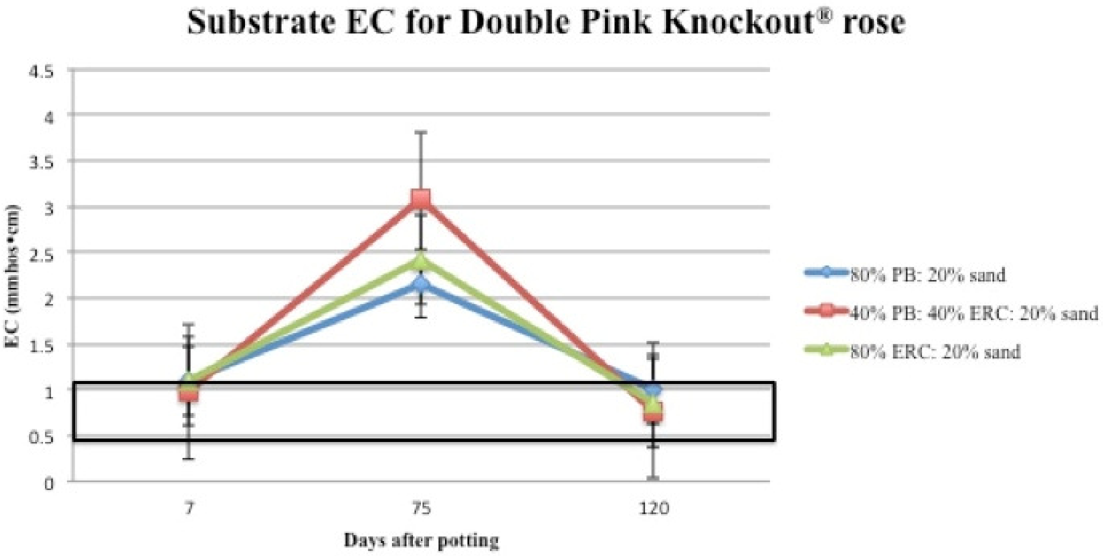

Figure 2.2 Substrate pH levels for plants grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand (by vol.) measured on double pink Knockout® rose overtime (black box indicates recommended ranges).

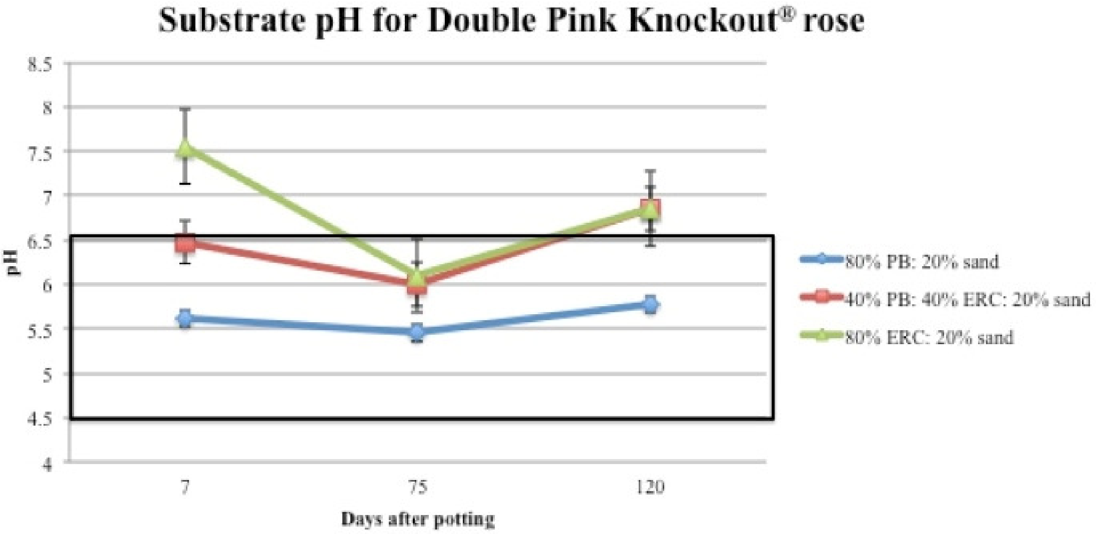

Figure 2.3 Hammer mill (C.S. Bell Co., Tiffin, OH, Model 30HMBL) used to grind eastern redcedar (*Juniperus virginiana* L.).

Figure 2.4 Substrate mixes of 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand (by vol.) evaluated in the production and landscape establishment study.

Figure 2.5 Allee® lacebark elm (*Ulmus parvifolia* 'Emer II') at harvest (336 days after planting) previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 40% sand, and 80% ERC: 20% sand (by vol.).

Figure 2.6 Double pink Knockout® rose (*Rosa* 'Radtkopink') previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand and field grown for 336 days, at harvest.

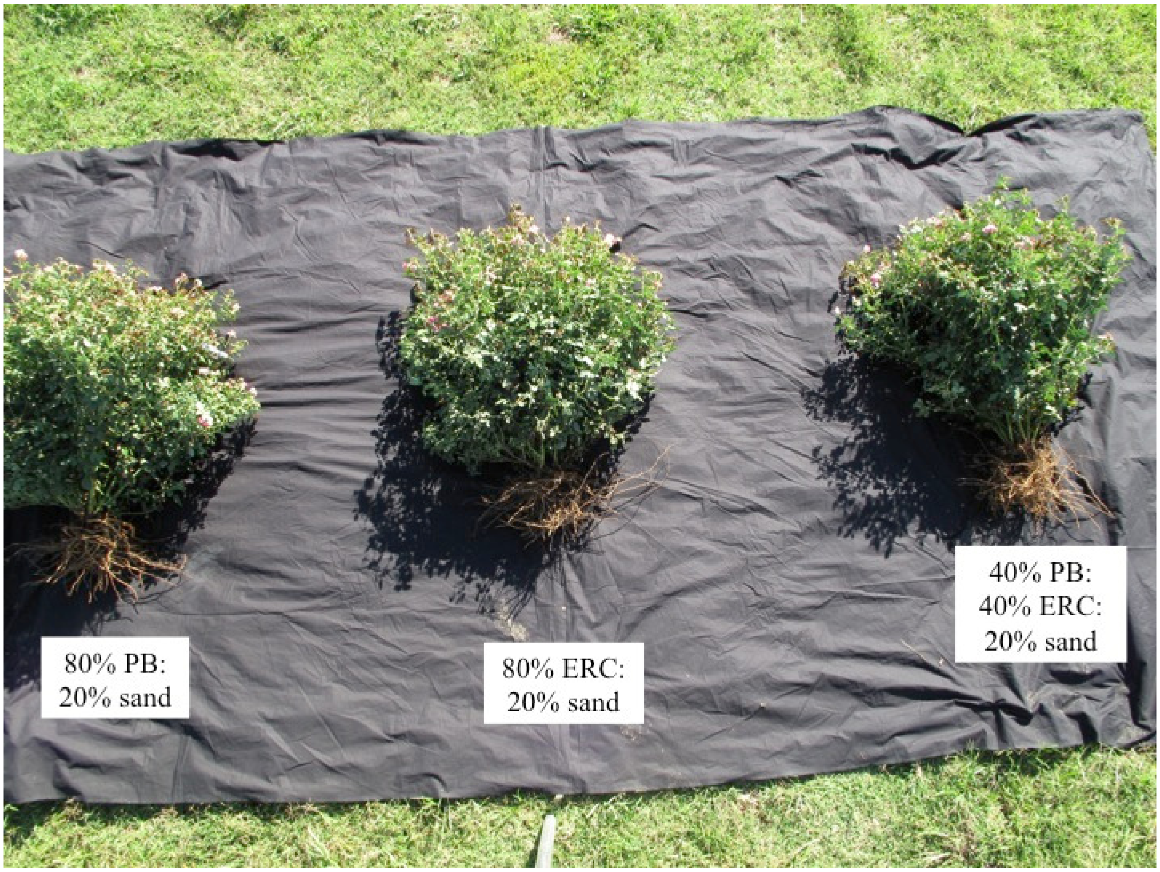

Figure 2.7 Inkberry holly (*Ilex glabra* 'Compacta') previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand and field grown for 336 days, at harvest.

Figure 2.8 ‘Little Kitten’ maiden grass (*Miscanthus sinensis* 'Little Kitten') previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand and field grown for 336 days, at harvest.

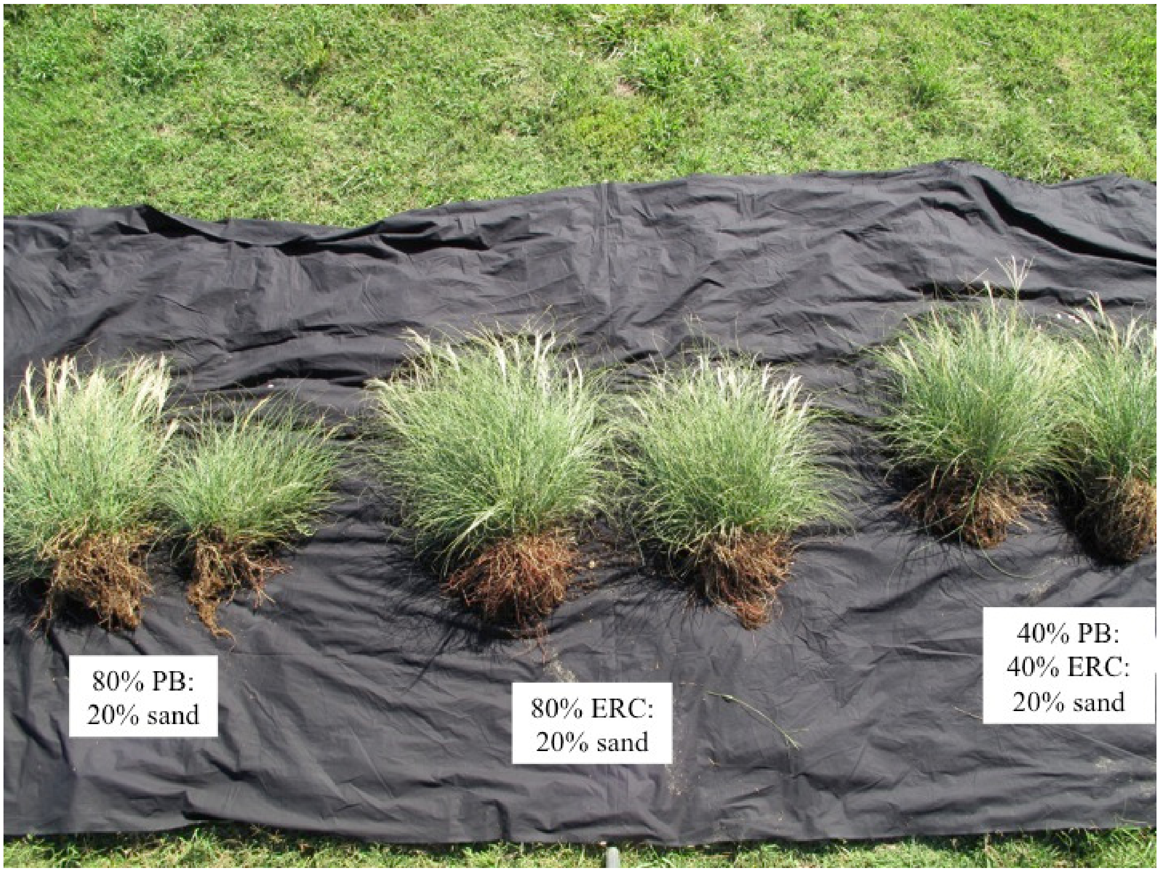

Figure 2.9 ‘Autumn Joy’ sedum (*Sedum telphium* 'Autumn Joy') previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand and field grown for 336 days, at harvest.

Figure 2.10 Hosta (*Hosta* 'Sum and Substance') previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, 80% ERC: 20% sand and field grown for 336 days, at harvest with blister beetle (*Epicauta pennsylvanica* De Geer) damage.

Figure 2.11 Daylily (*Hemerocallis* 'Charles Johnston') previously grown in 80% PB: 20% sand, 40% PB: 40% ERC: 20% sand, and 80% ERC: 20% sand and field grown for 336 days, at harvest.

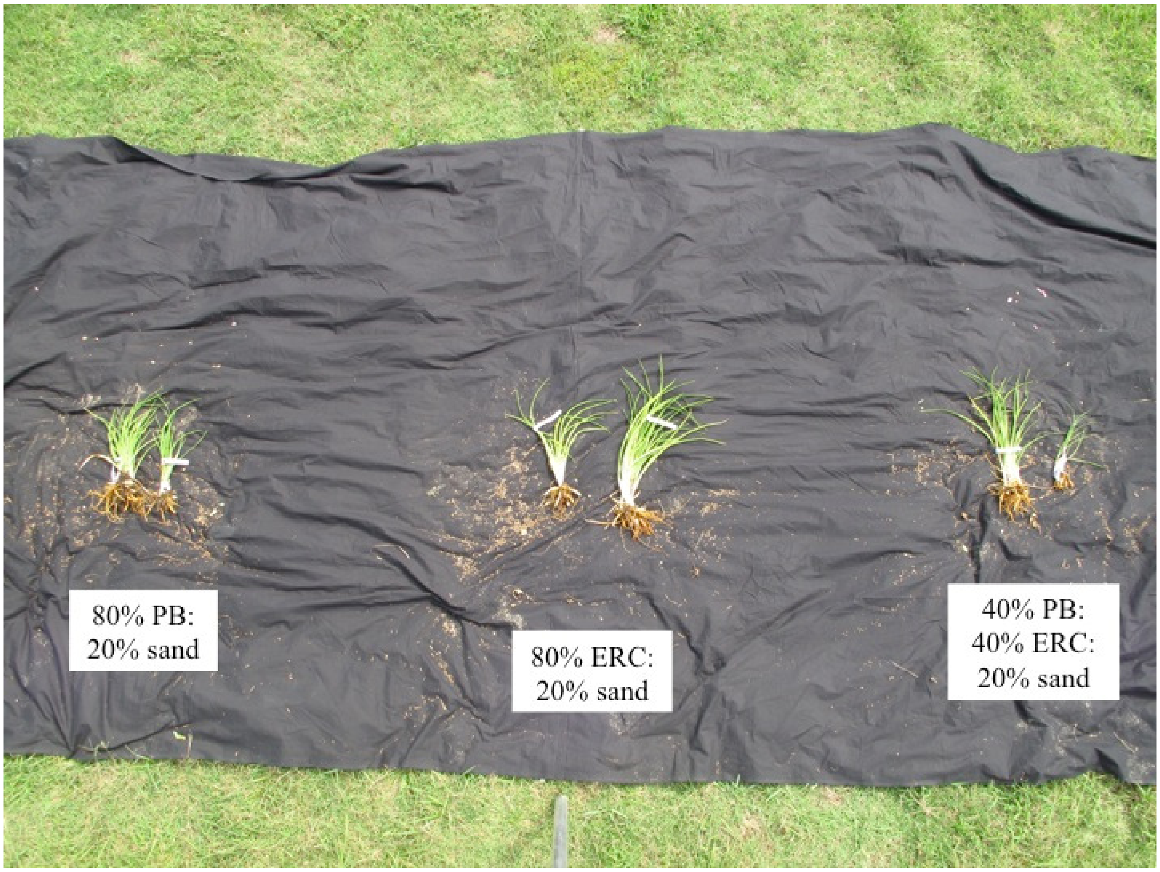

Table 2.1 Species, size, and source of plant material used for the production and landscape establishment phase.

Scientific name	Common name	Size	Source
Gaillardia x *grandiflora* Van Houtte	blanket flower	72 count cell pack	Emeral Coast Growers, Pensacola, FL
Hemerocallis L. 'Charles Johnston'	'Charles Johnston' daylily	bare-root stock	DeVroomen Bulb Co. Russell, IL
Hosta Tratt. 'Sum and Substance'	'Sum and Substance' hosta	bare-root stock	DeVroomen Bulb Co. Russell, IL
Ilex glabra (L.) A. Gray 'Compacta'	inkberry holly	32 count cell pack	Spring Meadow Nursery, Inc., Grand Haven, MI
Miscanthus sinensis N.J. 'Little Kitten'	'Little Kitten' maiden grass	72 count cell pack	Emeral Coast Growers, Pensacola, FL
Rosa L. 'Radtkopink'	double pink Knockout® rose	32 count cell pack	Spring Meadow Nursery, Inc., Grand Haven, MI
Sedum telphium L. 'Autumn Joy'	'Autumn Joy' sedum	50 couth cell pack	Emeral Coast Growers, Pensacola, FL
Ulmus parvifolia Jacq. 'Emer II'	Allee®lacebark elm	24 count Rootmaker®	Cedar Valley Nurseries, Ada, OK

Table 2.2 Physical properties of pine bark (PB)- and eastern redcedar (ERC)-based substrates[z].

	Air Space[y]	Container Capacity[x]	Total Porosity[w]	Bulk Density[v]
		(% vol)		(g•cm^{-3})
80% PB: 20% sand	13.74 b[u]	53.38 a	67.12 [NS]	0.44 a
40% PB: 40% ERC: 20% sand	28.06 a	43.06 b	71.12	0.40 b
80% ERC: 20% sand	34.10 a	33.24 c	67.34	0.38 c
Recommended Ranges	10-30	45-65	50-85	0.19-0.70

[z] Analysis performed using the North Carolina State University porometer (http://www.ncsu.edu/project/hortsublab/diagnostic/porometer/).
[y] Air space is volume of water drained from sample ÷ volume of sample.
[x] Container Capacity is (wet weight - oven dry weight) ÷ volume of sample.
[w] Total porosity is container capacity + air space.
[v] Bulk density after forced-air drying at 105°C for 24 h; 1 g•cm^{3}= 62.4274 lb•ft^{3}.
[u] Mean separation within column using Waller-Duncan Multiple Range test (α=0.05).
[t] Recommended ranges as reported by Yeager et al., 2007. Best Management Practices Guide for Producing Container-Grown Plants.
[NS] Means not significantly different.

Table 2.3 Particle size analysis of pine bark (PB)- and eastern redcedar (ERC)-based substrates^{z}.

		Substrate		
U.S Standard Sieve No.	Sieve opening (mm)^{y}	80% PB: 20% sand (g)	40% PB: 40% ERC: 20% sand (g)	80% ERC: 20% sand (g)
1/2	12.50	0.1 a^{x}	0.0 a	0.0 a
3/8	9.50	2.1 a	0.5 a	0.8 a
1/4	6.35	10.8 a	3.1 b	3.1 b
6	3.35	26.1 a	18.8 b	27.3 a
8	2.36	13.6 b	15.4 b	29 a
10	2.00	5.3 b	6.8 b	16.4 a
14	1.40	11.4 b	12.6 b	32.6 a
18	1.00	13.1 b	13.8 b	25.5 a
35	0.50	47.7 a	49.9 a	48.7 a
60	0.25	87.0 a	90.5 a	46.1 b
140	0.11	28.5 a	35.3 a	18.2 b
270	0.05	0.1 ab	1.9 a	0.7 b
pan	0.00	0.0 b	0.3 a	0.1 b
Texture^{w}				
Coarse		39.0 a	22.3 b	31.2 a
Medium		43.4 b	48.6 a	25.9 c
Fine		163.8 a	177.8 a	113.7 b

^{z}250 g (0.55 lb) of substratre used for analysis.

^{y}1 mm=0.0394 in.

^{x}Percent weight of sample collected on each screen, means within

^{w}Coarse=3.35-12.50 mm; Medium=1.00-2.36 mm; Fine=0.00-0.50 mr

Table 2.4 Substrate pH and electrical conductivity (EC) in pine bark (PB)- and eastern redcedar (ERC)- based substrates for container-grown double pink Knockout® rose (*Rosa* 'Radtkopink').

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

[z] DAP=days after planting

[x] EC measured as $1 mS \bullet cm^{-1} = 1 mmho \bullet cm^{-1}$.

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

Recommended ranges for pH 4.5-6.5 and EC 0.5-1.0

[NS] Means not significantly different.

Table 2.5 Effect of pine bark (PB)- and eastern redcedar (ERC)-based substrates on growth of *Gaillardia x grandiflora* 'Goblin', *Ilex glabra* 'Compacta', *Miscanthus sinensis* 'Little Kitten', *Rosa* 'Radtkopink', *Ulmus parvifolia* 'Emer II', and *Sedum telphium* 'Autumn Joy' in a nursery production setting.

	Allee® lacebark elm			Double pink Knockout® rose		Inkberry holly		Maiden grass		Sedum
	Shoot Dry Wt.(g)[z]	Root Dry Wt.(g)[y]	71 DAP[x] SPAD	Shoot Dry Wt. (g)	Root Dry Wt. (g)	Shoot Dry Wt.(g)	Root Dry Wt.(g)	Shoot Dry Wt.(g)	Root Dry Wt.(g)	120 DAP GI
80% PB: 20% sand	109.8 a[w]	109.9 a	50.1 [NS]	72.1 [NS]	14.8 [NS]	60.6 a[u]	23.9 [NS]	194.8 a	81.8 [NS]	30.0 b
40% PB: 40% ERC: 20% sand	93.3 a	96.5 a	48.1	83.3	25.3	46.3 ab	18.3	129.1 ab	52.5	33.3 a
80% ERC: 20% sand	55.6 b	67.8 b	51.0	74.5	23.1	33.8 b	15.5	69.3 b	55.2	32.2 ab
	113 DAP GI[v]	113 DAP Caliper[u]		120 DAP GI	71 DAP SPAD	120 DAP GI	71 DAP SPAD	120 DAP GI		
80% PB: 20% sand	83.5 ab	8.1 b		52.6 [NS]	45.2 ab	37.7 a	49.5 b	106.8 a		
40% PB: 40% ERC: 20% sand	88.8 a	9.0 a		58.2	39.0 b	36.5 a	50.3 ab	100.7 ab		
80% ERC: 20% sand	80.5 b	7.5 b		50.3	48.4 a	30.1 b	57.8 a	89.6 b		

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

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

[x] DAP= Days after potting.

[v] Growth index=(height+width+perpendicular width/3).

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

[w] Mean separation within column using Waller-Duncan Multiple Range test (α=0.05).

[NS] Means not significantly different.

Table 2.6. Effect of pine bark (PB)- and eastern redcedar (ERC)-based substrates on the growth and landscape establishment of inkberry holly and hosta plants. All other species showed no difference in growth for any of the measurements.

	Inkberry holly						**Hosta**				
	Growth Index			**Shoot Dry**	**Root Dry**	**SPAD**	**Growth Index**			**Shoot Dry**	**Root Dry**
	230 DAP[z]	**292 DAP**	**329 DAP**	**Weight[y] (g)**	**Weight[x] (g)**		**230 DAP**	**292 DAP**	**329 DAP**	**Weight (g)**	**Weight (g)**
80% PB: 20% sand	43 a[w]	51 a	58 a	253 a	139 [NS]	50 [NS]	43 a	37 a	33 a	26 a	65 a
40% PB: 40% ERC: 20% sand	44 a	50 ab	56 a	218 ab	144	49	37 b	31 b	27 ab	19 ab	42 b
80% ERC: 20% sand	36 b	42 b	47 b	169 b	118	49	28 c	24 b	25 b	12 b	24 b

[z] DAP=Days after potting.

[y] Shoots harvested at soil level and oven dried at 71°C until weight stablized (1 g=0.0035 oz).

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

[w] Means separation within column using Waller-Duncan Multiple Range test (α=0.05).

[NS] Means not significantly different.

Chapter 3 - Effect of Cyclic Irrigation on Growth of Container-Grown Perennials in Eastern Redcedar Amended Substrates

Abstract

To attempt to overcome the sub-optimal physical properties (high air space and low container capacity) of alternative substrates composed, in part, of eastern redcedar (*Juniperus virginiana* L.;ERC), cyclic irrigation was used to evaluate growth of *Sedum spectabile* Boreau 'Autumn Fire' (sedum), *Rudbeckia fulgida* Aiton 'Goldstrum' (black-eyed susan), and *Hibiscus moscheutos* L. 'Luna White' (hibiscus) in three substrates consisting of 80% pine bark (PB): 20% sand 40% PB: 40 ERC: 20% sand and 80% ERC: 20% sand. Cyclic irrigation is the splitting of the prescribed amount of water per day, among a series of cycles that consist of intervals of rest and irrigation. Using cyclic irrigation helps reduce run-off/leachate from containers in return increasing irrigation efficiency. The objective of this study was to evaluate the affect of irrigation frequency (1x, 2x, 3x, or 6x per day) and substrate ERC content on plant growth. Sedum had the greatest growth index (GI) and shoot dry weight in PB and when irrigated 1x and 2x per day had the greatest root dry weight regardless of substrate. Irrigation frequency had no significant difference for GI and shoot dry weight. Black-eyed susan had the greatest GI and shoot dry weight when grown in PB. Irrigation frequency only had an impact on shoot dry weight of black-eyed susan; plants irrigated 1x, 2x, and 3x per day had the greatest growth though 3x was similar to 6x. Hibiscus had the greatest growth in PB: ERC mix (GI, SPAD, flower count, shoot and root dry weight). Irrigation frequency had

no impact on growth of hibiscus. Cyclic irrigation does not overcome low water holding capacities in these three species when grown in a greenhouse. Overall, ERC can be used as a partial replacement to PB (up to 50%). However, further research evaluating effects of different fertility regimes on ERC substrate is warranted.

Significance to the Industry

Eastern redcedar (*Juniperus virginiana* L.; ERC) has become a weedy tree due to the lack of natural controls. For the Great Plains region, ERC has been evaluated as a local and sustainable alternative to pine bark (PB). Eastern redcedar is known for having high air space (AS) and low container capacity (CC). In this study, cyclic irrigation was used to try to overcome the poor physical properties (high AS and low CC) of ERC. At the conclusion of the study, cyclic irrigation did not overcome the physical properties of ERC in a greenhouse environment.

Introduction

Eastern redcedar (*Juniperus virginiana* L.; ERC) can be used as an alternative substrate component for nursery crops in the United States Great Plains, a region where pine bark (PB) for nursery production must be shipped great distances. Eastern redcedar, a weedy tree species, has become plentiful in the Great Plains region due to the lack of natural fires and livestock grazing (Starr et al., 2012; Drake and Todd, 2002; Stritzke and Rollins, 1984). Eastern redcedar is harvested (cut) in tree-infested pastures and allowed to dry for six months to one year before chipping of the trees occurs (Griffin, 2009). After chipping of ERC these chips can be used either for landscape mulch or can be processed further with a hammer mill for use as an alternative substrate. A study conducted by Starr et al. (2012) evaluated substrates containing ERC and hedge-apple [*Maclura pomifera*

(Raf.) C.K. Schneid] as alternatives to PB when growing black-eyed susan (*Rudbeckia fulgida* Aiton var. *fulgida*), 'Graziella' maiden grass (*Miscanthus sinensis* Andersson 'Graziella'), 'Arapaho' crapemyrtle (*Lagerstroemia* L. x 'Arapaho'), baldcypress [*Taxodium distichum* (L.) Rich.], and redbud (*Cercis Canadensis* L.). In this study, shoot dry weight and plant growth indices decreased as particle size of ERC increased. This difference was attributed to low container capacity (CC) and high air space (AS)(Starr et al., 2012). Mixing either ERC or hedge-apple with PB could help adjust CC into recommended ranges.

Soil-less substrates typically have low moisture retention properties necessitating daily watering during the growing season (Warren and Bilderback, 2002; Yeager et al. 2007). In particular, wood-based substrates such as ERC have high AS and low CC, resulting in the substrate drying out faster than traditional mixes, which could reduce plant growth. Several studies have cited this as a potential reason for reduced growth in wood-based substrates. It is possible that increasing irrigation frequency (but not volume) may help overcome these issues with wood-based substrates. Surveys conducted in the Southeastern U.S. noted that producers tend to follow the best management practice of irrigating plants before 1000 HR. Most nurseries irrigate for one hour applying approximately 2.45 cm/hr (1 in/hr; Fain et al., 2000). Nurseries in the study were monitored for one year, and it was noted that the nurseries were under-applying the inch of water by 40% or only applied an average of 0.6 in/hr (1.6 cm/hr). Keever and Cobb (1985) noted that plants respond to a split irrigation regimen (a.k.a. cyclic irrigation). Splitting the irrigation up over two applications for container-grown 'Skogholm' cotoneaster (*Cotoneaster dammeri* C.K. Schneid. 'Skogholm') increased shoot and root growth and resulting in decreased canopy and substrate temperatures. The authors showed that reduced substrate temperatures have a positive impact on plant growth. Irrigating plants during the day when plants are more actively transpiring and taking up water has been shown to increase growth and reduce water stress by making more water available in the substrate during the night hours (Warren and Bilderback, 2002).

Cyclic irrigation is the splitting of the prescribed amount of water per day, among a series of cycles that consist of intervals of rest and irrigation. These series of cycles help improve irrigation efficiency and nutrient retention (Warren and Bilderback, 2002; Tyler et al., 1996). By allowing rest periods between irrigation cycles, water then has the time to move from the macropore system to the micropore system of the containers substrate. These resting periods reduce the amount of run-off/leachate and also help retain nutrients in the container substrate reducing fertilizer costs and environmental remediation efforts.

The objective of this study was to determine if cyclic irrigation can help overcome reduced growth potentially caused by high AS and low CC in ERC-based substrates. Water was applied to container-grown crops in alternative substrates in a series of cycles in order to keep constant moisture in the root zone, reducing plant stress and improving growth.

Materials and Methods

Experiment 1 (Sedum)

Eastern redcedar (Queal Enterprises, Pratt, KS) was processed through a hammer mill (C. S. Bell Co., Tiffin, OH, Model 30HMBL) with a 0.95 cm (3/8 in.) screen on June 23, 2011. On July 22, 2011, substrates consisting of 80% PB (SunGro, Bellevue, WA):

20% sand; 40% ERC 40% PB: 20% sand (PB:ERC); or 80% ERC: 20% sand (by vol.) were mixed using a rotary mixer (Whiteman Industries Inc., Carson, CA, Model WM-70). There were no pre-plant incorporated nutrients. Rooted liners of *Sedum spectabile* Boreau 'Autumn Fire' (sedum; Emerald Coast Growers, Pensacola, FL 50 count cell pack) were transplanted into quart (1.7 L) containers (Classic 200, Nursery Supplies Inc., Chambersburg, PA) on July 22, 2011. Plants were placed in a glass greenhouse maintained at 80°F (26.7°C) day-time and 70°F (21.1°C) night-time temp at Throckmorton Plant Science Center greenhouse complex located on Kansas State University campus in Manhattan, KS. Plants were watered by hand as needed for 15 days after planting (DAP) to allow plugs to root into the new substrates and to ensure that the entire substrate profile was moist at the beginning of the irrigation cycle treatments. Containers were top-dressed with 1 g (0.002 lb.) of Osmoform 18N-5P-13K 3 – 4 month slow release fertilizer (The Scotts Co. Maryville, OH) on Aug 6, 2011 (16 DAP).

Substrate physical properties were determined using the porometer procedures set forth by North Carolina State University (Fonteno and Harden, 2003). Particle size distribution analysis was conducted by placing 250 g (0.55 lb.) of substrate in a Ro-Tap sieve shaker (W.S. Tyler, Mentor, OH). Substrates were allowed to pass through 12 sieves:12.50, 9.50, 6.35, 3.35, 2.36, 2.00, 1.40, 1.00, 0.50, 0.25, 0.11, 0.05, and pan. Sieve sizes were grouped into coarse (12.50, 9.50, 6.35, 3.35, 2.36, 2.00, and 1.40), medium (1.00, 0.50, and 0.25) and fine (0.11, 0.05, and pan) to determine particle distribution.

An irrigation system using a Rain Bird STP9PL (Rain Bird Corp. Tucson, AZ; Figure 3.1) controller was designed to irrigate plants at four frequencies (1x, 2x, 3x, and

6x; Figure 3.2). All plants received 208 cm^3 (7.03 oz.) of water per day using drip stakes (Angle Arrow Dripper 5/3, Netafim, Tel Aviv, Israel). To control the amount of water applied daily, 1892.7 cm^3 per hr (0.5 gallons per hr; gph) pressure compensating drip emitters (0.5 gph Woodpecker Pressure Compensating Junior Drip Emitter, Netafim, Tel Aviv, Israel) were attached to the main line for each treatment. Sedum irrigated 1x were irrigated at 0800 HR; 2x irrigated at 1100 and 1500 HR; 3x irrigated at 0900, 1200 and 1500 HR; and 6x irrigated at 0800, 1000, 1200, 1400, 1600, and 1800 HR. At 15 DAP the irrigation treatments were initiated. Electrical conductivity (EC) and pH were measured at 42, 62, and 81 DAP using the Pour-Through method (Wright, 1986). Growth index (GI) [(height x width x perpendicular width) ÷ 3] was measured at 25 and 80 DAP and substrate shrinkage was measured at 42 DAP. At the conclusion of the study shoots were severed at substrate level and roots were washed of all substrate. Shoots and roots were placed into paper bags and dried in a forced-air oven (Grieve SC-350 Electric Shelf Oven, Round Lake, Il) at 71°C (160°F) until dry weight stabilized (13 days). The experimental design was a 3 x 4 factorial (substrate by irrigation frequency) arranged in a randomized complete block with 6 single plant reps. Data was analyzed with SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) and means were separated by the Waller-Duncan Multiple Range Test (α=0.05).

Experiments 2 and 3 (Rudbeckia and Hibiscus)

Eastern redcedar (Queal Enterprises. Pratt, KS) was processed through a hammer mill (C. S. Bell Co., Tiffin, OH, Model 30HMBL) with a 3/8-inch screen on February 24, 2012 and April 25, 2012. On Feb 29, 2012 and June 19, 2012, substrates consisting of 80% PB (SunGro, Bellevue, WA): 20% sand; 40% ERC 40% PB: 20% sand (PB:ERC);

and 80% ERC: 20% sand (by vol.) were mixed using a rotary mixer (Whiteman Industries Inc., Carson, CA, Model WM-70). Osmoform 18N-5P-13K with micronutrients, 3 – 4 month slow release fertilizer (The Scotts Co. Maryville, OH) was incorporated into the substrates during mixing. Substrate physical properties and particle size analysis were analyzed the same as experiment 1. Rooted liners of *Rudbeckia fulgida* Aiton 'Goldstrum' (black-eyed susan, 72 count cell pack) and *Hibiscus moscheutos* L. 'Luna White' (hibiscus, 50 count cell pack) [Emerald Coast Growers (Pensacola, FL)] were transplanted into 1-gallon (3.8 L) containers (Classic 400, Nursery Supply Inc. Chambersburg, PA) on February 29, 2012 and June 19, 2012 respectively. Plants were placed in a glass greenhouse maintained at 70°F (21.1°C) day-time and 65°F (18.3°C) night-time temp at Throckmorton Plant Science Center greenhouse complex located in Manhattan, KS. *Rudbeckia* were hand-watered for 7 days after planting (DAP) and *Hibiscus* were hand-watered for 3 DAP to allow plugs to begin rooting into the new substrates and to ensure that the entire substrate profile was moist.

A 12-station Sterling Controller (Superior Controls Co., INC, Torrance, CA; Figure 3.3) was used to program the four watering frequencies, 1x, 2x, 3x, and 6x per day (Figure 3.4). Each of the four zones used a Rain Bird (Rain Bird Corp. Tucson, AZ) 1.91 cm (¾ inch) valve with flow control attached to polyethylene tubing that delivered 11356.2 ml per hr (3 gph) Woodpecker pressure-compensating drip emitters (Netafim, Tel Aviv, Israel) and 11356.2 ml per hr (3 gph) Netafim spray stakes (Netafim, Tel Aviv, Israel) were attached to the end of spaghetti polyethylene tubing for each container in that particular water frequency. Black-eyed susan and hibiscus were irrigated 1x at 0800 HR; 2x irrigated at 1100 and 1500 HR; 3x irrigated at 0900, 1200 and 1500 HR; and 6x irrigated at 0800, 1000, 1200, 1400, 1600, and 1800 HR all four frequencies totaling 350 mL (11.83 oz.) of water per day. Black-eyed susan and hibiscus were chosen for these two studies due to their perceived negative response to water deficit stress. The experimental design was a 3x4 factorial (substrate by irrigation frequency) arranged in a randomized complete block design with 6 single plant reps. Data was analyzed using SAS (Statistical Analysis System, SAS Institute Inc., Cary, NC) and means were separated by using Waller-Duncan Multiple Range Test (α=0.05).

Rudbeckia data collection

Growth indices for black-eyed susan were measured at 8 and 91 DAP. On 91 DAP leaf greenness was measured by taking the average of 4 fully expanded leaves using a SPAD-502 Chlorophyll Meter (Konica Minolta, Ramsey, NJ). Electrical conductivity (EC) and pH were measured on 43, 57, 75, and 90 DAP. Leachates obtained for pH and EC measurements were obtained the same way as experiment 1. At the conclusion of the study shoots were severed at the soil surface and placed into a paper bag for drying. Roots were washed of substrate before being placed into a paper bag. Shoot and roots were then placed into a forced-air oven (Grieve SC-350 Electric Shelf Oven, Round Lake, Il) at 160°F (71°C) until weight stabilized, 8 days.

Hibiscus data collection

Growth indices for Hibiscus were measured on 2 and 58 DAP. On 22 and 58 DAP leaf greenness was determined similarly to experiment 2. Electrical conductivity and pH were measured on 20, 35, and 50 DAP. Leachate obtained for pH and EC measurements were obtained the same as experiment 1 and 2. Leachate was filtered through Whatman® No. 2 filter paper (Whatman International Ltd, Maidston, England) before being frozen until the conclusion of the study. Leachates were analyzed at the Kansas State University, Department of Agronomy Soil Testing Laboratory (Manhattan, KS) for nutrient analysis. Leachate nitrate were prepared for analysis using a cadmium reduction and colorimetric reaction (Alpkem, 1986a). Leachate ammonia were prepared for analysis using an indophenol colorimetric reaction (Alpkem, 1986b). Both nitrate and ammonia solutions were analyzed using a Rapid Flow Analyzer (Model RFA-300, Alpkem Corp. Clackamas, OR). Leachate phosphorus (P) and potassium (K) were analyzed using a Inductively Coupled Plasma (ICP) Spectrometer (Model 720-ES ICP Optical Emission Spectrometer, Varian Australia Pty LTD, Mulgrave, Vic Australia). Once flowering started, approximately 49 DAP, flower counts were measured daily, any fully-opened flowers, were removed from the plant at the natural point of abscission. At the conclusion of the study, ten-recently mature leaves were harvested and analyzed for leaf nutrient content by Kansas State University, Department of Agronomy, Soil Testing Laboratory (Manhattan, KS). Leaf nutrient analysis for nitrogen (N), P and K were prepared using the Sulfuric Peroxide digest (Linder and Harley, 1942; Thomas et al., 1967). Leaves used for ammonia analysis were prepared using a colorimetric procedure (nirtoprusside-sodium hypochlorie; Alpkem, 1986c). Leaf N-levels were analyzed using a Rapid Flow Analyzer (Model RFA-300. Alpkem Cor. Clackamas, OR). Leaf P and K were analyzed using a Inductively Coupled Plasma (ICP) Spectrometer (Model 720-EC ICP Optical Emission Spectrometer, Varian Australia Pty Ltd, Mulgrave, Vic Australia). Shoots and roots were harvested and processed similarly to the previous experiments.

Results

Experiment 1 (Sedum)

pH and EC

Eighty-one DAP, substrate pH was highest for plants grown in ERC and PB: ERC (Table 3.1). pH was unaffected by irrigation frequency at any of the DAP measured. EC levels were unaffected by substrates until 81 DAP with PB: ERC being greatest and PB being the lowest while ERC being similar to both. Throughout the entire study pH and EC levels were not affected by irrigation frequency.

Physical Properties

Air space of ERC and PB: ERC was higher than the recommended range (Table 3.2; Yeager et al., 2007). Container capacity of PB was highest when compared to PB:ERC and ERC, which were below recommended ranges. All three substrates showed similarities and were within the recommended ranges for total porosity (TP) and bulk density (BD) (Table 3.2). Eastern redcedar had equal coarse particle sizes to PB (Table 3.3). Pine bark:ERC had the greatest amount of medium particles compared to the other treatments. Pine bark and ERC had similar amounts of fine particles. Eastern redcedar had the greatest substrate shrinkage when compared to PB and PB:ERC, which were similar to each other (Table 3.4).

Sedum

By 80 DAP plants grown in ERC had significantly lower GI than plants grown in PB and PB: ERC mix (Table 3.4). For the duration of the study, irrigation frequencies did not have an impact on GI. Shoot dry weight was greatest for plants grown in PB followed by PB:ERC and then ERC. In contrast, shoot dry weight was unaffected by irrigation frequency. Sedum grown in PB had root dry weight greater than PB: ERC mix, but not different from ERC. Root dry weight was significantly affected by irrigation frequencies with 1x per day being greater than 3x and 6x per day (Figure 3.5; Figure 3.6; Figure 3.7). This suggests that Sedum had best root growth when watered 1x per day, but also could tolerate irrigating 2x. Data also shows that while root growth was not greatly affected by alternative substrates, shoot growth was inhibited with increasing ERC content.

Experiment 2 and 3 (Rudbeckia and Hibiscus)

pH and EC

Black-eyed Susan

Throughout the study, ERC had the highest substrate pH levels while PB and PB:ERC were lower and all were above recommended ranges except for 76 DAP (Table 3.1). Irrigation frequency did not influence substrate pH. Electrical conductivity showed no differences among substrates at 29 DAP, but there were differences observed among irrigation frequency (Table 3.1). At 29 DAP, 2x irrigation frequency had the highest EC, with similarities to 1x and 6x. Throughout the remainder of the study, except for 58 DAP, ERC and PB: ERC mix had a higher EC level when compared to PB. After 29 DAP, irrigation frequency did not influence EC levels.

Hibiscus

At the end of the study PB: ERC mix had the lowest substrate pH when compared to PB and ERC (Table 3.1). Irrigation frequency did not influence pH levels at any point during the study. Electrical conductivity at 50 DAP was similar for PB:ERC and ERC though ERC was also similar to PB (Table 3.1). Irrigation frequency did not influence EC until 50 DAP, then 6x was higher than 1x, although 2x and 3x were similar to both 6x and 1x.

Physical Properties

No significant differences for AS were observed among substrates (Table 3.2). Container capacity was significantly lowest among substrates containing ERC (and below recommended levels). There were no differences for TP or BD. Unlike previous substrates evaluated (sedum study) where there were significant differences in particle size distribution, in the study with black-eyed susan and hibiscus there were no significant differences among the three substrates and the size distribution of coarse and fine particles with ERC and PB:ERC having similar medium particle size (Table 3.5).

Growth Data

Black-eyed susan

Plant growth was similar to sedum in that at 91 DAP plants grown in PB had higher GI and shoot dry weight followed by PB:ERC then ERC (Figure 3.8; Figure 3.9; Figure 3.10; Table 3.4). However, root dry weight showed no significant differences among substrates. Irrigation frequency did not affect any measurement except shoot dry weight, with plants irrigated 6x had less biomass than all other frequencies except 3x (Figure 3.11). There were no differences in leaf greenness at any rating date, nor was it affected by irrigation frequency (Table 3.4).

Hibiscus

For all growth measurement (GI, shoot dry weight, root dry weight, SPAD and flower count) the greatest plant response was obtained with the PB:ERC mix, followed by PB and then ERC (Figure 3.12; Figure 3.13; Figure 3.14; Table 3.4). There is one exception for SPAD where PB:ERC was similar to ERC (PB was less green than both). Throughout the study irrigation frequency had no influence on any measurement except SPAD, where plants irrigated 1x and 2x had greater leaf greenness than other treatments (Figure 3.15).

Nutrient Analysis

Given that data from the first two experiments indicated that root growth was similar among substrates and increasing irrigation frequency did not overcome less shoot growth, we hypothesized that nutrients might be leaching more readily from ERC-based substrates. Therefore, in the 3rd experiment (Hibiscus), leachate and leaf samples were collected for analysis to determine fertilizer level in the substrates.

Leachate nutrient analysis at 20 DAP showed PB and PB:ERC had similar NH_4 (ammonium) levels while plants grown in ERC had lower levels (Table 3.6). No significant differences for NO_3 (nitrate) levels were seen among the three substrates. Pine bark leachate indicated higher levels of phosphorus (P) when compared to PB:ERC and ERC. Pine bark leachate also indicated higher levels of potassium (K) when compared to PB:ERC and ERC with ERC having the lowest levels (Table 3.6). Irrigation frequency influenced NO_3 levels with 3x per day having the highest presence in the leachate, however, 3x per day was also comparable to 1x and 6x per day. Irrigating two times per day had the lowest level but was also comparable to one and six times per day. At 35 and 50 DAP there were no significant differences in NH_4, NO_3, or P among the three substrates. However, K at 35 and 50 DAP was highest for PB when compared to PB:ERC and ERC, which were similar to each other.

Leaf nutrient analysis showed that ERC and PB:ERC had the highest levels of N. Irrigation frequency did not influence nitrogen (N) levels in the leaf (Table 3.6). Plants grown in the three substrates were within the recommended N range (1.0 to 6.0%) for N (Mills and Jones, 1996). Plants grown in ERC had the highest levels of P in the leaves when compared to PB and PB:ERC, which were similar to each other. Only ERC was within the recommended P range (0.2 to 0.5%). Whereas, plants grown in PB and PB:ERC were below the recommended P range. These plants would be considered P deficient. When P drops below 0.2%, retarded growth and lowered shoot to root ratio can occur (Mills and Jones, 1996). Irrigation frequency had an influence on P levels in plants irrigated 6x which had the highest level, but were similar to 2x and 3x. Plants irrigated 2x to 3x also showed similarities to 1x, which had a lower P levels when compared to 6x. Potassium levels were highest in plants grown in PB:ERC when compared to PB and ERC, which showed similarities between the two substrates. Plants grown in the three substrates were within recommended K range of 1.5 to 4%. Irrigation frequency did not influence K levels within the leaf.

Discussion

Sedum and black-eyed susan displayed the greatest growth in PB when irrigated 1x per day, with black-eyed susan able to be irrigated 2x and 3x per day. Irrigation frequency for black-eyed susan had no influence on GI, root dry weights and SPAD. Unavailable nutrients could potentially be the reason for the difference in shoot growth among substrates. Studies conducted by Jackson et al., (2008) suggests wood-based substrates may need higher fertilizer rates than PB to achieve similar growth due to increased microbial activity in decomposing wood-based substrates. Hibiscus grown in

PB:ERC with cyclic irrigation resulted in no influence on growth. At the end of the study, nutrient analysis of substrate leachate had no influence on nutrient levels except for potassium (K). Leaf nutrient analysis showed that only phosphorus (P) was influenced irrigation frequency with the highest levels of P in plants that were irrigation 6x per day.

Increasing irrigation frequency did not overcome low CC in ERC-based substrates and had no major influence on perennial plants growth in alternative substrates under greenhouse settings. Results of the three studies indicate that ERC can be used as a partial replacement/supplement for PB, but it will be important to determine the cause of reduced plant growth in ERC. Future studies should focus on evaluating the use of a variety of fertilizer regimens to determine optimum plant nutrition for improving shoot growth of plants grown in ERC-based substrates.

Literature Cited

Alpkem Corporation. 1986a. RFA Methodology No. A303-S170.

Alpkem Corporation. 1986b. RFA Methodology No. A303-S021.

Alpkem Corporation. 1986c. RFA Methodology No. A303-S072

Drake, B., and P. Todd. 2002. A strategy for control and utilization of invasive juniper species in Oklahoma: Final report of the "Redcedar Task Force". Oklahoma Dept. of Ag, Food, and Forestry. 17 July 2012. <http://www.forestry.ok.gov/websites/forestry/images/rcstf.pdf>

Fain, G.B., C.H. Gilliam, K.M. Tilt, J.W. Olive, B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18: 142-144.

Fonteno W.C. and C.T. Harden. 2003 Procedures for determining physical properties of horticultural substrates using the NCSU porometer. North Carolina State University.

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

Jackson, B.E., R.D. Wright, J.F. Browder, J.R. Harris, and A.X. Niemiera. 2008. Effect of fertilizer rate on growth of azalea and holly in pine bark and pine tree substrates. HortScience. 43: 1561-1568.

Keever, G.J. and G.S. Cobb. 1985. Irrigation scheduling effects on container media and canopy temperature and growth of 'Hershey's Red' azalea. HortScience 20: 921-923.

Linder, R.C, and C.P. Harley. 1942. A rapid method for the determination of nitrogen in plant tissue. Sci. 96565-96566.

Mills, H.A., and J.B. Jones, Jr. 1996. Plant Analysis Handbook II. Micromacro Publishing, Athens, GA.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59240-59243.

Tyler, H.H., S.L. Warren, T.E. Bilderback. 1996. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14: 194

Starr, Z.W., C.R. Boyer, and J.J Griffin. 2012. Eastern redcedar (*Juniperus virginiana*) as a substrate component effects growth of three tree species. J. Envrion. Hort. 30: 189-194.

Stritzke, J.F. and D. Roolins. 1984. Eastern redcedar and its control. Weeds Today. 7-8.

Warren, S.L. and T.E. Bilderback. 2002. Timing of low pressure irrigation affects plant growth and water utilization efficiency. J. Environ. Hort. 20: 184-188.

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

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best management practices guide for production nursery crops. Southern Nurs. Assoc., Atlanta, GA.

Figure 3.1 Rain Bird irrigation controller used for first cyclic irrigation in alternative substrate study (sedum).

Figure 3.2 Irrigation setup including PVC manifold and solenoids used for cyclic irrigation alternative substrate study (sedum).

Figure 3.3 Sterling controller used for cyclic irrigation alternative substrate studies (black-eyed susan and hibiscus).

Figure 3.4 Irrigation setup of PVC manifold and solenoids used for cyclic irrigation alternative substrate studies (black-eyed susan and hibiscus).

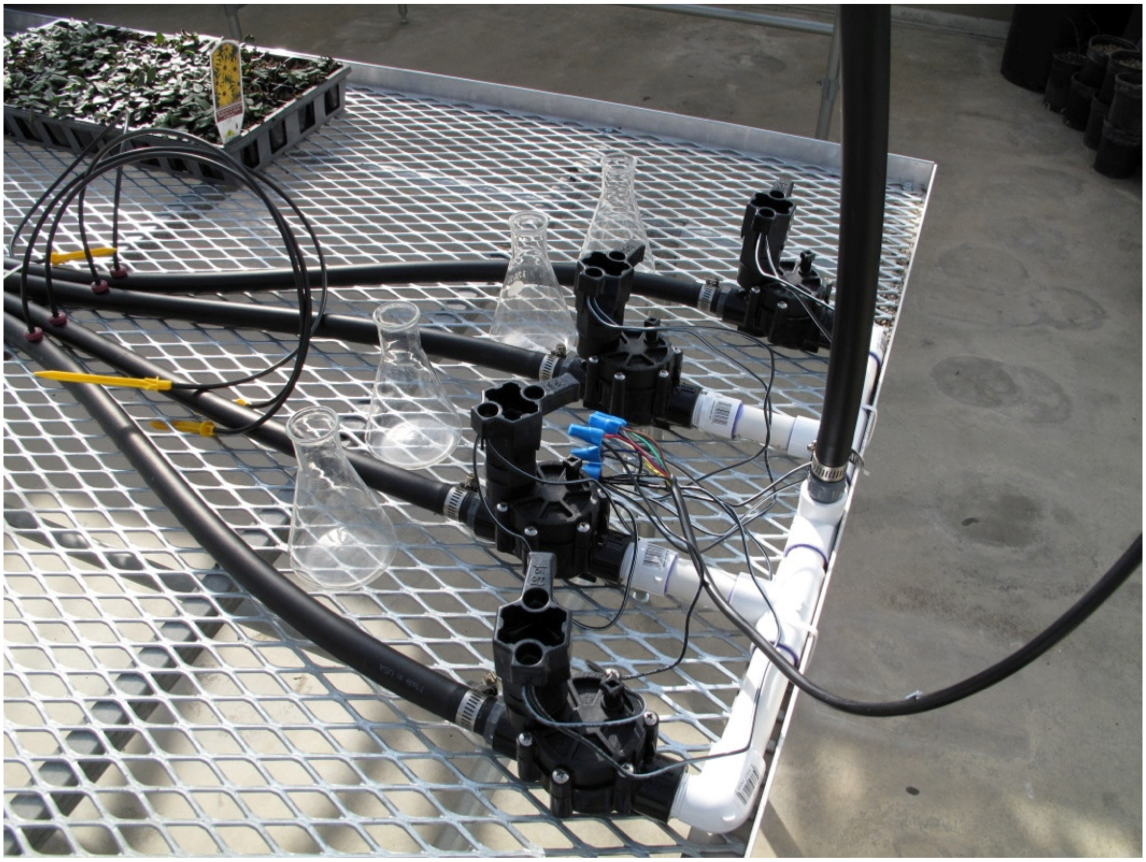

Figure 3.5 Effect of irrigation frequency on sedum (*Sedum spectabile* 'Autumn Fire') grown in PB-based substrates. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

Figure 3.6 Effects of irrigation frequency on sedum (*Sedum spectabile* 'Autumn Fire') grown in PB:ERC-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x, and 6x.

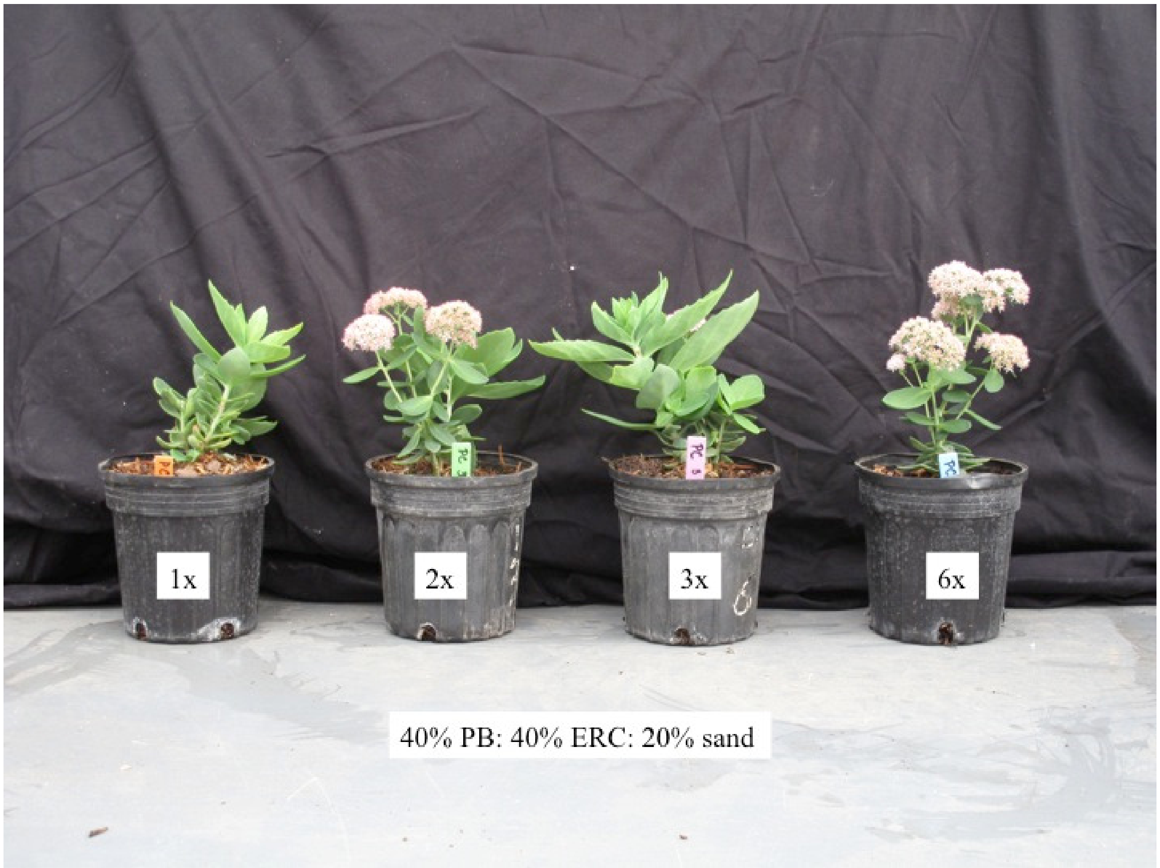

Figure 3.7 Effect of irrigation frequency on sedum (*Sedum spectabile* 'Autumn Fire') grown in ERC-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

Figure 3.8 Effects of irrigation frequency on black-eyed susan (*Rudbeckia fulgida* 'Goldstrum') grown in PB-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

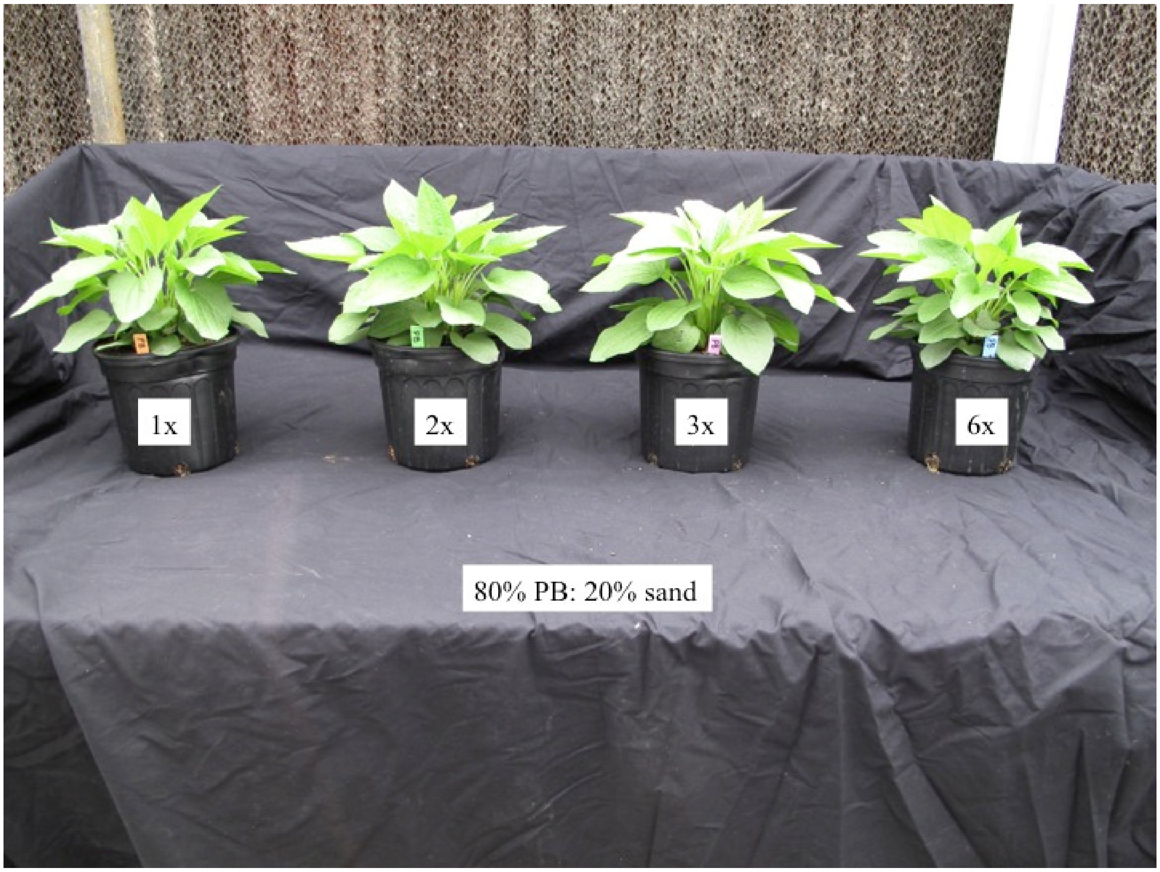

Figure 3.9 Effect of irrigation on black-eyed susan (*Rudbeckia fulgida* 'Goldstrum') grown in PB:ERC-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

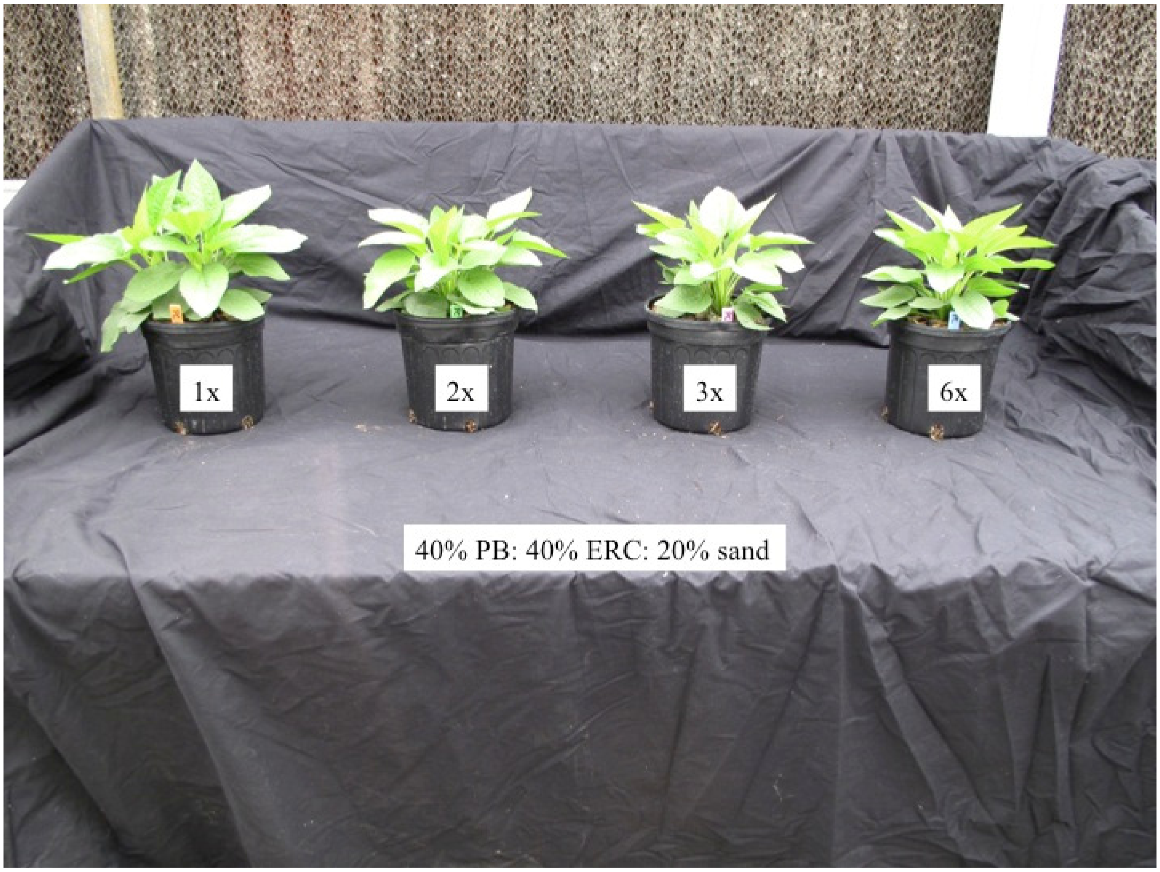

Figure 3.10 Effect of irrigation frequency on black-eyed susan (*Rudbeckia fulgida* 'Goldstrum') grown in ERC-based substrate. Irrigation frequency on a per day basis is noted by 1x, 2x, 3x and 6x.

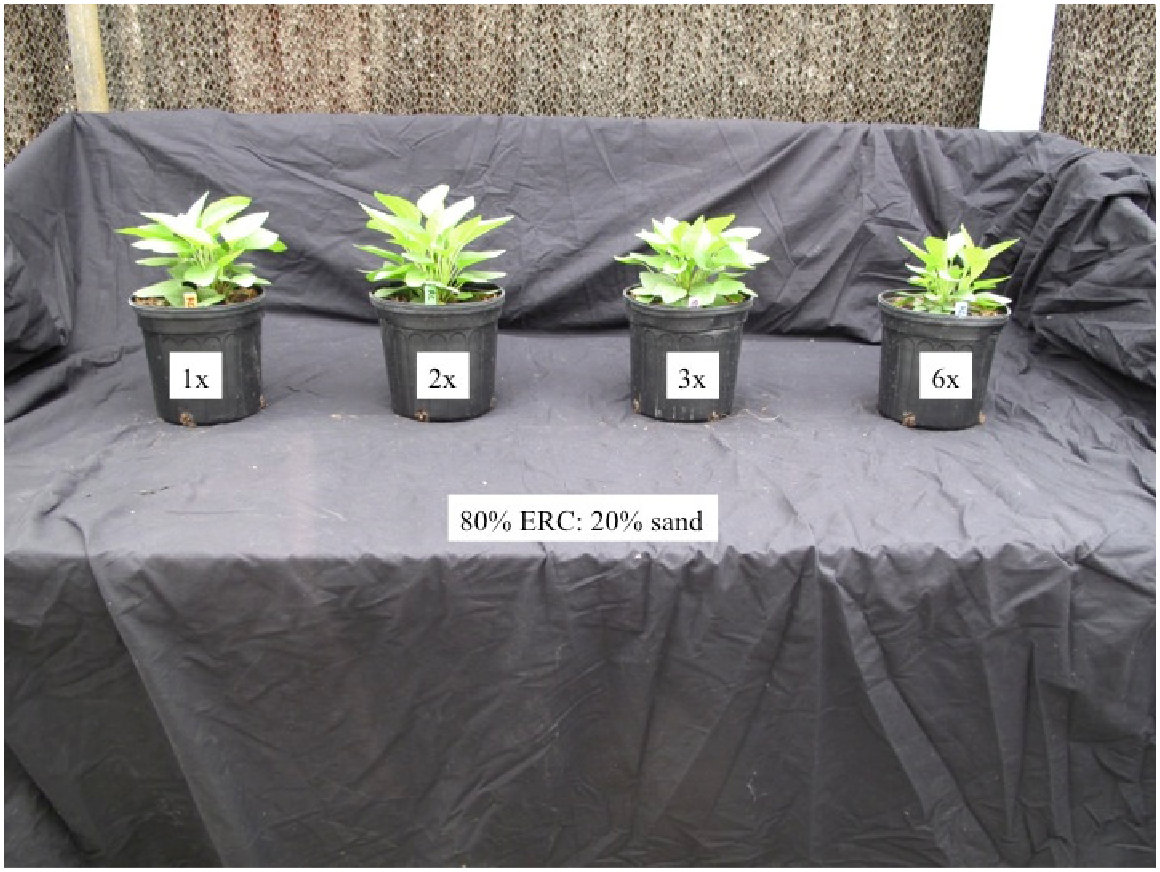

Figure 3.11 Effects of irrigation frequency on black-eyed susan (*Rudbeckia fulgida* 'Goldstrum') blocked by substrate and irrigation frequency. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

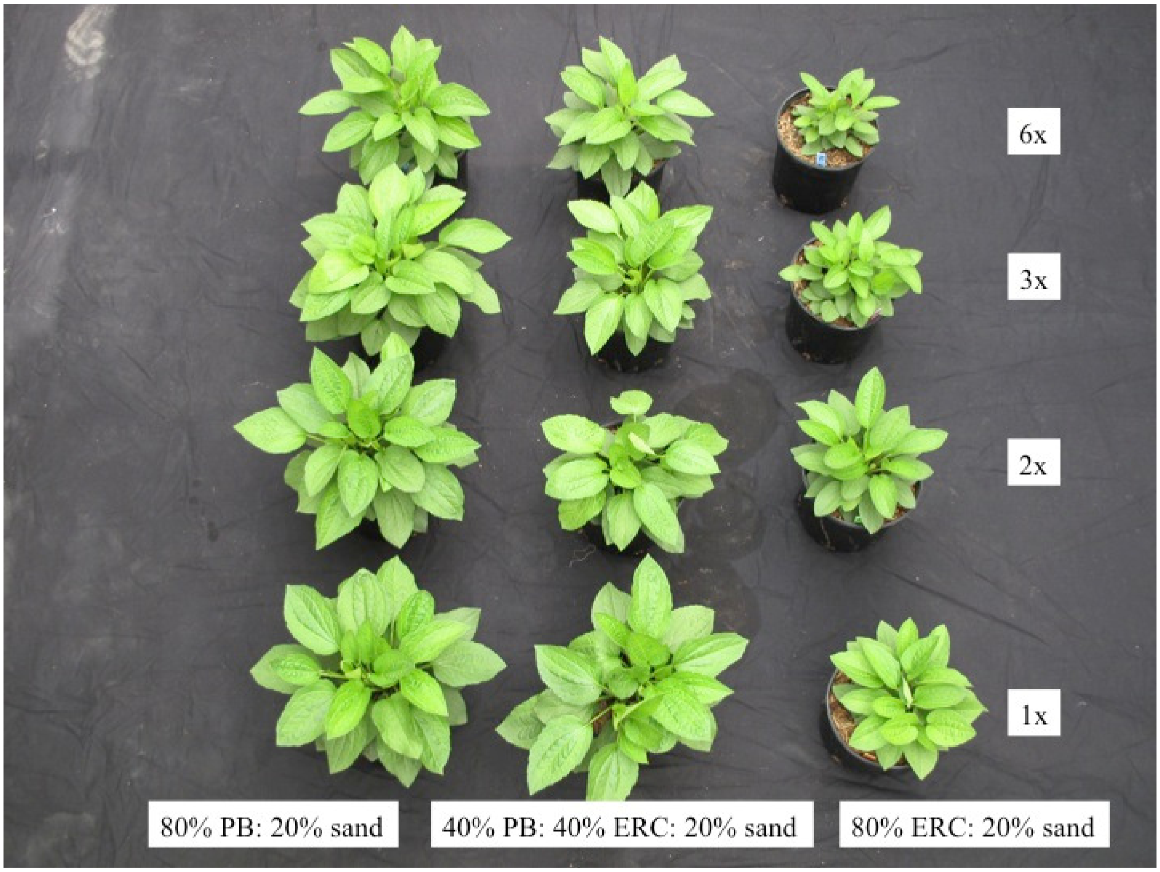

Figure 3.12 Effect of irrigation frequency on hibiscus (*Hibiscus moscheutos* 'Luna White') grown in PB-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

Figure 3.13 Effect of irrigation frequency on hibiscus (*Hibiscus moscheutos* 'Luna White') grown in PB:ERC-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

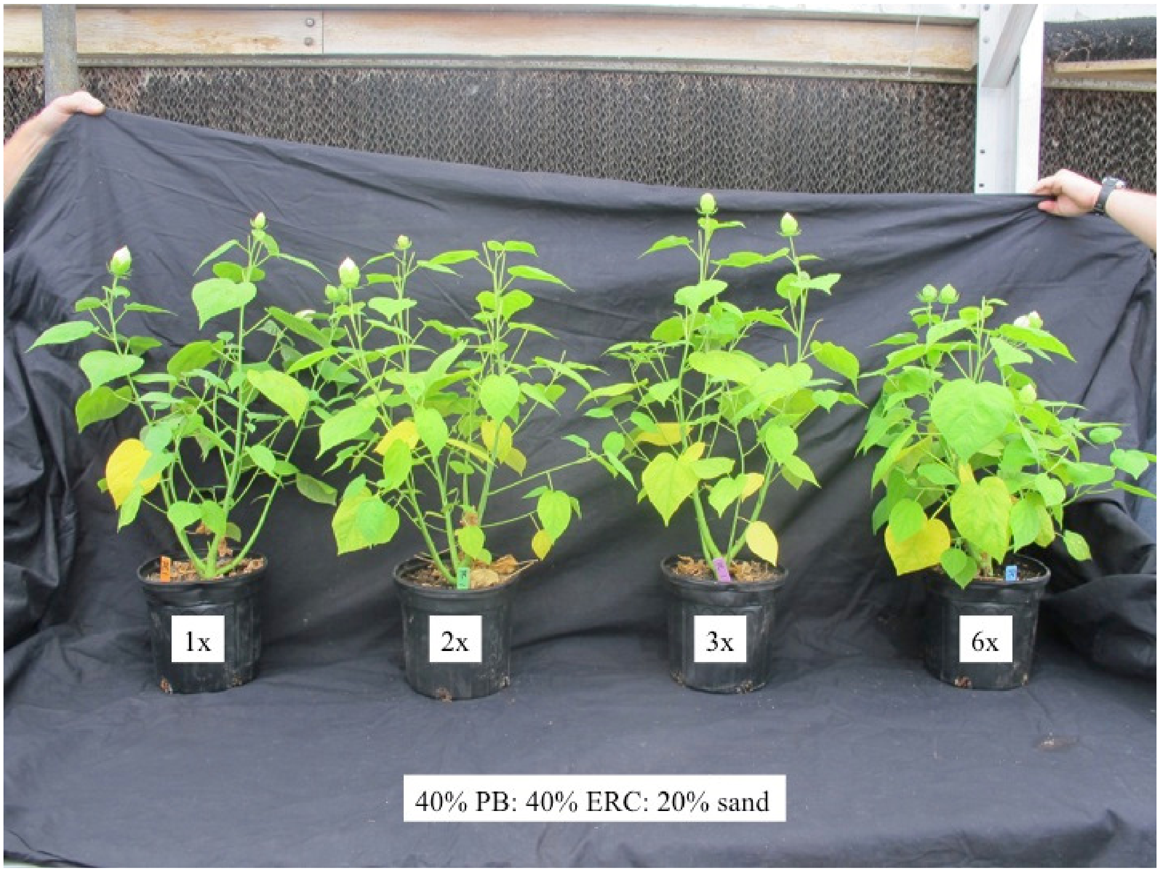

Figure 3.14 Effect of irrigation frequency on hibiscus (*Hibiscus moscheutos* 'Luna White') grown in ERC-based substrate. Irrigation frequency on a per day basis noted by 1x, 2x, 3x, 6x.

Figure 3.15 Effect of irrigation frequency on hibiscus (*Hibiscus moscheutos* 'Luna White') blocked by substrate and irrigation frequency. Irrigation frequency on a per day basis noted by 1x, 2x, 3x and 6x.

Table 3.1 Leachate solution pH and electrical conductivity (EC) of *Sedum spectabile* ‘Autumn Fire’, *Rudbeckia fulgida* ‘Goldstrum’, and *Hibiscus moscheutos* ‘Luna White’ grown in pine bark (PB)- and eastern redcedar (ERC)-based substrates and irrigation either 1x, 2x, 3x, or 6x per day.

	Sedum					
	42 DAP^{y}		62 DAP		81 DAP	
Substrate	**pH**	**EC (dS/m)^{x}**	**pH**	**EC (dS/m)**	**pH**	**EC (dS/m)**
80% PB: 20% sand	7.19 c^{w}	0.46 ^{NS}	7.20 b	0.47 ^{NS}	7.38 b	0.44 b
40% PB: 40% ERC: 20% sand	7.48 b	0.52	7.5 a	0.49	7.66 a	0.50 a
80% ERC: 20% sand	7.78 a	0.45	7.5 a	0.49	7.62 a	0.49 ab
Irrigation						
1x per day	7.51 ^{NS}	0.53 ^{NS}	7.4 ^{NS}	0.53 ^{NS}	7.54 ^{NS}	0.51 ^{NS}
2x per day	7.44	0.45	7.5	0.47	7.89	0.47
3x per day	7.49	0.49	7.4	0.44	7.52	0.48
6x per day	7.49	0.44	7.4	0.49	7.56	0.44
Irrigation water	7.40	0.49	7.2	0.34	7.30	0.36
Interactions^{v}						
Irritaion*Substrate	NS	NS	***	NS	***	NS

	Rudbeckia									
	29 DAP		44 DAP		58 DAP		76 DAP		91 DAP	
	pH	**EC (dS/m)**	**pH**	**EC (dS/m)**	**pH**	**EC (dS/m)**	**pH**	**EC (dS/m)**	**pH**	**EC (dS/m)**
80% PB: 20% sand	6.82 c	1.05 ^{NS}	7.03 b	0.67 b	7.34 b	0.55 ^{NS}	7.02 ab	0.48 b	7.13 b	0.42 b
40% PB: 40% ERC: 20% sand	7.12 b	1.12	7.1 b	1.05 a	7.43 b	0.75	6.9 b	0.66 a	7.21 b	0.60 a
80% ERC: 20% sand	7.74 a	0.95	7.6 a	0.82 b	7.74 a	0.67	7.3 a	0.68 a	7.5 a	0.69 a
Irrigation										
1x per day	7.25 ^{NS}	1.03 ab	7.2 ^{NS}	0.81 ^{NS}	7.44 ^{NS}	0.75 ^{NS}	7.1 ^{NS}	0.63 ^{NS}	7.26 ^{NS}	0.53 ^{NS}
2x per day	7.18	1.30 a	7.3	0.84	7.54	0.59	7.1	0.60	7.26	0.60
3x per day	7.28	0.82 b	7.3	0.77	7.43	0.68	7.1	0.64	7.32	0.61
6x per day	7.20	1.00 ab	7.1	0.96	7.49	0.59	7.1	0.55	7.28	0.54
Irrigation water	7.19	0.42	7.4	0.43	7.27	0.49	7.2	0.37	7.10	0.34
Interactions										
Irrigation*Substrate	NS	NS	**	NS	***	NS	NS	NS	**	NS

	Hibiscus					
	20 DAP		35 DAP		50 DAP	
	pH	**EC (dS/m)**	**pH**	**EC (dS/m)**	**pH**	**EC (dS/m)**
80% PB: 20% sand	7.00 b	0.53 ^{NS}	7.3 b	0.51 b	7.03 b	0.59 b
40% PB: 40% ERC: 20% sand	6.88 b	0.51	7.2 b	0.65 a	6.83 c	0.71 a
80% ERC: 20% sand	7.36 a	0.53	7.6 a	0.58 ab	7.40 a	0.62 ab
Irrigation						
1x per day	7.09 ^{NS}	0.48 ^{NS}	7.4 ^{NS}	0.55 ^{NS}	7.11 ^{NS}	0.57 b
2x per day	7.14	0.50	7.4	0.57	7.07	0.62 ab
3x per day	6.99	0.58	7.4	0.55	7.07	0.63 ab
6x per day	7.11	0.53	7.4	0.64	7.09	0.74 a
Irrigation water	6.97	0.33	7.2	0.39	7.17	0.39
Interactions						
Irrigation*Substrate	***	NS	**	NS	***	NS

^{z}pH and EC of solution obtained by the pour-through method.

^{y}Days after planting.

^{x}Recommended range for pH 4.5 - 6.5 and EC 0.5 - 1.0 dS/m (mmhos/cm)

^{w}Mean separation within column by Waller-Duncan Multiple Range test ($\alpha = 0.05$, n = 48).

^{v}Significant at $P \leq 0.05$ (*), 0.01 (**), 0.001 (***)

^{NS}Means not significantly different

Table 3.2 Substrate physical properties [air space (AS), container capacity (CC), total porosity (TP), and bulk density (BD)] of pine bark (PB)- and eastern redcedar (ERC)-based substrates.

	Experiment 1			
	AS[y] (%)	**CC[x] (%)**	**TP[w] (%)**	**BD[v] (g/cc)**
80% PB: 20% sand	13.74 b[u]	53.38 a	67.12 [NS]	0.44 a
40% PB: 40% ERC: 20% sand	28.06 a	43.06 b	71.12	0.40 b
80% ERC: 20% sand	34.1 a	33.24 c	67.34	0.38 c

	Experiment 2 and 3			
	AS (%)	**CC (%)**	**TP (%)**	**BD (g/cc)**
80% PB: 20% sand	16.26 [NS]	45.8 a	62.06 [NS]	0.48 [NS]
40% PB: 40% ERC: 20% sand	22.23	42.85 b	65.08	0.50
80% ERC: 20% sand	21.87	38.44 c	60.31	0.49

	Recommended[t]			
	AS (%)	**CC (%)**	**TP (%)**	**BD (g/cc)**
	10-30	45-65	50-85	0.19-0.70

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

[y] Air space is volume of water drained from sample ÷ volume of sample.

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

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

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

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

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

[NS] Means not significantly different.

Table 3.3 Particle size analysis of pine bark (PB)- and eastern redcedar (ERC)- based substrates used for experiment 1.

		Substrate		
U.S Standard Sieve No.	Sieve opening (mm)[y]	80% PB: 20% sand (g)	40% PB: 40% ERC: 20% sand (g)	80% ERC: 20% sand (g)
1/2	12.50	0.1 a[x]	0.0 a	0.0 a
3/8	9.50	2.1 a	0.5 a	0.8 a
1/4	6.35	10.8 a	3.1 b	3.1 b
6	3.35	26.1 a	18.8 b	27.3 a
8	2.36	13.6 b	15.4 b	29 a
10	2.00	5.3 b	6.8 b	16.4 a
14	1.40	11.4 b	12.6 b	32.6 a
18	1.00	13.1 b	13.8 b	25.5 a
35	0.50	47.7 a	49.9 a	48.7 a
60	0.25	87.0 a	90.5 a	46.1 b
140	0.11	28.5 a	35.3 a	18.2 b
270	0.05	0.1 ab	1.9 a	0.7 b
pan	0.00	0.0 b	0.3 a	0.1 b
Texture[w]				
Coarse		39.0 a	22.3 b	31.2 a
Medium		43.4 b	48.6 a	25.9 c
Fine		163.8 a	177.8 a	113.7 b

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

[y] 1 mm=0.0394 in.

[x] Percent weight of sample collected on each screen, means within

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

Table 3.4 Effect of pine bark (PB)- and eastern redcedar (ERC)-based substrates and irrigation frequency of either 1x, 2x, 3x or 6x per day on the growth of container-grown *Sedum spectabile* 'Autumn Fire', *Rudbeckia fulgida* 'Goldstrum', and *Hibiscus moscheutos* 'Luna White' in a greenhouse.

	Sedum				
Substrate	**25 DAP GI**	**80 DAP GI**	**Shoot Dry Weight (g)^{y}**	**Root Dry Weight (g)^{x}**	**42 DAP Shrinkage**
80% PB: 20% sand	12.8 a^{v}	19.4 a	7.3 a	10.2 a	1.24 b
40% PB: 40% ERC: 20% sand	11.0 ab	17.8 b	5.8 b	7.8 b	1.34 b
80% ERC: 20% sand	9.4 b	14.8 c	4.4 c	8.6 ab	1.93 a
Irrigation Frequency					
1x per day	12.0 ^{NS}	17.7 ^{NS}	6.0 ^{NS}	10.6 a	1.4 ^{NS}
2x per day	12.0	17.1	6.0	9.7 ab	1.4
3x per day	10.5	17.5	6.1	7.2 c	1.5
6x per day	9.6	17.1	5.3	8.0 bc	1.8
Interaction^{u}					
Irrigation*Substrate	NS	NS	NS	NS	NS

	Black-eyed susan				
	91 DAP GI	**Shoot Dry Weight (g)**	**Root Dry Weight (g)**	**54 DAP SPAD**	**91 DAP SPAD**
80% PB: 20% sand	31.6 a	11.8 a	19.8 ^{NS}	46.5 ^{NS}	33.0 ^{NS}
40% PB: 40% ERC: 20% sand	27.3 b	8.7 b	21.7	48.2	32.4
80% ERC: 20% sand	19.0 c	3.8 c	16.3	47.7	32.1
Irrigation Frequency					
1x per day	26.7 ^{NS}	8.7 a	22.3 ^{NS}	47.7 ^{NS}	33.1 ^{NS}
2x per day	26.3	8.8 a	19.7	46.9	32.6
3x per day	26.6	8.2 ab	20.8	48.4	32.7
6x per day	24.2	6.6 b	14.3	46.8	31.5
Interaction					
Irrigation*Substrate	NS	NS	NS	NS	NS

	Hibiscus					
	58 DAP GI	**Shoot Dry Weight (g)**	**Root Dry Weight (g)**	**21 DAP SPAD**	**57 DAP SPAD**	**Flower Count**
80% PB: 20% sand	46.4 b	16.4 b	19.5 b	34.0 b	24.3 b	8.2 b
40% PB: 40% ERC: 20% sand	48.7 a	20.3 a	24.1 a	36.5 a	25.8 a	10.4 a
80% ERC: 20% sand	37.3 c	8.4 c	18.3 b	34.9 ab	23.5 b	5.7 c
Irrigation Frequency						
1x per day	43.7 ^{NS}	15.6 ^{NS}	21.3 ^{NS}	37.4 a	26.2 a	8.2 ^{NS}
2x per day	46.1	15.6	21.1	35.4 ab	24.5 ab	8.7
3x per day	43.0	14.6	19.2	34.6 b	23.9 b	8.6
6x per day	43.9	14.3	21.0	33.2 b	23.6 b	6.9
Interaction						
Irrigation*Substrate	NS	NS	NS	NS	NS	NS

^{z}Growth Index = (height + width + perpendicular width) / 3 (1cm = 0.397 in.).

^{y}Shoots harvested at substrate surface and oven dried at 71°C for 13 days (1g = 0.0035 oz).

^{x}Roots wased and oven dried at 71°C for 13 days (1 g = 0.0035 oz).

^{w}Measurement taken from top of container to ssurface of substrate.

^{v}Mean separation within column by Waller-Duncan Multiple Range test (n=72, $\alpha = 0.05$).

^{u}Significant at $P \leq 0.05$ (*), 0.01 (**), 0.001 (***)

Table 3.5 Particle size analysis of pine bark (PB)- and eastern redcedar (ERC)- based substrates used for experiments 2 and 3.

U.S Standard Sieve No.	Sieve opening (mm)^z	Substrate 80% PB: 20% sand (g)	 40% PB: 40% ERC: 20% sand (g)	 80% ERC: 20% sand (g)
1/2	12.50	0.0 a^y	0.0 a	0.1 a
3/8	9.50	0.1 a	0.2 a	0.1 a
1/4	6.35	4.2 a	2.7 b	1.0 c
6	3.35	13.9 a	15.1 a	13.9 a
8	2.36	11.6 b	14.9 a	18.0 a
10	2.00	8.0 b	10.9 a	12.2 a
14	1.40	34.5 b	37.3 a	38.6 a
18	1.00	37.7 a	37.9 a	36.5 a
35	0.50	63.6 a	62.5 a	59.3 a
60	0.25	49.9 a	45.4 a	45.9 a
140	0.11	21.1 a	18.7 a	20.2 a
270	0.05	2.7 a	2.1 b	2.4 ab
pan	0.00	1.2 a	1.1 a	1.1 a
Texture^x				
Coarse		18.1 ^{NS}	18.0	15.0
Medium		91.8 b	101.1 a	105.3 a
Fine		138.5 ^{NS}	129.7	128.8

^{z}250 g (0.55 lb) of substrate used for analysis.

^{z}1 mm=0.0394 in.

^{y}Mean separation within row using Waller-Duncan Multiple Range test (n= 12, α=0.05).

^{x}Coarse=3.35-12.50 mm; Medium=1.00-2.36 mm; Fine=0.00-0.50 mm.

Table 3.6 Water analysis of leachate and leaf sample analysis for *Hibiscus moscheutos* 'Luna White' grown in pine bark (PB)- or eastern redcedar (ERC)- based substrates.

	Leachate Analysis												**Leaf Analysis^{z}**		
	20 DAP^{y}				**35 DAP**				**50 DAP**				**N (%)**	**P (%)**	**K (%)**
Substrate	**NH$_4$ ppm^{x}**	**NO$_3$ ppm**	**P ppm**	**K ppm**	**NH$_4$ ppm**	**NO$_3$ ppm**	**P ppm**	**K ppm**	**NH$_4$ ppm**	**NO$_3$ ppm**	**P ppm**	**K ppm**			
80% PB: 20% sand	1.3 a^{w}	7.3 ^{NS}	5.2 a	87.8 a	0.3 ^{NS}	0.5 ^{NS}	0.7 ^{NS}	32.6 a	0.3 ^{NS}	0.3 ^{NS}	0.5 ^{NS}	14.6 a	1.2 b	0.2 b	2.6 b
40% PB: 40% ERC: 20% sand	1.4 a	8.8	2.0 b	51.2 b	1.9	4.5	0.9	15.1 b	0.4	0.8	0.5	7.0 b	1.4 a	0.2 b	2.9 a
80% ERC: 20% sand	0.4 b	3.3	2.0 b	27.3 c	1.1	4.2	0.9	12.9 b	0.2	0.7	0.7	6.4 b	1.4 a	0.4 a	2.6 b
Irrigation Frequency															
1x per day	1.0 ^{NS}	6.8 ab	2.3 ^{NS}	44.8 ^{NS}	1.3 ^{NS}	4.7 ^{NS}	0.9 ^{NS}	21.3 ^{NS}	0.5 ^{NS}	0.6 ^{NS}	0.6 ^{NS}	8.8 ^{NS}	1.4 ^{NS}	0.2 b	2.8 ^{NS}
2x per day	0.6	3.4 b	2.3	49.7	1.2	2.8	0.9	17.4	0.3	1.0	0.5	7.3	1.3	0.2 ab	2.7
3x per day	1.5	10.9 a	3.7	69.0	0.5	1.3	0.7	21.0	0.2	0.5	0.6	9.3	1.3	0.3 ab	2.7
6x per day	1.1	4.9 ab	3.9	58.3	1.5	3.4	0.9	21.1	0.3	0.3	0.6	11.8	1.4	0.3 a	2.7
Interaction^{v}															
Irrigation*Substrate	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	***	*

[z] Ten random mature leafs were harvested, dried, and ground

[y] DAP=Days after planting

[x] ppm=parts per million

[w] means separated by using Waller-Duncan Multiple Range Test (n= 48, α=0.05)

[v] Significant at $P \leq 0.05$ (*), 0.01 (**), or 0.001 (***)

[NS] Means not significantly different

Leachate recommended nutrient levels: NH$_4$ and NO$_3$ (15 to 25), P (5 to 10), and K (10 to 20)

Leaf recommended nutrient levels: N (1.0 to 6.0%), P (0.2 to 0.5%), and K (1.5 to 4.0%)

Chapter 4 - Conclusion

Production and Landscape Establishment

Plant growth parameters evaluated during the production phase were similar to a previous study (Starr et al., 2010), where *Taxodium distichum* (L.) Rich. (baldcypress) grown in a pine bark (PB): eastern redcedar (*Juniperus virginiana* L.; ERC) mixture grew similar to baldcypress grown in PB only. Root dry weight for blanket flower (*Gaillardia x grandiflora* Van Houtte), inkberry holly (*Ilex glabra* (L.) A. Gray 'Compacta', 'Little Kitten' maiden grass (*Miscanthus sinensis* Andersson 'Little Kitten', and double pink Knockout™ rose (*Rosa* L. 'Radtkopink') showed that the roots grew well in any of the three substrates. Growth index and shoot dry weight data suggest plants grown in substrates amended with ERC may require a higher fertilizer rate or different irrigation schedule than plants grown in PB. Jackson et al. (2008) suggested wood-based substrates may need additional fertilization in addition to the slow-release fertilizer incorporated at time of mixing due to higher levels of microbial activity as the wood substrates decomposes. During the growing season, all species demonstrated they could be grown in a PB:ERC mix with similar size and marketability (personal observation) as compared to plants grown in PB even under the extreme Great Plains weather conditions, ranging from a wet spring to 53 days of +100°F (37.8°C) in the summer.

All species in the landscape establishment phase, except inkberry holly and hosta (*Hosta* Tratt. 'Sum and Substance'), performed similarly among substrates regardless of the container substrate used during the production study. Plants grown in ERC that were smaller at the end of the production study caught up to plants grown in PB and PB:ERC mix by the end of the landscape study. Results observed in this study are similar to a study by Marble et al. (2012), where the authors studied the performance of ‘Acoma’ crapemyrtle (*Lagerstroemia indica* L. x *faurei* ‘Acoma’), ‘D.D. Blanchard’ magnolia (*Magnolia grandiflora* L. ‘D.D. Blanchard’), and shumard oak (*Quercus shumardii* Buckley) that were container-grown in *WholeTree*, Clean Chip Residual, or PB then planted into the landscape. It was shown that all species performed similarly regardless of the container substrate. The work described herein demonstrated ERC is an acceptable amendment (up to 50%) for PB-based substrates. Most plants in this study were of marketable quality and grew well in the landscape, regardless of the substrate. Great Plains nursery growers should strongly consider supplementing their substrates with ERC in order to reduce costs and increase sustainability efforts.

Cyclic Irrigation

Sedum and black-eyed susan had the greatest growth when grown in PB and irrigated 1x per day, with black-eyed susan able to be irrigated 2x and 3x per day. Irrigation frequency for black-eyed susan had no effects on GI, root dry weights or SPAD. Unavailable nutrients could potentially be the reason for the difference in shoot growth among substrates. Hibiscus preferred PB:ERC with cyclic irrigation having no influence on growth. Nutrient analysis of substrate leachate showed that by the end of the study, substrates had no influence on nutrient levels except for potassium (K). Leaf nutrient analysis showed only phosphorus (P) was influenced by irrigation frequency with the highest P levels in plants irrigation six times per day.

Increasing irrigation frequency did not overcome low CC in ERC-based substrates and had no major influence on perennial plant growth alternative substrates in a greenhouse setting. Results of the three studies indicate ERC could be used as a partial replacement/supplement for PB. Future studies should focus on evaluating the use of a variety of fertilizer regimens to determine optimum plant nutrition in ERC substrates for improving shoot growth of plants.

Bibliography

Alpkem Corporation. 1986a. RFA Methodology No. A303-S170.

Alpkem Corporation. 1986b. RFA Methodology No. A303-S021.

Alpkem Corporation. 1986c. RFA Methodology No. A303-S072.

Altland, J. 2010. Use of processed biofuel crops for nursery substrates. J. Environ. Hort. 28: 129-134.

Altland, J. and C. Krause. 2009. Use of switchgrass as a nursery container substrate. HortScience 44: 1861-1865.

Arnold, M.A. and G.V. McDonald. 2009. Groundcovers, organic and inorganic mulches, and masonry surfaces differentially affect establishment and root zone characteristics of urban trees. Arbor. and Urban For. 35: 232-240.

Brown, E.F., F.A. Pokorny. 1975. Physical and chemical properties of media composed of milled pine bark and sand. J. Amer. Soc. Hort. Sci. 100:119-121.

Bowman, D.C., R.Y. Evans, and L.L. Dodge. 1994. Growth of chrysanthemum with ground automobile tires used as a container soil amendment. HortScience 29: 774-776.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L Sibley. 2008a. Clean chip residual: A substrate component for growing annuals. HortTechnology 18: 423-431.

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

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

Boyer, C.R., H.A. Torbert, C.H. Gilliam, G.B. Fain, T.V. Gallagher, and J.L Sibley. 2012a. Nitrogen immobilization in plant growth substrates: clean chip residual, pine bark, and peatmoss. Intern. Journ. Of Agr. Vol 2012. <http://www.hindawi.com/journals/ija/2012/978528/>

Boyer, C.R., T.V. Gallagher, C.H. Gilliam, G.B. Fain, H.A. Torbert, and J.L. Sibley. 2012b. Description of clean chip residual forest harvest and its availability for horticultural uses in the southeastern United States. HortTechnology 22: 381-387.

Bryan, D.L., M.A. Arnold, A. Volder, W.T. Watson, L. Lombardini, J.J. Sloan, L.A. Valdes-Aguilar, and A.D. Cartmill. 2010. Planting depth during container production and landscape establishment affects growth of *Ulmus parvifolia*. HortScience 45:54-60.

Buamscha, M.G, J.E. Altland, D.M. Sullivan, D.A. Horneck, and J. Cassidy. 2007. Chemical and physical properties of douglas fir bark relevant to the production of container plants. HortScience 42:1281-1286.

Carmichael, T.R., C.R. Boyer, S.L. Warren, and J.J. Griffin. 2012. Effect of irrigation frequency on sedum grown in alternative substrates. Proc. South. Nurs. Assn. Res. Conf. 57:2-5.

Chandler, P.A., R.D. Durbin, J. Ferguson, J.W. Huffman, O.A. Matkin, D.E. Munnecke, C.N. Roistacher, W.R. Schoonover, and R.H. Sciaroni. 1957. The U.C. system for producing healthy container-grown plants through the use of clean soil, clean stock, and sanitation. Univ. of California Div. of Agri. Science: Agri. experimentation station – ext. service.

Chong, C. and R.A. Cline. 1993. Response of four ornamental shrubs to container substrate amended with two sources of raw paper mill sludge. HortScience. 28: 807-809.

Croxton, S.D., J.L. Sibley, W. Lu, and M. Schaefer. 2004. Evaluation of composted household garbage as a horticultural substrate. Proc. Southern. Nurs. Assn. Res. Conf. 49: 296-298.

Daniel, T.C., P.A. Moore, Jr., A.N. Sharpley, and C.W. Wood. 1995. Poultry manure management: Environmentally sound options. J. of Soil and Water Conserv. 50:321.

Davidson, H., R. Mechlenburg, C. Peterson. 2000. Nursery management administration and culture, Fourth Edition. Prentice Hall. Upper Saddle River, NJ.

Davis, J.G. and C.R. Wilson. 2005. Choosing a soil amendment. Colorado State University Extension. Factsheet 7.235. www.ext.colostate.edu/pubs/garden/07235.html.

Dirr, M.A. 2009. Manual of woody landscape plants: Their identification, ornamental characteristics, culture, propagation, and uses, Sixth Edition. Stipes Publishing L.L.C.. Champaign, Il.

Drake, B., and P. Todd. 2002. A strategy for control and utilization of invasive juniper species in Oklahoma: Final report of the "Redcedar Task Force". Oklahoma Dept of Ag, Food, and For. 17 July 2012. <http://www.forestry.ok.gov/websites/forestry/images/rcstf.pdf>

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

Fain, G.B., C.H. Gilliam, J.L. Sibley, and C.R. Boyer. 2008b. Establishment of greenhouse-grown *Tagetes patula* and *Petunia* x *hybrida* in '*WholeTree'* substrates. Acta Hort. 782:387-393.

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

Fain, G.B., C.H. Gilliam, K.M. Tilt, J.W. Olive, B. Wallace. 2000. Survey of best management practices in container production nurseries. J. Environ. Hort. 18: 142-144.

Fonteno, W.C. and C.T. Harden. 2003. Procedures for determining physical properties of horticultural substrates using the NCSU porometer. Horticultural Substrates Laboratory. North Carolina State University.

Gabriel, M.Z., J.E. Altland, and J.S. Owen Jr. 2009. The effect of physical and hydraulic properties of peatmoss and pumice on douglas fir bark based soilless substrates. HortScience 44:874-878.

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

Gilman, E.F. 2001. Effect of nursery production method, irrigation, and inoculation with mycorrhizae-forming fungi on establishment of *Quercus virginiana*. J. Arboriculture. 27:30-39.

Gómez, C. and J. Robbins. 2011. Pine bark substrates amended with parboiled rice hulls: Physical properties and growth of container-grown spirea during long-term nursery production. HortScience 46: 784-790.

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

Haynes, R. W., tech. coord. 2003. An analysis of the timber situation in United State: 1952-2050. USDA Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-560.

Jackson, B.E., R.D. Wright, J.F. Browder, J.R. Harris, and A.X. Niemiera. 2008. Effect of fertilizer rate on growth of azalea and holly in pine bark and pine tree substrates. HortScience 43:1561-1568.

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

Johnson, P. and D. Tatum. 1996. The use of crumb rubber amendment in the production of poinsettias. Proc. Southern Nurs. Assn. Res. Conf. 41: 111-115

Kahtz, A.W. and N.J. Gawel. 2003. Use of recycled waste as an amendment in container production media. Proc. Southern Nurs. Assn. Res. Conf. 48: 71-73.

Keever, G.J. and G.S. Cobb.1985. Irrigation scheduling effects on container media and canopy temperature and growth of ‘Hersery’s Red’s azalea. HortScience 20: 921-923

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

Liner, R.C. and C.P. Harley. 1942. A rapid method for the determination of nitrogen in plant tissue. Sci. 96565-96566.

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

Maggard, A.O., R.E. Will, T.C. Hennessey, C.R. McKinley, and J.C. Cole. 2012. Tree-based mulches influence soil properties and plant growth. HortTechnology 22: 353-361.

Marble, S.C., G.B. Fain, C.H. Gilliam, G.B. Runion, S.A Prior, H.A. Torbert, and D.E. Wells. 2012. Landscape establishment of woody ornamentals grown in alternative wood-based container substrates. J. Environ. Hort. 30:13-16.

Marble, S.C., C.H.Gilliam, J.L. Sibley, G.B. Fain, H.A. Torbert, T.V. Gallagher, and J.W. Olive. 2010. Evaluation of composted poultry litter as a substrate amendment for *WholeTree*, clean chip residual, and pine bark for container grown woody nursery crops. J. Environ. Hort. 28:107-116.

Marshall, M.D. and E.F. Gilman. 1998. Effects of nursery container type on root growth and landscape establishment of *Acer rubrum* L. J. Environ. Hort. 16:55-59.

Mills, H.A., and J.B. Jones, Jr. 1996. Plant Analysis Handbook II. Micromacro Publishing, Athens, GA.

Murphy, A.M., C.H. Gilliam, G.B. Fain, H.A. Torbert, T. V. Gallagher, J. L. Sibley, S. C. Marble, and A. L. Witcher. 2010. Extending pine bark supplies with wholetree and clean chip residual substrates. J. Environ. Hort. 28:217-223.

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

Newman, S.E., K.L. Panter, M.J. Roll, and R.O. Miller. 1997. Growth and nutrition of geraniums grown in media developed from waste tire components. HortScience 32: 674-676.

Owen, J.S. Jr., J.E. Altland. 2008. Container height and douglas fir bark texture affect substrate physical properties. HortScience 43:505-508.

Penick, E. B. 1980. Future of the horticultural bark industry in the United States. p. 2-3. *In*: R. C. Allison. Organic and Fuel Uses for Bark and Wood Residues. Proceedings No. P-80-27, Forest Products Research Society, Madison, WI.

Scheiber, S.M., E.F. Gilman, M. Paz, and K.A. Moore. 2007. Irrigation affects landscape establishment of burford holy, pittosporum, and sweet viburnum. HortScience 42:344-348.

Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2012. Eastern redcedar (*Juniperus virginiana*) as a substrate component effects growth of three tree species. J. Environ. Hort. 30: 189-194.

Starr, Z.W., C.R. Boyer, and J.J. Griffin. 2013. Post harvest processing of eastern redcedar and hedge-apple substrates affect nursery crop growth. J. Environ. Hort. 31: 7-13.

Stritzke, J.F. and D. Rollins. 1984. Eastern redcedar and its control. Weeds Today. 7-8.

Svenson, S.E., J. Bukelew, B. Becker, and J. Paxson. 2001. Growth of nursery crops in compost-amended douglas-fir bark. Proc. Southern Nurs. Assn. Res. Conf. 46: 123-125.

Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59240-59243.

Tripepi, R.R., M.W. George, A.G. Campbell, and B. Shafii. 1996. Evaluating pulp and paper sludge as a substrate for peat moss in container media. J. Environ. Hort. 14: 91-96

Tyler, H.H., S.L. Warren, T.E. Bilderback. 1996. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14: 194-198.

Warren, S.L. and T.E. Bilderback. 2002. Timing of low pressure irrigation affects plant growth and water utilization efficiency. J. Environ. Hort. 20: 184-188.

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

Wright, R.D., B.E. Jackson, J.F. Browder, and J.G. Latimer. 2008. Growth of chrysanthemum in a pine tree substrate requires additional fertilizer. HortTechnology 18:111-115.

Wright, R.D., B.E. Jackson, M.C. Barnes, and J.F. Browder. 2009. The landscape performance of annual bedding plants grown in pine tree substrate. HortTechnology 19:78-82.

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

Yeager, T., T. Bilderback, D. Fare, C. Gilliam, J. Lea-Cox, A. Niemiera, J. Ruter, K. Tilt, S. Warren, T. Whitwell, R. Wright. 2007. Best management practices guide for production nursery crops. Southern Nurs. Assn., Atlanta, GA.

Appendix A -

Table A.1 Effect of pine bark- and eastern redcedar- based substrates on growth of *Gaillardia* x *grandiflora* 'Goblin', *Ilex glabra* 'Compacta', *Miscanthus sinensis* 'Little Kitten', *Rosa* 'Radtkopink', *Ulmus parvifolia* 'Emer II', and *Sedum telphium* 'Autumn Joy' in a nursery production setting.

	Lacebark elm			**Knockout rose**		**Holly**		**Maiden grass**		**Blanket Flower**		**Sedum**
	Shoot Dry Wt.(g)	**Root Dry Wt.(g)**	**71 DAP SPAD**	**Shoot Dry Wt. (g)**	**Root Dry Wt. (g)**	**Shoot Dry Wt.(g)**	**Root Dry Wt.(g)**	**Shoot Dry Wt.(g)**	**Root Dry Wt.(g)**	**Shoot Dry Wt. (g)**	**Root Dry Wt. (g)**	**120 DAP GI**
80% Pine Bark (PB): 20% sand	109.80a	109.90a	50.13[NS]	72.05[NS]	14.75[NS]	60.55a[u]	23.90[NS]	194.80a	81.77[NS]	65.05[NS]	19.39[NS]	29.97b
40% PB: 40% Eastern Redcedar(ERC): 20% sand	93.30a	96.54a	48.13	83.3	25.31	46.30ab	18.27	129.05ab	52.46	65.05	44.84	33.30 a
80% ERC: 20% sand	55.55b	67.81b	50.98	74.47	23.07	33.80b	15.50	69.30b	55.22	55.80	37.55	32.18ab
	113 DAP GI	**113 DAP Caliper[v]**		**120 DAP GI**	**71 DAP SPAD**	**120 DAP GI**	**71 DAP SPAD**	**120 DAP GI**		**120 DAP GI**	**71 DAP SPAD**	
80% Pine Bark (PB): 20% sand	83.45ab	8.05b		52.56[NS]	45.23ab	37.65a	49.53b	106.82a		45.05[NS]	54.13[NS]	
40% PB: 40% ERC: 20% sand	88.78a	9.04a		58.19	38.98b	36.49a	50.3 ab	100.74ab		46.38	57.35	
80% ERC: 20% sand	80.46b	7.48b		50.33	48.35a	30.10b	57.78a	89.62b		41.31	55.10	

[z] DAP= Days after potting.

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

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

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

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

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

[NS] Means not significantly different.

Table A.2 Effect of pine bark- and eastern redcedar- based substrates on the growth and landscape establishment of woody and herbaceous plants.

	Lacebark elm								
	Growth Index			Caliper^{v}			Shoot Dry Weight (g)	Root Dry Weight (g)	SPAD
	230 DAP	292 DAP	329 DAP	230 DAP	292 DAP	329 DAP			
80% Pine Bark (PB): 20% sand	91.70^{NS}	145.40^{NS}	159.23^{NS}	16.79^{NS}	32.11^{NS}	39.49^{NS}	1702.00^{NS}	770.20^{NS}	44.30^{NS}
40% PB: 40% Eastern Redcedar (ERC): 20% sand	92.78	142.85	157.50	16.70	31.07	36.69	1439.50	805.50	45.75
80% ERC: 20% sand	91.93	144.10	157.87	15.97	33.68	37.89	1543.70	698.00	45.11

	Holly						Knockout rose					
	Growth Index			Shoot Dry Weight (g)	Root Dry Weight (g)	SPAD	Growth Index			Shoot Dry Weight (g)^{y}	Root Dry Weight (g)^{x}	SPAD
	230 DAP	292 DAP	329 DAP				230 DAP^{z}	292 DAP	329 DAP			
80% Pine Bark (PB): 20% sand	43.23 a^{w}	51.07 a	57.47 a	253.10 a	139.10^{NS}	49.48^{NS}	74.20^{NS}	108.93^{NS}	116.40^{NS}	1386.60^{NS}	295.80^{NS}	58.01^{NS}
40% PB: 40% ERC: 20% sand	43.50 a	50.13 ab	56.43 a	217.9 ab	144.30	48.99	75.10	108.37	113.73	1384.20	254.10	54.90
80% ERC: 20% sand	35.67 b	42.23 b	47.43 b	168.80 b	118.00	48.72	70.67	110.47	116.88	1330.20	274.40	55.93

	Maiden grass					Sedum				
	Growth Index			Shoot Dry Weight (g)	Root Dry Weight (g)	Growth Index			Shoot Dry Weight (g)	Root Dry Weight (g)
	230 DAP	292 DAP	329 DAP			230 DAP	292 DAP	329 DAP		
80% Pine Bark (PB): 20% sand	62.60^{NS}	95.90^{NS}	115.40^{NS}	861.20^{NS}	1302.70^{NS}	30.13^{NS}	48.43^{NS}	53.90^{NS}	153.50^{NS}	72.30^{NS}
40% PB: 40% ERC: 20% sand	54.48	85.85	101.37	725.50	1323.90	26.07	39.73	43.83	96.70	63.80
80% ERC: 20% sand	54.70	96.52	106.15	666.60	1282.00	28.83	43.77	48.50	150.70	99.70

	Daylily					Hosta				
	Fan Count			Shoot Dry Weight (g)	Root Dry Weight (g)	Growth Index			Shoot Dry Weight (g)	Root Dry Weight (g)
	230 DAP	292 DAP	329 DAP			230 DAP	292 DAP	329 DAP		
80% Pine Bark (PB): 20% sand	2.50^{NS}	2.40^{NS}	2.40^{NS}	5.60^{NS}	13.20^{NS}	43.00 a	37.25 a	33.13 a	25.50 a	65.13 a
40% PB: 40% ERC: 20% sand	3.00	2.60	3.80	11.20	26.60	36.83 b	30.46 b	26.67 ab	19.00 ab	42.00 b
80% ERC: 20% sand	2.00	2.50	2.50	13.20	23.40	28.21 c	24.25b	25.13 b	11.63 b	24.13 b

[z] DAP=Days after planting.

[y] Shoots harvested at soil level and oven dried at 71°C until weight stablized (1 g=0.0035 oz).

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

[w] Means separation within column using Waller-Duncan Multiple Range test (α=0.05).

[v] Caliper measured 4 in (10.16 cm) above soil surface.

[NS] Means not significantly different.

Table A.3 Effect of pine bark (PB)- and eastern redcedar (ERC)- based substrates on percent growth of plants planted into the landscape.

	Increase in plant size (%)^{z}					
Substrate	**Knockout rose**	**Maiden grass**	**Holly**	**Hosta**	**Sedum**	**Lacebark elm**
80% PB: 20% sand	35.62^{NS}	45.47^{NS}	25.02^{NS}	-31.23 ^{NS}	43.3^{NS}	42.38^{NS}
40% PB: 40% ERC: 20% sand	33.74	45.38	22.93	-53.45	41.09	40.75
80% ERC: 20% sand	38.89	46.20	24.30	-13.30	36.71	41.61

^{z}Growth was the product of the height x width x perpendicular width ÷ 3 [growth index (GI)]; percent increase of growth calculated by [(GI at harvesting-GI at field planting)÷ harvest GI]x100.

^{NS}Means no significant difference.