ORGANIC MATTER TYPE AFFECTS GROWTH AND PHYSIOLOGY OF NATIVE

PLANTS PLANTED ABOVE-GRADE

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ORGANIC MATTER TYPE AFFECTS GROWTH AND PHYSIOLOGY OF NATIVE PLANTS PLANTED ABOVE-GRADE

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ORGANIC MATTER TYPE AFFECTS GROWTH AND PHYSIOLOGY OF NATIVE PLANTS PLANTED ABOVE-GRADE

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Scott Burton Hanes, son of Steve and Nancy Hanes, was born on November 28, 1980 in Las Vegas, Nevada. He has one sister, Shannon, and two dogs, Chief and Chlöe. In 1999, he graduated from McIntosh High School in Peachtree City, GA, then attended Auburn University, met his future wife, and earned a Bachelor of Science in Horticulture in 2004. After graduation, he moved to Tallahassee, FL to work for Imperial Nurseries as a sales representative until summer 2007. In August 2007, he returned to Auburn University to pursue a Master of Science degree in Horticulture and marry his wife, Julie. Scott received his Master of Science in Horticulture degree December 18, 2009 and is grateful for all the support, friendship, and good times along the way.

THESIS ABSTRACT

ORGANIC MATTER TYPE AFFECTS GROWTH AND PHYSIOLOGY OF SELECTED NATIVE PLANTS PLANTED ABOVE-GRADE

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Experiments quantified the response of three native taxa to different substrates utilized in above-grade planting. In a greenhouse study, *Hydrangea quercifolia* Bartr. ‘Alice’ (oakleaf hydrangea), *Chionanthus virginicus* L. (white fringetree), and *Rhododendron austrinum* Rehd. (Florida flame azalea) were planted in Horhizotrons™ on 28 Feb. 2008 (run 1), 22 Aug. 2008 (run 2), and 25 Feb. 2009 (run 3), and root growth into each of four quadrants was monitored. Bottom halves (10 cm depth) of each quadrant were filled with soil, while top halves (10 cm depth) of quadrants were filled with one of four substrates [coconut coir (CC), chipped pine trees (PT), peat moss (PM), or pine bark (PB)] to simulate above-grade planting. Horizontal root length (HRL) was measured throughout the experiment and root dry weight (RDW) was recorded at experiment termination. HRL of all taxa increased linearly over time in all substrates and runs. Based on RDW, more roots grew into soil than in substrate. HRL and RDW for *H.*

quercifolia 'Alice' were generally highest in CC and PT substrates, while HRL for *C. virginicus* and *R. austrinum* was generally highest in PM. *C. virginicus* RDW only differed among treatments in run 1, in which RDW was highest in CC and PB.

A field study was conducted to evaluate effects of the same substrates on growth of the same taxon planted above-grade compared to planting at-grade with no organic matter (NOM). For *C. virginicus* and *R. austrinum*, net photosynthesis (Ps) was measured once in summer 2008 and twice in summer 2009 (before and after irrigation), and stem water potential (SWP) was measured twice (before and after irrigation) in summer 2009. Growth index (GI) was recorded at planting (17 Mar. 2008), 23 Oct. 2008, and 6 Jul. 2009. Visual ratings (VR) and root ball diameter (RBD) were determined at experiment termination (Jul. 2009). GI increased linearly in response to treatments in *C. virginicus* and *R. austrinum*, and quadratically or linearly in *H. quercifolia* 'Alice' depending on treatment. VR and RBD of *C. virginicus* and *H. quercifolia* 'Alice' were not affected by treatments. GI was not different among treatments in *C. virginicus*, while GI was highest in PT and lowest in NOM for *H. quercifolia* 'Alice'. RBD for *R. austrinum* was highest in PM; VR was highest in PM and CC; and final GI was not different among treatments. In 2008, Ps was not different among treatments in all taxa; however, in 2009, Ps was lower in PB than other substrates for *C. virginicus* and highest in PM for *R. austrinum*. SWP in *C. virginicus* was highest in CC and PB and lowest in NOM, but there were no differences in SWP among treatments in *R. austrinum*. Physical and chemical properties of soil and substrates as well as taxon affects results of this technique, and CC or PT are acceptable replacements for PM and PB in above-grade planting.

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CHAPTER I

LITERATURE REVIEW

Introduction

Soils characterized by compaction, artificial layering, stony texture, anthropic debris, and low organic matter concentration are often referred to as "urban" soils, with this description extending to soils from suburban, residential, and municipal settings. A majority of soils in the 21st century, with influences from urban development and common landscape maintenance, may not meet the needs of most exotic or native species without amending the soil or modifying the planting technique to ensure plant establishment after transplanting. Most poor or urban soils are characterized by a loss of natural pedological horizons that have been replaced by artificial layering and mixing of anthropic substances, resulting in soils characterized by great spatial variability and structural degradation, with low nutrient and organic matter concentrations (Jim, 1998). Humans are the main cause of this disturbance in urban soils, rather than natural processes of wind, water, and gravity (Craul, 1999). Urban soils are described as having a non-agricultural, man-made surface layer more than 50 cm thick that was produced by mixing and filling, or by contamination of land surface in urban areas (Effland and Pouyat, 1997).

Urban soils have high levels of soil organic carbon, particularly in areas such as residential lawns, where water and fertilizer have been repeatedly added (Pouyet et al., 2006). Humans further contribute to degradation of urban soils by sequentially dumping fill materials to create excessively stony and coarse-textured soils that are filled with anthropic rubble such as concrete, glass, brick, asphalt, wood, and plastic. These and other foreign materials make planting difficult and create conditions unsuitable for plant and microbial growth (Beyer et al., 1995; Scharenbroch et al., 2005). In addition to these foreign materials, root growth in urban soils is inhibited by an abundance of underground utility pipes, lines, and cables (Jim, 1998), some of which release toxic chemicals into the soil through leaks in piping (Craul, 1985). There is also pollution by lead and other heavy metals in urban soils, often due to airborne pollution from vehicle emissions (Jim, 1998). These problems in urban soils often contribute to additional problems, such as compaction, that create irregular soil temperatures and moisture contents, reduce aeration and drainage, impede root growth, and increase runoff and erosion (Craul, 1999; Jim, 1998; Patterson, 1977; Scharenbroch et al., 2005). Urban landscape maintenance often includes collecting leaf droppings and other debris that would accumulate and contribute organic matter to the soil. When this material is bagged and removed from the site, the soil is deprived of additional organic matter in its upper horizon (Beyer et al., 1995). Root exploitation of this organic layer is prevented, reducing the efficiency at which roots acquire nutrients and thus affecting landscape sustainability (Cotrufo, 2006; Patterson, 1977). Organic matter in the upper layer of the soil must be replaced, or humification of plant remains into organic residues should be enhanced, to improve soil ecology for transplant success (Beyer et al., 1995).

Remediation of Poor Soils

Organic matter incorporation reduces soil bulk density and mechanical impedance, while improving aggregate stability, porosity, infiltration, and water holding capacity (Cogger, 2005). These conditions create a favorable root zone environment that may enhance plant growth after transplanting (Corley, 1984). Research also indicates that humates (acids remaining in the soil after organic matter is degraded) build soil structure, increase root penetrability, and promote sustainability of landscape plantings (Saebo and Ferrini, 2006). Chemical fertilizers do not contribute to this humus content in the soil, as they are taken up by the plant before they are able to contribute to the structure of the soil (Bulluck III et al., 2002). Organic matter in soil increases cation exchange capacity and nutrient availability within the soil (Parfitt et al., 1995). In addition to providing nutrients and carbon to the soil, organic matter provides food for earthworms and microorganisms (Cogger, 2005), both of which improve soil structure, nutrient cycling (Edwards and Fletcher, 1988; Steinberg et al., 1997), and resistance to plant disease (Cook et al., 1996). Organic matter also supports necessary symbiotic mycorrhizal associations with plant roots in the rhizosphere (Singer and Munns, 2002). Furthermore, organic matter helps to prevent drought in city plantings by increasing the water holding capacity of soil (Johnston, 2007), and its incorporation is also beneficial for restoration of native habitats (Zink and Allen, 1998).

Organic matter varies in its physical properties, so it is important that a suitable organic matter is utilized, at a proper rate, based on site-specific conditions as determined by laboratory soil tests. Utilizing organic matter in the landscape can improve establishment of transplanted shrubs and trees and reduce losses from plant mortality, while providing a useful outlet for some human generated wastes instead of deposition in landfills (Saebo and Ferrini, 2006).

There are several methods of utilizing organic matter in the landscape to improve soils and promote the establishment of sustainable native plant communities. Saebo and Ferrini (2006) describe a method that involves tilling up to 8 cm (3.2 in) of compost into the top 15-20 cm (6-8 in) of topsoil, increasing organic matter incorporation to a depth of up to 45 cm (18 in) in areas of compaction. Landscapers using compost should conduct soil tests, obtain compost from sources that can describe the compost's nutritive and salt concentration, and use this information to modify their fertilizer regime to limit available nitrogen levels during establishment to 120 $kg\bullet N\bullet ha^{-1}\bullet year^{-1}$ (107 $lb\bullet N\bullet ha^{-1}\bullet year^{-1}$) (Saebo and Ferrini, 2006). Using mulch in the landscape provides weed control, as mulch damages weeds by removing light, interfering with stem elongation, encouraging fungal growth, and acting as a physical barrier to weed growth (Greenly and Rakow, 1995). Mulch thickness of up to 10 cm (4 in) or more is often used to provide sufficient protection from germinating weeds without inhibiting plant growth, depending on mulch type (Billeaud and Zajicek, 1989). The application of organic matter and mulch to the soil surface also provides erosion control. In addition to tilling organic matter into the topsoil, organic matter can also be incorporated as an amendment to the soil backfill at planting to decrease impedance of root growth into compacted soil. As a backfill soil amendment, organic matter helps roots grow past the gradient between the container substrate and surrounding field soil (Wright et al., 2007). The improved gradient from pure organic matter to an organic matter:soil mixture to pure field soil results in greater root penetration and shoot growth following transplanting (Ferrini et al., 2005). However, there has been much disagreement as to how beneficial backfill incorporation of organic matter really is. While previous literature may recommend amending backfill with organic matter to promote transplant success (Flemer, 1982), recent research suggests there is no benefit from or incentive for incorporating organic matter into the backfill (Gilman, 2004; Hodel et al., 2006; Watson et al., 1992) and even native field soil has been recommended as the most suitable backfill, as non-native soil may not provide the proper soil nutritive and environmental conditions for native plant roots (Smalley and Wood, 1995). Furthermore, the incorporation of peat and other organic materials may be detrimental to transplant establishment, as the organic matter may wick water away from roots and the soil surrounding them, creating plant water stress (Harris and Bassuk, 1993; Hitchmough and Fieldhouse, 2004).

Planting Above-Grade

In addition to examining backfill amendments, research surrounding planting practices for trees and shrubs has often focused on planting hole shape and size (Kopinga, 1985; Watson et al., 1992), although effects of planting depth have also been considered (Arnold and Welsh, 1995). Planting below-grade is sometimes recommended to reduce problems caused by roots coming into contact with sidewalks in urban plantings (Randrup et al., 2001). However, soil or mulch covering the root ball as a result of deep planting will intercept water, causing a drier root ball which threatens initial establishment and survival (Gilman and Grabosky, 2004). The response to deep planting varies among taxa and is exacerbated by the addition of a mulch layer on top (Arnold et al., 2005). In contrast, studies have shown that positioning a plant's root ball above-grade can yield improved growth for trees and shrubs planted in city landscapes (Arnold et al., 2005; Wright et al., 2007). Arnold (2007) also reported that for a variety of taxa, plants planted above-grade 7.6 cm (3 in) demonstrated growth comparable to or greater than plants planted at or below-grade, particularly for species such as sycamore and oleander, which experienced higher survival rates and grew to larger heights when planted above-grade. When planting above-grade, part of the root ball is left exposed above the finished soil surface/grade, then soil is mounded around the exposed (above-grade) portion of the root ball, often followed by a mulch layer for weed suppression.

Wright et al. (2007) determined that pine bark substrate can also be effectively utilized in place of a field soil mound. This led to development of a modified above-grade planting technique. In the modified above-grade planting technique, plants are planted so that the top 1/3 of the root ball remains above soil grade, then organic matter is mounded on and around the above-grade portion of the root ball to mimic the natural layer of accumulated organic matter that supports root penetration and subsequent growth following transplanting due to its low bulk density (Hodge, 2004). The organic matter mound helps remediate problems of compaction and other poor soil conditions to increase post-transplant root and shoot growth by shrubs and trees (Guckenberger and Wright, 2007; Price et al., 2009). For example, this modified, above-grade planting technique improved transplant establishment of *Kalmia latifolia* (L.), for which initial root growth after transplanting was greatest where roots grew into the upper, organic layer (Wright et al., 2007). Utilizing this above-grade planting technique is especially important when transplanting containerized nursery plants. The low bulk density of the organic matter mound facilitates initial lateral root penetration into the backfill by allowing roots to overcome gradients drawing moisture from the original container substrate into surrounding field soil (Costello and Paul, 1975; Nelms and Spomer, 1983). Surrounding soil type has an effect on establishment, as containerized plants acclimated to the low bulk density of pine bark or peat-based media may not successfully penetrate higher bulk-density soils, even if adequate nutritional and physical conditions are provided (Masle and Passioura, 1987; Nicolosi and Fretz, 1980). Positioning transplanted containerized plants above-grade with organic matter may help reduce both the mechanical impedance and the negative moisture gradient to improve initial root penetration and growth following transplanting.

Organic Matter Types

Several organic matter substrates have proven beneficial for landscape plant establishment, and these vary in cost and market availability (Saebo and Ferrini, 2006). Sources of organic matter include yard wastes, wood chips, brewery byproducts, manure, food residues, organic household wastes, paper, municipal sludge, and a large number of other wastes that can be recycled for use in soil remediation (Hernández-Apaolaza et al., 2004; Saebo and Ferrini, 2006). It is important to identify a variety of substrates with different physical and chemical properties that are suitable for landscape use, as the performance of organic substrates varies with site conditions and species cultural requirements (Bilderback et al., 2005; Guérin et al., 2001).

Coconut coir, pine tree and pine bark substrates, and more traditional peat-based substrates are typically used as container substrates. While substrates composed of peat moss or pine bark are the accepted nursery industry standard, coconut coir and pine tree substrates can produce similar growth results in container production (Abad et al., 2005; Fornes et al., 2003; Wright et al., 2007). Coconut coir and chipped pine tree substrates may also be economical alternatives to peat moss. Pine bark generally has the lowest cost among substrates, and was purchased locally for $12 per cubic yard for use in this study. Pine tree substrate is generally closest in cost to pine bark, and was purchased locally for $15 per cubic yard. Without freight, coconut coir was purchased for approximately $51 per cubic yard. Peat moss carries the highest cost among substrates, and was purchased locally for $127 per cubic yard. Successful use of alternative substrates for container production suggests these substrates may also be useful and economical for some landscape applications.

Substrates such as coconut coir and ground or chipped pine materials are more attractive alternatives to traditional peat moss and pine bark for many reasons. While peat moss serves as an excellent substrate and amendment, wetland protection acts and laws regulating harvesting and reclamation of peat bogs create growing costs to peat manufacturers (Barkham, 1993; Robertson, 1993). For example, disturbances from mining and harvesting of peat moss in bogs have proven detrimental to fish and shellfish, amphibians, birds, and plants, and facilitates the invasion of competitive small-mammal species in mined areas that are drier than unexploited bogs, leading to eventual desiccation of wetland bogs (Mazerolle et al., 2001; Surette et al., 2002). As widespread as its use is, there are still concerns surrounding peat moss, and even with government regulations in place, the renewability of peat bogs remains a threat (Van Seters and Price, 2001). Organic matter in these ‘peatlands’ is only replaced by a rate of 10-20 cm per century, creating a supply that does not meet the current demand of consumers. Alternative substrates are therefore receiving attention due to the environmental impacts of peat mining. According to a thorough review of alternative substrates by Schmilewski (2008), composted biowaste, bark and composted bark, wood fibre, and coir products show the most promise as future alternative substrates, although the author foresees peat as a continued need for substrate constituent.

Fain et al. (2005) reported that when ground, logging byproducts of various *Pinus* L. species have potential as alternative sustainable horticultural substrates. Ground or chipped pine tree substrate, made using entire loblolly pine trees, shows good potential for commercial use as a renewable substrate and may and allow more localized sourcing at a greatly reduced cost (Wright and Browder, 2005; Wright et al., 2008). Researchers are evaluating various pine logging by-products and other substrates for horticultural use, finding that while potentially suitable as landscape and container substrates, these alternatives have limitations due to availability and consistency, caused by variation from harvesting, processing, and storing methods (Boyer et al., 2008; Wright and Browder, 2005; Wright et al., 2008). However, when compared to container production in pine bark or other traditional nursery substrates, chipped pine tree substrate may require additional fertilizer input as a landscape amendment (Wright et al., 2008; Wright et al., 2006).

Coconut coir also has potential to replace peat moss as a landscape soil amendment because of its similar physical properties to peat, although particle size significantly affects performance and is largely determined by the origin or batch of coir dust used for substrate production (Abad et al., 2005). Coconut coir consists of the thick, fibrous middle layer or mesocarp from the *Cocos nucifera* (L.) fruit husk and is used in the manufacture of several industrial products. The industrial waste byproduct created in this process consists of small fibers and dust and is a major export from countries such as Sri Lanka and the Phillipines for horticultural applications (Abad et al., 2005). While similar to peat moss in rewetting properties, coconut coir differs in particle size, and coconut coir's lightweight, coarse texture provides higher porosity, air content, and aeration than peat moss, which often has a finer particle size and slightly higher water holding capacity (Abad et al., 2005). Some variation does exist among coconut coir sources and batches in production, and inland sources that rinse coir substrate to remove high salt levels are most suitable for horticultural applications (Evans et al., 1996; Konduru et al., 1999; Noguera et al., 2003). The pH of coconut coir in general tends to be slightly acidic but is much higher than peat moss, having greater available phosphorous and potassium and lower nitrogen, calcium, and magnesium compared to peat, creating conditions that inhibit nitrification (Abad et al., 2005). For many plant species, coconut coir has proven to increase root growth, control fungus gnats, and even suppress pathogens like *Phytophthora* spp. and *Pythium* spp. (Waller et al., 2008). Coconut coir has also found several uses in improving hydroponic vegetable production, especially as an alternative to rockwool (Lopez et al., 1996; Shahidul Islam et al., 2002; Urayama et al., 2005; Yavari et al., 2009).

Quantifying Plant and Soil Responses to Organic Matter Use

Once organic matter has been applied or incorporated in the landscape, it is important to ensure soil moisture content is sufficient for plant growth and establishment. Soil moisture sensors can be used to accurately determine volumetric moisture content of soil (Nemali et al., 2007). For precise and accurate measurements, a Theta Probe (ML2x; Houston, TX) can reliably determine soil volumetric moisture content. Measurements of soil volumetric moisture content can be utilized to schedule irrigation for conservative and effective substrate moisture management (Burnett and van Iersel, 2008; Nemali et al., 2007). The Theta Probe allows for a single equation to be used for water content measurements in different organic substrates, with EC or temperature having little effect on resulting output (Nemali et al., 2007). The Theta Probe can be calibrated for different soil and substrates by programming substrate-specific calibration curves. For this study, the Theta Probe's standard 'Organic' setting was used to measure substrate volumetric moisture content, and a 'Mineral' setting was used to measure soil volumetric moisture content in NOM treatments, as these settings used calibration curves representative of calibration curves calculated separately for each substrate and for soil (data not shown). Theta Probes can provide direct readouts of volume-based, plant-available soil moisture, rather than just reflect the water holding capacity of soil or substrates. Pressure chambers (PMS 1000; Corvallis, OR) can be used to measure stem water potential to quantify internal plant water relations. To obtain accurate measurements, stem cuttings are generally collected [8-10 cm (3-4 in) in length] between 10:00 AM and 2:00 PM and transported on ice to a pressure chamber.

In addition to analyzing soil moisture content and stem water potential, a photosynthesis system is an excellent tool that can be used to non-destructively measure a plant's ability to photosynthesize and use light energy under varying environmental conditions. Net photosynthesis rates are expressed as rates of CO_2 uptake (µmol) per unit leaf area (m^2) per second, measured in an open design where air flows through a plant chamber with the CO_2 level maintained at a steady state without environmental variability. Measuring stem water potential and photosynthesis will help quantify plant health and water uptake as influenced by organic matter.

Plant roots should also be thoroughly evaluated after transplanting to determine plant root growth response to organic matter type, since root growth following transplanting is essential to successful establishment and sustainability. Several methods measure root growth following transplanting. For field experiments, the core method takes soil samples outside of the root ball to quantify post-transplant root growth. Plant root balls can also be excavated and the dimensions measured at the termination of field experiments, or roots can be separated from soil, dried, and weighed to further quantify root growth. Other methods of root study include in-ground rhizotrons, where roots can be viewed as they grow from glass viewing windows underground, and container-type rhizotrons, where roots are visible through the walls of the transparent container in which grow (Böhm, 1979). Cameras and root growth analyzing software also make root growth analysis more powerful. In a similar but more controlled approach to these methods of root growth quantification, the Horhizotron™ provides an inexpensive, above-ground device that facilitates measurement of lateral post-transplant root growth in greenhouse and field studies (Wright and Wright, 2004). A container-grown plant is removed from its container and placed in the center of a Horhizotron. Four glass quadrants, each in a triangular shape, extend outward from the root ball. Each quadrant is filled with soil or substrate, creating 4 separate rhizosphere conditions into which roots can grow after transplanting. Lateral root growth after transplanting can be easily measured as viewed through these glass panes without damaging the plant and while roots actively grow. In addition to measuring lateral root growth with the Horhizotron, the root distribution through the soil profile can also be evaluated.

Native Plants for Southern U.S. Landscapes

Certain selections of native plant species can be suitable for landscape use and perform well in a variety of landscaping situations while providing ornamental features. Native plants are often recommended for use in sustainable landscapes since several native ornamental taxa may be able to withstand local environmental extremes (Franco et al., 2006). Defining native plants can be difficult, as many plants imported centuries ago have since naturalized within their new environment and are often embraced as 'natives', while these are actually naturalized exotics (Henderson et al., 2006). In the strictest sense, native plants are those that arrived before neolithic time, without human aid (Kendle and Rose, 2000). Landscapers are increasingly purchasing locally-sourced native plants for sustainable, low-input urban and residential landscapes (Brzuszek et al., 2007). Non-native, exotic plantings can become invasive and supplant native communities, although native plants can also dominate communities (Henderson et al., 2006). As explained by the enemies release hypothesis, domination by exotic plants may increase in cases where natural predators are eliminated removed from their intrinsic habitat (Colautti et al., 2004). In some cases, exotic plants lead to higher maintenance costs due to more frequent watering, fertilizing, and pruning requirements, along with greater costs in fuel from increased mowing, debris removal, and pruning (Simberloff, 2005). There are often labor expenses associated with clearing native vegetation to make way for non-native plant selections, further wasting time and money for a less economical solution (Sutton, 1975). Even with their potential benefits, native plants still face the challenge of establishment after transplanting. Problems may be complicated in poor urban soils, often rendered unsuitable for plant growth due to problems of compaction, anaerobic conditions, poor nutrient cycling, and removal of the natural litter layer (Craul, 1985).

Ecological impacts of landscaping must be assessed so wiser choices can be made to protect the species diversity represented by natural ecosystems. Some landscapes composed of non-native plants may not fully support native biodiversity of plants and animals typical to a region (Franklin, 1993). Plants also exhibit localized phenotypic and genotypic adaptations that contribute to ecosystem stability (Kane and Rieseberg, 2007). Plants may naturalize in a region to which they were not native, but soil and environmental conditions may not mimic their indigenous habitat (Hufford and Mazer, 2003). In addition to decreasing biodiversity (Meiners, 2007; Simberloff, 2005), invasion by exotic plants can often modify the soil organic matter content and carbon mineralization of a particular site, altering biogeochemical cycles, soil microorganisms, and other soil properties such as soil nitrogen cycles and phosphorus status (Chapuis-Lardy et al., 2006; Mack et al., 2001; Koutika et al., 2007; Rout and Callaway, 2009). As exotic species are introduced into ecosystems where they do not belong, such disturbances of the natural soil character and its processes could even lead to increased environmental disturbances such as insect pest outbreaks (Simberloff, 2005).

Native plants are a valuable natural resource in the landscape, and their importance in ecosystem stability and functionality is often overlooked. For centuries, many early American settlers ignored native plant species and instead planted popular European species (Kramer, 1973; Sutton, 1975). Exotic species dominate the nursery market (Ricciardi, 2007), while natives adapted to local environmental conditions are less frequently promoted in the nursery industry (Reichard and White, 2001). Native plants may be tolerant of local environmental extremes and have good visual appearance, providing a sense of locality and a connection to the native environment (Kendle and Rose, 2000).

Some laws now require the use of native plant species in native landscape restoration and reclamation projects (Brzuszek et al., 2007), and lawns and exotic plants in many American landscapes are being replaced with several drought-tolerant native species in efforts to create water-conserving landscapes (Himelick, 1989). Municipalities may place restrictions on water available for landscape use, adopt precision landscape irrigation, and seek alternative water sources such as reclaimed water to reduce water use (Kjelgren et al., 2000). Landscape firms are also using more native plants in their designs, in some cases reducing maintenance costs and achieving better plant performance in the landscape. Support from landscapers is, in turn, invigorating retail support for native landscape plants (Brzuszek et al., 2007). Homeowners seem to favor federal and state policies regarding the use of natives in landscaping and are even willing to pay more for a native landscape to enjoy potential benefits of reduced labor, water conservation, and sustainability (Hefland et al., 2006). Availability of native plants still limits their landscape use, but landscapers, garden centers, and wholesale nurseries are starting to use and appreciate them for their landscape value (Armitage, 2006). Use of native plants is often highest in residential projects, followed by commercial, municipal, and federal projects (Brzuszek et al., 2007).

Alabama has an extremely diverse collection of native plants in comparison to other states (Mohr, 1901), and several of Alabama’s native taxa demonstrate good potential for utilization in above-grade planting techniques to create native sustainable landscapes. *Kalmia latifolia* L., *Illicium floridanum* Ellis, and *Morella cerifera* L. are evergreen shrubs that are native to south Alabama and have ornamental that respond positively to above-grade planting with organic matter (Guckenberger and Wright, 2007; Price et al., 2009). *Hydrangea quercifolia* Batr. (oakleaf hydrangea) is another showy native landscape shrub with cinnamon-colored exfoliating bark and white panicles that last into the fall, changing to pink and then burgandy red as cooler temperatures approach. Oakleaf hydrangea panicles also make excellent cutflowers and dried arrangements (Dirr, 1998). This multi-stemmed, open-formed shrub transplants well and grows 2 to 3 m (6 to 10 feet) tall or larger, and up to twice as wide (Langdon, 1980), as it suckers from the roots and often grows in colonies (Gilman, 1999). Leaves are as interesting as the flowers, changing from shades of green in growing stages to red, orange, and purple during fall senescence, often remaining attached to the plant and displaying their color into the winter. *H. quercifolia* is hardy from USDA zones 5 to 9 and flowers from old woody stems every summer, even with some winter dieback (Dirr, 1998), although the plant should be protected in zone 5, as stems and buds experience injury at temperatures below -23ºC (-10ºF) (Damm and Miller, 2001). *H. quercifolia* prefers moist, well-drained and fertile acid soil, with full sun to part-shade exposure, although it tolerates a wide range of soil and light conditions (Langdon, 1980). Proper care includes maintaining a cool, moist root zone, pruning after flowering to ensure bud development and subsequent flowering the following spring; and although the species requires little attention once established (Gilman, 1999), it may need to be cut back considerably each fall to control its size (Langdon, 1980). This species exhibits resistance to most insects and disease, and while nursery growers have trouble producing uniform crops due to its rapid growth of underground stolons, once planted in the landscape these problems are less prevalent (Gilman, 1999; Langdon, 1980). Often this species prefers limestone soils in woodland settings with high organic matter. Several cultivars are available in the trade that vary in panicle and plant size, hardiness (USDA zones 5 to 9), and other aspects. Most are propagated from juvenile cuttings rooted in well-drained substrate during the summer, although they can be easily propagated from seed or division of colonizing suckers (Gilman, 1999). *H. quercifolia* 'Alice' is a tough, nearly maintenance-free selection for deep shade or moist, woodland areas and remains a staple of the southern American landscape. Used as a specimen, background or screen, under oaks or other large trees, or in a variety of other applications, this sprawling species provides year-round interest (Langdon, 1980).

Chionanthus virginicus L. (white fingetree), also known as "Grancy's greybeard", is a desirable native woody landscape plant often under-utilized by landscapers. This moderately slow growing shrub or small tree does well in part-sun or part-shade conditions. *C. virginicus* is dioecious, with male plants having a more showy floral display and both male and female plants are required for fruit and seed production. It has an open, spreading form, with panicles of creamy white fragrant flowers in late spring, followed by dark olive-like blue fruit in the fall that attract birds and other wildlife (Dirr, 1998). White fringetree is often used as a raw material by pharmaceutical companies in preparing homeopathy tinctures, and antioxidant activity is high in *C. virginicus* root bark (Gülçin et al., 2006; Gülçin et al., 2007). For use in urban landscaping, *C. virginicus* is tolerant to air pollution and flowers early in its development after transplanting. *C. virginicus* is a good urban tree suitable for a wide range of landscape uses, as a native specimen suitable for buffer strips around parking lots, sidewalks, or highway medians, growing well near streams or ponds, with hardiness from USDA zones 3 to 9 (Gilman and Watson, 1993). At maturity, it reaches up to 30 feet (9 m) tall with equal spread. *C. virginicus* often grows wild along streams and swamp borders and thrives in moist and fertile, acid soils, especially in the understory of mixed pine/hardwood forests. Harris et al. (1996) demonstrated that *C. virginicus* transplanted more successfully in the fall than in the spring, and first season post-transplant irrigation regimes should focus on providing water to the root balls rather than to surrounding soil areas. *C. virginicus* is very drought tolerant, however, and is as drought tolerance as some oak and maple species (Augé et al., 1998). Pruning or other maintenance is seldom required for *C. virginicus* (Gilman and Watson, 1993). *C. virginicus* is most commonly propagated by seed, and asexual propagation is extremely difficult, but progress is being made towards the rooting of stem cuttings, and other techniques such as layering, grafting, or budding onto ash seedlings have been attempted (Dirr and Heuser, 1987). *C. virginicus* is becoming more available in the nursery trade, and shows good potential as a ornamental and drought tolerant native landscape plant.

Rhododendron austrinum Rehd. (Florida flame azalea) is also common to southern U.S. native landscapes. Known as the “Florida azalea” or “Florida flame azalea”, this species grows up to 10 feet (3 m) tall as a loose, multi-stemmed shrub. It produces flowers from April to May, ranging in color from orange to creamy yellow to red and emitting a honeysuckle-like fragrance. These flowers are frequently visited by butterflies, and hummingbirds alike, although the species is reportedly resistant to grazing by deer (Bartlett and Curtis, 2003) and damage from azalea lace bug (Braman and Pendley, 1992). There are many flowers to each truss, with trusses sometimes ball-shaped, and the plant is very similar in attributes to *R. canescens* L., although with less genotypic and phenotypic variation (Coleman, 2008). *R. austrinum* may be used as a specimen, border plant, or in mass plantings at 1-1.5 m (3-5 ft), although it is recommended that specimens be allowed at least 1.8 m (6 ft) spread to develop into its true cascading form (Gilman, 1999). *R. austrinum* makes an excellent understory plant for light, moist, acid soils and has good drought tolerance once established (Gilman, 1999). Florida flame azaleas thrive in filtered shade with some direct sun, as provided by most woodland settings (Gilman, 1999). The only major problems in culture to avoid are mushroom root rot, which occurs in anaerobic soil conditions, and iron deficiencies that may occur at high soil pH (Gilman, 1999). *R. asutrinum* should be protected from strong winds, root competition, and drought, and a thick mulch layer may be useful for moisture retention (Gilman, 1999). The species is hardy from USDA Zones 6 -10 and has a tight vertical branching form for added winter interest. Pruning is seldom necessary but should be completed after flowering in the spring, and pruning can contribute to increased branching and bloom count (Gilman, 1999). *R. austrinum* is generally propagated by seed collected beginning in September, as seed pods turn from green to brown and before dehiscence, but also by stem cuttings, division of suckers, layering, and grafting (Hay et al., 2006). The Florida Flame Azalea is currently an endangered species (Shaw and Thibodeau, 1985); several nurseries have *R. austrinum* in commercial production, and the species is gaining popularity for landscape use.

Conclusion

Utilizing selected native plants in the landscape could be part of the solution to the major drought situation often faced in landscape maintenance. Although this study evaluates the effects of organic matter types in above-grade planting under idealized soil conditions, the above-grade planting technique is also effective when utilized in urban soils (Smith, 1998). Planting depth is important for a plant's survival under severe moisture stress, especially in cases of compaction and poor soil that are typical of urban landscapes, where both drought and high rates of irrigation may be detrimental in compacted soils (Smith, 1998). This research aims to evaluate several common types of organic matter for use in the above-grade planting technique under optimized environmental conditions (irrigation, drainage, nutrition), in hopes of improving establishment and sustainability of landscape plants. Establishment, however, may be difficult to clearly define. While many studies have quantified and evaluated plant growth, there appears to be no studies that have effectively described the point at which a plant has become established. There is some speculation that plants may be established after one season's growth, but literature does not seem to provide specific details of the point or means by which plants achieve establishment. In evaluating chipped pine tree substrate, coconut coir, pine bark, and peat moss as organic amendments, this research will investigate which amendments facilitate initial post-transplant growth which may contribute to successful establishment for a diverse selection of native deciduous shrubs when planted using a modified above-grade technique. *H. quercifolia*, *C. virginicus*, and *R. austrinum* were chosen to provide as good representatives of native plants found in different natural environments, and because of their ornamental qualities. Besides determining organic matter preferences in this above-grade planting technique, this research may provide information that can be applied to improve survival of these selected native shrubs after planting in the landscape, possibly encouraging increased use of these taxa by landscapers. In utilizing the above-grade planting method and properly mounding the right type and amount of organic matter at the time of planting, the ornamental value and benefits of these native deciduous shrubs can be fully developed.

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CHAPTER II

ORGANIC MATTER TYPE AFFECTS ROOT GROWTH OF THREE NATIVE SHRUBS PLANTED USING A SIMULATED ABOVE-GRADE PLANTING TECHNIQUE

Additional index words. Horhizotron, substrate, *Hydrangea quercifolia* ‘Alice’, *Chionanthus virginicus*, *Rhododendron austrinum*, landscape, establishment, shrub

Abstract

Using organic matter when planting above-grade can mimic the natural organic layer that supports root growth after transplanting. In a series of three runs, Horhizotrons were used to create simulated, above-grade planting conditions to evaluate the effect of organic matter type on post-transplant root growth of *Chionanthus virginicus* L., *Rhododendron austrinum* Rehd., and *Hydrangea quercifolia* Bartr. ‘Alice’ in a greenhouse in Auburn, Ala. with one of four substrates layered on top [coconut coir (CC), chipped pine trees (PT), peat moss (PM), or pine bark (PB)]. Horizontal root length (HRL) was measured weekly or bi-weekly. At experiment termination, roots growing into each quadrant were cut from the original container root ball, divided into soil and substrate portions, rinsed to remove soil and substrates from roots, dried, and weighed. HRL increased linearly over time in all substrate treatments for all taxa in all runs. Root growth response varied

among taxa for each substrate treatment, although generally more roots grew into soil than into substrate for all taxa in all runs. HRL and RDW for *H. quercifolia 'Alice'* were generally greatest in CC and PT substrates, while HRL for *R. austrinum* was generally longest in PM in all three runs. HRL was generally highest for *C. virginicus* in PM, yet results varied among runs, and there were very few differences among treatments in RDW.

Introduction

Despite a rising interest in the promotion of native landscapes, native plants still face the challenge of successful establishment. This problem may be compounded in poor urban soils, often rendered unsuitable for plant growth due to problems of compaction and the removal of the natural organic litter layer (Craul, 1985; Jim, 1998; Montagu et al., 2001). It is especially challenging for containerized plants with fine or fibrous root systems to overcome the mechanical impedance associated with compacted soils, yet successful root penetration into the soil backfill is essential to promote nutrient uptake and resulting post-transplant growth. Planting plants above-grade utilizing organic matter is one way to remediate poor soil conditions to increase post-transplant root and shoot growth for shrubs and trees (Arnold et al., 2007; Guckenberger and Wright, 2007; Price et al., 2009; Wright et al., 2007). In this method, plants are planted such that the top one-third of the root ball remains above soil grade, and organic matter such as pine bark or peat moss is mounded around the above-grade portion of the root ball. This organic layer mimics the natural layer of accumulated organic matter in upper soil horizons and supports plant root growth after transplanting due to its low bulk density (Hodge, 2004; Kozlowski, 1999; Sayer, 2006). The above-grade planting technique is simple, and could be effective when utilized by landscapers and home gardeners to enhance establishment and resulting survival of transplanted shrubs and trees. A previous study of this planting technique with three evergreen native shrub species (*Kalmia latifolia* L., *Illicium floridanum* Ellis, and *Morella cerifera* L.) indicated that cotton gin compost, despite its successful use in nursery production, was not an acceptable substitute for common landscape soil amendments such as pine bark and peat moss (Guckenberger and Wright, 2007; Price et al., 2009). While substrates composed of peat moss or pine bark are commonly used in landscaping and in the nursery industry, other substrates such as coconut coir and ground or chipped pine tree substrates have also proven suitable for nursery container production (Abad et al., 2005; Fornes et al., 2003; Noguera et al., 2003; Wright et al., 2008), and may be suitable for landscape use. Based on the success of this above-grade technique and the need to explore the uses of alternative substrates, it is important to determine which organic materials successfully encourage post-transplant root growth for a range of native species when utilized in this above-grade planting technique. The objective of this study was to determine the effect of organic matter type on root growth of three native deciduous shrubs in a simulated above-grade planting technique.

Materials and Methods

Experiments were conducted beginning 21 Feb. 2008 (run 1), 23 Jul. 2008 (run 2), and 25 Feb. 2009 (run 3). Plants planted during February were fully dormant with little or no budswell, while leaves of plants planted in July were fully emerged following active spring growth. All plants were transplanted from 11.4 L (3 gal) containers. For the first and third runs, *Hydrangea quercifolia* Bartr. 'Alice' (oakleaf hydrangea) plants were obtained Jan. 2008 and Feb. 2009, respectively from Greene Hill Nursery in

Waverly, Ala. [2-year liners, propagated from stem cuttings taken from existing nursery stock and grown in 9:1 pine bark:sand substrate]. *Hydrangea quercifolia* 'Alice' plants used in run 2 were obtained in Jul. 2008 from Southern Growers Nursery in Montgomery, Ala. (2-year liners, propagated from stem cuttings taken from existing nursery stock and grown in 9:1 pine bark:sand substrate). *Chionanthus virginicus* L. (white fringetree) plants were obtained from Dodd & Dodd Nursery in Semmes, Ala. (2-year liners, propagated from seed at Superior Trees in Lee, Fla. And grown in 100% pine bark substrate) during Feb. 2008 (runs 1 and 2) and Feb. 2009 (run 3). *Rhododendron austrinum* Rehd. (Florida flame azalea) plants were obtained in Feb. 2008 (runs 1 and 2) and Feb. 2009 (run 3), from Moore & Davis Nursery in Shorter, Ala. (2-year liners, propagated from stem cuttings taken from existing nursery stock and grown in 9:1 pine bark:sand substrate).

Each run was conducted in a greenhouse at Auburn University's Paterson Horticulture Greenhouse complex (Auburn, Ala.) [day/night temperatures set at 26/21°C (79/70°F)]. In each run, five plants each of *H. quercifolia* 'Alice', *C. virginicus*, and *R. austrinum* were removed from their containers and planted into Horhizotrons™ (one plant per Horhizotron), with the bottom of each containerized root ball resting directly on the center of the respective Horhizotron base (Price et al., 2009; Wright and Wright, 2004;). The Horhizotron provides a non-destructive method for measuring root growth over time in up to four different rhizosphere conditions and can be used to simulate field conditions (Wright and Wright, 2004). Horizontal root growth from the original container root ball into the surrounding soil or substrate can be directly measured on the glass panes of each quadrant and used to quantify root growth and penetration under different soil and substrate conditions. Each Horhizotron contained eight 20.3 x 26.7 cm (8.0 x 10.5 in) glass panes arranged to form four 3.7 L (1 gal) wedge-shaped quadrants extending outward from the root ball.

Soil (Marvyn sandy loam) was obtained from field research plots on Auburn University's campus, and rocks, sticks, large roots, and other debris were removed by hand to create a uniform soil. Soil was added to each of the 4 quadrants to a height of 10 cm (4 in) (half full). Top halves of each quadrant were filled to grade level with one of four randomly assigned organic matter substrates (100% pine bark, 100% peat moss, 100% coconut coir, or 100% chipped pine trees).

To prepare coconut coir (FibreDust LLC, Glastonbury, Conn.) for use, 26.5 L (7 gal) of tap water was added to a 5 kg (11 lb) block and mixed to yield approximately 0.07 m^3 (2.5 ft^3) of coir substrate. Pine tree substrate was obtained from *Pinus taeda* L. (loblolly pine) logs harvested 21 Jan. 2008, from Virginia Tech's Southern Piedmont Agriculture Research & Extension Center in Blackstone, Va. The pine tree logs were coarsely chipped on 13 Feb. 2008 with a 1996 Bandit Model 200 Chipper, then hammered with 25% by volume pine bark on the same day with a Mills 25 hp hammer-mill to a size of 0.5 cm (0.2 in). To prepare peat moss (Fafard Inc., Agawam, Mass.), pine bark (Pineywoods Mulch Co., Alexander City, Ala.), and chipped pine trees for use, substrates were thoroughly moistened with warm tap water.

Physical properties of all substrates were determined at Auburn University (Auburn, Ala.) using the NCSU Porometer™ method (Fonteno et al., 1981) and compared to measurements published by North Carolina State University's Horticultural Substrates Lab (Raleigh, NC). Subsamples of each substrate (same batch of production) were sent to Quality Analytical Laboratories (Panama City, Fla.) to compare physical properties results among laboratories (Table 1). Substrate and soil chemical properties [nutrient concentrations, electrical conductivity (EC), soluble salts, and pH] and soil physical and chemical properties (particle size, texture, and nutrient concentration) were determined by Auburn University Soil Testing Laboratory (Auburn, Ala.) (Tables 2, 3, and 4). No fertilizer was added in run 1. In the second and third runs, each quadrant was top-dressed at planting with 9 g (0.1 oz) (medium rate) of Polyon 17N-5P_2O_5-11K_2O (PTI, Sylacauga, Ala.) 12-month controlled release fertilizer. In run 3, *C. virginicus* plants began showing symptoms of micronutrient deficiencies, and a water-soluble micronutrient foliar spray (Jack's Professional® MOST – Mix of Soluble Traces; J. R. Peters, Allentown, Penn.) was applied to plant canopies [0.6 $g{\cdot}L^{-1}$ (0.08 $oz{\cdot}gal^{-1}$) rate] for corrective measures. At installation, plant shoots were pruned to a similar size and shape within each taxon, and growth indices {[widest width (cm) + perpendicular width (cm) + height (cm)]/3} were recorded at the installation and termination of each experiment. Plant visual quality (VR, based on a scale from 1 through 5, where 1=lowest visual quality and 5=highest visual quality) was recorded within each taxon at experiment termination.

Taxa were irrigated independently of one another, and within each taxon, quadrants were irrigated separately among treatments and separate from the root ball. Irrigation was scheduled during the first run based on volumetric moisture content of the root ball and soil moisture in each quadrant as measured by a ML2X Theta Probe (Dynamax, Houston, Tx.). In the second and third runs, ECH_2O EC-5 soil moisture sensors (Dynamax, Houston, Tx.) were installed in two Horhizotrons per taxon, with one sensor in each of the 4 quadrants and one in the root ball to measure volumetric moisture content. Irrigation was applied when percent moisture of a quadrant or root ball dropped to 20%. When irrigated, approximately 800 mL (0.2 gal) tap water was applied to a quadrant or root ball to fully saturate the substrate and soil in that quadrant or root ball without excessive leaching.

Root growth into substrate and soil in each quadrant, as visible on each glass pane (2 per quadrant) was determined by measuring horizontal root length (HRL) (Price et al., 2009; Wright and Wright, 2004) every 1-2 weeks using a Scale Master® II (6325; Carson City, Nev.). In runs 1 and 2, HRL was measured for the five longest roots growing into substrate or soil on each side of a quadrant. In run 3, HRL of the 10 longest roots in the substrate portion and the 10 longest roots in the soil portion were recorded for each quadrant (independent of side). When there were less than 10 roots in a quadrant, HRL for visible roots only was included in data analysis (HRL measurements of 0 were omitted from data). When roots within any treatment for a taxon began to approach the end of the quadrant (26 cm, 10 in), the run for that taxon was terminated. At termination, substrate, soil, and roots growing into each quadrant were cut from the original root ball using a large knife and separated into substrate and soil portions for each quadrant. Substrates and soil were rinsed from roots by hand, and roots were dried at 68°C (155°F) for 48 hours before weighing. Dry weight of roots (RDW) was determined separately for soil (soil RDW) and substrate (substrate RDW) portions in each quadrant. There was great difficulty in separating soil and substrate particles from *R. austrinum*'s fine, hair-like roots, therefore, RDW data were not collected for *R. austrinum*. Instead, visual ratings of roots were recorded (run 3 only) for each quadrant face, with 1 being little or no root growth and 5 being roots nearly filling the quadrant and the density of proliferation increasing with rating number (Table 5). Within each run, treatments were arranged in a randomized complete block design with 5 blocks (Horhizotrons) per taxon. Data were analyzed using GLM procedures, regression analysis, and LSD means separation at $\alpha = 0.05$ (SAS Institute, 2003).

Results

Shoot growth indices increased at similar rates over time within each taxon since all plants received the same treatments. Roots grew into both substrate and soil portions of each quadrant, and days to experiment termination varied among taxa (Figs. 1-5). Root growth in all treatments was most rapid in *H. quercifolia* ‘Alice’, with the lowest days after planting (DAP) to termination for all three runs, followed by *C. virginicus* and *R. austrinum*, respectively. HRL increased linearly over time in all treatments and for all taxa (Tables 6-8). For all taxa, run 2 was terminated earlier than run 1, as roots of all species reached the ends of their respective quadrants at fewer DAP than in run 1. In run 3, *H. quercifolia* ‘Alice’ and *C. virginicus* required more DAP to termination than in run 2, but DAP to termination was similar between runs 1 and 3 for these taxa. Run 3 has not been terminated for *R. austrinum*; however, it will likely be terminated before approximately 150 DAP.

Hydrangea quercifolia ‘Alice’. Differences in HRL among treatments were observed 33 days after planting (DAP) (run 1), 18 DAP (run 2), and 37 DAP (run 3), with HRL being longer in coconut coir (CC) (runs 1 and 3) or pine tree substrate (PT) (run 2) than in other substrates and with these trends continuing throughout most of the run (Fig. 1). HRL was shortest in peat moss (PM) for runs 1 and 2 (Table 6, Fig. 1). Similar to HRL, total RDW (soil RDW + substrate RDW) was also generally highest in CC and PT, with the lowest total RDW in pine bark (PB) (runs 1 and 2) and PM (run 3) (Fig. 4). In run 1, substrate RDW was highest in CC and lowest in PM, with PT and PB being intermediate (Fig. 4A). Soil RDW in run 1 was highest in CC and PT treatments and lowest in PB (Fig. 4A). For runs 2 and 3, there were no differences in total, substrate, or soil RDW among treatments (Figs. 4B-C).

Chionanthus virginicus. In run 1, there was initially no HRL difference among treatments, yet from 75 DAP until termination, HRL was longest in PM, intermediate in PT, and shortest in CC and PB (Table 7, Fig. 2). In run 2, there were no differences among treatments throughout the duration of the experiment. In run 3, HRL was not different among treatments in substrate layers of quadrants, but HRL in soil layers of quadrants was longest in CC, followed closely by PT at 71 DAP, and this trend continued throughout the duration of the run. In run 1, total RDW was highest in CC and PB, substrate RDW was highest in PB and lowest in PT, and there were no differences among treatments in soil RDW (Fig. 5A). There were no differences in total RDW, substrate RDW, or soil RDW among treatments in runs 2 and 3 (Figs. 5B-C).

Rhododendron austrinum. HRL in run 1 was longest in PM throughout the duration of the experiment, followed closely by that in CC (Fig. 3). After 61 DAP, HRL was longer in PM and CC treatments than in PB and PT treatments for the duration of run 1. In run 2, HRL was longer in PT and PM than CC and PB, with HRL in PT generally longest among treatments from 48 DAP until termination. In run 3, there was initially little difference in HRL among treatments, but from 85 DAP until termination, HRL was longest in PM and PTintermediate in PB, and shortest in CC. HRL in all 3 runs was longer in PM than in PB or CC. Root visual ratings in run 3 were highest in PM, intermediate in PT and PB, and lowest in CC (Table 5).

Discussion

Differences in treatment response between total RDW and HRL in *C. virginicus* and *H. quercifolia* 'Alice' may indicate that HRL and RDW are more closely correlated in *H. quercifolia* 'Alice' than in *C. virginicus*. Whereas some roots elongate quickly while others branch densely, it is important to examine both root length and root dry weight to accurately characterize root growth responses. For example, root diameter can increase when roots encounter compacted soils as this allows them to relieve stress in front of the root apex and decrease buckling (Bengough et al., 2006). Physical characteristics of roots varied among taxa, with fleshy, white-cream colored roots of *C. virginicus* being thickest and visibly having the largest diameter and least branching, while diameter and branching of *H. quercifolia* 'Alice' roots were intermediate, and diameter and branching of *R. austrinum* roots were least. *R. austrinum* roots were thin, somewhat translucent and very fibrous, producing a dense mat of roots with extensive branching. The mat of *R. austrinum* roots were tightly interwoven amongst and directly through soil particles, preventing the separation of soil and substrate from roots for RDW data collection. Due to the inherent experimental error associated with this process, RDW for *R. austrinum* was not analyzed. *H. quercifolia* 'Alice' roots were also thin (slightly thicker than *R. austrinum* roots), but branching did not form such a dense mat growing through soil particles. *H. quercifolia* 'Alice' and *C. virginicus* roots also appeared to be stronger, more aggressive, and more robust (than those of *R. austrinum*) with faster rates of root elongation and penetration. Roots of *H. quercifolia* 'Alice' and *C. virginicus* facilitated separation procedures needed to obtain RDW with minimal root loss or damage. Although not compared statistically, root growth rate appeared to be highest for *H. quercifolia* 'Alice' and lowest for *R. austrinum*, with *C. virginicus* being intermediate (Figs. 1-3). Roots of all taxa initially grew outward from the original container root ball into each quadrant in both substrate and soil portions, but often roots of *R. austrinum* unexpectedly grew into soil portions first. Following initial penetration of roots into substrate portions, roots of all taxa would alter the angle of their rooting front from a horizontal direction across the upper profile to a more downward slope. Roots having initially grown into the upper substrate layer would grow outward and down at an angle, gradually approaching the soil layer as HRL increased. When fertilizer was surface applied, however, more roots maintained their original horizontal direction of growth into their respective substrate or soil portions of each quadrant, and the root growth front was in effect more even across substrate and soil portions, as the localized fertility increase in the upper substrate layer may have prevented roots from growing downwards towards the soil layer in search of nutrients. Roots were generally distributed evenly within quadrants, as roots grew both near glass panes and within the center of quadrant layers.

The age and health or vigor of plants and plant roots at planting may affect the rate or success of establishment (Gao et al., 1998; Korbobo, 1959). For example, containerized plants often become pot-bound and experience extensive root circling around the sides and bottom of the container. When transplanting plants with containerized root balls in this condition, the matted roots are often much slower to extend outward from the original root ball and penetrate surrounding soil. This phenomenon may have occurred with *R. austrinum*, as plants in run 3 had been in their respective containers for over a year longer than plants used (same age and source) for runs 1 and 2 and showed some signs of root circling. As a result, *R. austrinum* plants used in run 3 required more DAP for completion compared to the first two runs. Results also suggest that season may have affected the rate of root growth more than the addition of controlled-release fertilizer, as taxa had similar growth rates and substrate preferences between runs 1 (planted in Feb., no fertilizer added) and 3 (planted in Feb., fertilizer added), while requiring more DAP to reach experiment termination in run 2 (planted in summer) (Figs. 1-3). In this study, urban soils were not directly addressed, as Marvyn sandy loam field soil may contain higher nutrient concentrations, include more organic matter, and have better drainage than typical urban soils. The quality of sandy loam soil used in this study could have reduced root stress and influenced more root growth into the soil. Fertility may affect the direction of root growth, and increased root growth in soil portions of each quadrant may have been influenced by increased nutrient concentrations and pH differences in soil compared to substrates (Somma et al., 1998).

Values for total RDW, substrate RDW, and soil RDW in run 1 (*H. quercifolia* 'Alice' and *C. virginicus*) reflect root growth into the soil portions of each quadrant (Figs. 4-5). In the landscape, such growth is important to sustain and promote long-term establishment. While roots in these experiments grew into each substrate, often more roots grew into the soil portions of each quadrant, especially in run 1, where soil RDW was higher than substrate RDW (Figs. 4-5). The increased root growth into mineral soil portions may be due to chemical properties and plant-available nutrients in soil portions compared to substrate portions (Tables 3-4). Topdressing with controlled-release fertilizer could have encouraged more roots to grow into substrate portions of each quadrant, effectively increasing substrate RDW among taxa for runs 2 and 3, especially for *H. quercifolia* 'Alice' (Fig. 4). The addition of fertilizer may also have contributed to the lack of total RDW differences among treatments for runs 2 and 3 (Figs. 4-5). Such results suggest it may be beneficial to apply (topdress) controlled-release fertilizer when utilizing organic matter in this modified above-grade planting technique to promote more root growth into the substrate mound. These observations also suggest that adding fertilizer to this planting technique may improve the performance of some substrates used or reduce differences among substrates, facilitating successful landscape use.

Each taxa was treated as a separate experiment, but plants appeared to demonstrate taxa-specific root growth responses to substrate treatments. HRL and RDW data for *H. quercifolia* 'Alice' suggest that CC and PT substrates may be substitutes for PB and PM substrates for utilization with this technique (Table 6, Fig. 1, Fig. 4). Likewise, HRL and visual rating data for *R. austrinum* suggest that PM is generally preferred over other substrates for use in above-grade planting. There is a lack of correlation between HRL and RDW data for *C. virginicus*. There is variability among taxa in this study in nutrient requirements (dry weight basis), and thus different responses to the different chemical properties of soils and substrates (Mills and Jones, 1996). For example, the sufficiency range of Mn (dry matter basis) for *R. austrinum* is nearly 6 times higher than for *H. quercifolia* 'Alice' or *C. virginicus* (Mills and Jones, 1996). Other micronutrients are required in high levels by *R. austrinum*, such as Fe and B (2 and 4 times dry weight requirement for *C. virginicus*, respectively) (Mills and Jones, 1996). Twice as much Mg is also recommended in sufficiency ranges for *R. austrinum* compared to those for other taxa (Mills and Jones, 1996). The Mg and micronutrient fertility provided by the field soil (Table 4) may have provided greater available nutrition for *R. austrinum*, causing more roots to grow into soil portions of each quadrant. This was surprising and in contrast with published and unpublished results, since low bulk density and typical physical and chemical properties of substrates are often preferred by the finer roots of *R. austrinum* and similar taxa (Guckenberger and Wright, 2007). It is possible that in this instance, the higher nutrient concentration in soil (especially micronutrients) was better able to support root growth.

CC had the highest soluble salt concentration, EC, and pH among substrates (Table 3). The pH of CC and PT substrates was closer to the preferred pH range of these native taxa, as PM and PB both had a very low pH range without lime amendment (Table 3) (Mills and Jones, 1996). Despite the potential effects of substrate chemical properties on growth, HRL did not appear to be solely correlated with substrate pH or EC, or nutrient concentration. Rather, it is likely that a combination of factors affect root growth of each taxon. Physical and chemical properties of substrates may therefore influence the effectiveness of this technique for improving landscape establishment.

While bulk density was similar among substrates, WHC was highest in CC and PM, while coarser, pine-based substrates PT and PB had a lower WHC percentage (Table 1). Rewetting properties also varied among substrates. CC and PT readily absorbed water quickly and evenly, even when very dry (visual observation). On the other hand, PM has a high WHC (Table 1) but becomes hydrophobic when only slightly dry (visual observation). PB instead has a low WHC (Table 1), and water quickly drains through with little retained in the substrate (visual observation). PB also shares similar hydrophobic properties to PM when dry (visual observation). As PB quadrants drained fastest, the most frequent irrigation was required for PB (watered daily), followed by PT (watered every other day) and CC (watered every 2-3 days), respectively. PM dried out most slowly (watered weekly), even compared to original container root balls (watered every 3-5 days). When irrigated, all water penetrated substrates fairly quickly and drained into soil portions. This seemed to result in soil portions remaining wetter throughout each experiment than substrate portions (visual observation). None of the substrates appeared to degrade or break down, but careful pouring of water during irrigation had to be exercised to prevent displacement of substrate from its respective quadrant. Some shrinkage or shifting and settling of substrates did occur as plants were watered over time, but substrates generally remained within their respective quadrants.

Results for HRL and RDW suggest that CC or PT may be acceptable replacements for PM or PB when utilized in this above-grade planting technique and may improve the establishment and survival of these and other native taxa when transplanted into the landscape. CC and PT substrates are readily available and demonstrate potential as alternative substrates to replace traditional landscape amendments like PM and PB. Previous research indicated that PM and PB were the most effective substrates when three native species [*Morella cerifera* L. (wax myrtle), *Illicium floridanum* Ellis (Florida anise tree), and *Kalmia latifolia* L. (mountain laurel)] were planted using this technique (Guckenberger and Wright, 2007; Price et al., 2009). Continued assessment of these and additional substrates may help to refine this technique and improve its application. Both current and prior research demonstrate the variance of substrate preference among taxa; therefore, the continued evaluation of this above-grade planting technique for a range of native shrubs and a variety of substrates is needed to advance the successful implementation of native, sustainable landscapes.

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Table 1. Physical properties of substrates[z].

	Porosity (%)			WHC (%)		
Substrate	AU[y]	NCSU[x]	QAL[w]	AU	NCSU	QAL
Pine Bark	63.2b[v]	75-80	76.60	79.2a	81	77.24
Coconut Coir	79.4a	92-95	93.36	63.0b	56	51.28
Chipped Pine Trees	72.8a	75	87.95	72.6a	59	75.29
Peat Moss	77.4a	89-94	75.28	77.1a	74-77	64.35
	Air Space (%)			**Bulk Density (g/cc)**		
Substrate	AU	NCSU	QAL	AU	NCSU	QAL
Pine Bark	23.0a	19-24	25.32	0.2a	0.2	0.2
Coconut Coir	23.7a	11-14	16.12	0.1b	0.1	0.1
Chipped Pine Trees	22.7a	16	12.66	0.1a	0.3	0.2
Peat Moss	22.6a	12-20	10.94	0.1a	0.1	0.1

[z]Properties determined for each substrate, using subsamples from the same batch of production for each substrate.

[y]Properties determined at Auburn University (Auburn, Ala.) using the NCSU Porometer™ (Fonteno et al., 1981).

[x]Properties published by North Carolina State University Horticultural Substrates Lab (Raleigh, NC) as determined through several NCSU Porometer tests (Fonteno and Harden, 2003).

[w]Properties determined at Quality Analytical Laboratories (Panama City, Fla.) using the NCSU Porometer.

[v]Letters denote means separation among treatments using LSD at $\alpha = 0.05$ (SAS Institute, 2004).

Table 2. Substrate particle size distribution analysis[z].

Substrate	Weight (g) Sieve Mesh Size[y] 12.50 mm	9.50 mm	6.30 mm	3.35 mm	2.36 mm	2.00 mm	1.40 mm
Pine Bark	0.00	6.67	3.63	1.70	1.60	0.07	9.70
Coconut Coir	0.07	20.47	10.07	2.07	0.53	0.07	0.20
Chipped Pine Trees	0.00	20.80	12.67	3.20	1.07	0.00	0.03
Peat Moss	2.40	15.53	12.17	3.30	1.47	2.53	6.10

Substrate	Weight (g) Sieve Mesh Size 1.00 mm	0.50 mm	0.25 mm	0.11 mm	0.05 mm	< 0.05 mm
Pine Bark	26.13	12.43	4.77	11.03	8.77	12.30
Coconut Coir	1.70	4.50	3.47	12.50	15.17	28.70
Chipped Pine Trees	0.13	0.63	1.07	12.53	18.67	28.77
Peat Moss	12.87	7.83	3.00	7.70	7.53	16.57

[z]Substrate samples (100 g each) were shaken through a series of 12 sieves using a Rotap Shaker (Tyler Industrial Products, Menton, Oh.) for 5 minutes before weighing contents of each sieve.
[y]Mesh opening size (mm) of each sieve screen through which substrates pass.

Table 3. Electrical conductivity (mmhos·cm^{-1}), pH, and concentration (mg·L^{-1}) of soluble salts (SS), macronutrients, and micronutrients in saturated extract of substrates[z].

Substrate	EC	SS	pH	NH_4 N	NO_3 N
Pine Bark	0.2b[y]	156.8b	4.0c	0.70b	0.00b
Coconut Coir	2.1a	1484.0a	6.0a	0.12b	0.05b
Chipped Pine Trees	0.1b	89.6b	5.2b	0.02b	0.04b
Peat Moss	0.2b	141.4b	3.7d	12.38a	1.22a

Substrate	Ca	K	Mg	P	Al	B	Cd	Cr
Pine Bark	16.4a	31.1b	14.9a	4.1b	5.7a	≤0.1b	≤0.1[x]	≤0.1
Coconut Coir	7.2b	533.2a	14.9a	20.4a	0.1c	0.2a	≤0.1	≤0.1
Chipped Pine Trees	2.3c	29.8b	1.1b	0.8c	1.1b	≤0.1b	≤0.1	≤0.1
Peat Moss	1.7c	4.4b	1.5b	2.8b	≤0.1c	≤0.1b	≤0.1	≤0.1

Substrate	Fe	Mn	Na	Ni	Pb	Zn	Cu
Pine Bark	1.6a	1.2a	3.8b	≤0.1	≤0.1	0.2a	≤0.1
Coconut Coir	≤0.1c	≤0.1c	174.4a	≤0.1	≤0.1	≤0.1b	≤0.1
Chipped Pine Trees	0.3b	0.2b	4.5b	≤0.1	≤0.1	≤0.1b	≤0.1
Peat Moss	≤0.1c	≤0.1c	8.6b	≤0.1	≤0.1	≤0.1b	≤0.1

[z]Substrate analysis of saturated extracts, conducted using the Microplate method (Shand et al., 2008) at Auburn University Soil Testing Laboratory, Auburn, Ala.

[y]Letters denote means separation among treatments using LSD at $\alpha = 0.05$ (SAS Institute, 2004). Letters are omitted if there are no differences.

[x]≤0.1 = measurements were below the detection limit

Table 4. Textural and elemental analysis of five soil subsamples of Marvyn sandy loam field soil at Auburn University Soil Testing Laboratory, Auburn, Ala.

Textural analysis		
	Mean	St.Dev.
% Sand	54.1	1.9
% Silt	22.2	0.7
% Clay	23.8	1.8
H_2O Availability[z]	0.1	0.0
pH	5.5	0.1
Micronutrients[y]		
	Concentration (mg·liter^{-1})	
Al	171.7 ±9.5	
B	0.1 ±0.0	
Cd	0.1 ±0.0	
Cr	0.1 ±0.0	
Cu	1.4 ±2.0	
Fe	16.9 ±5.7	
Mn	13.3 ±1.3	
Na	33.5 ±0.9	
Ni	0.1 ±0.0	
Pb	2.2 ±3.2	
Zn	2.1 ±0.4	
Macronutrients[x]		
	Concentration (kg·ha^{-1})	
P	6.4 ±1.2	
K	126.8 ±7.7	
Mg	229.8 ±94.1	
Ca	1059.6 ±49.9	

[z]Hydrometer method (Bouyoucos, 1962) used to determine water availability (cm^3 water/cm^3 soil) based on percentages of sand, silt, and clay particles.

[y]Mehlich-1 method used to measure extractable micronutrients from saturated extract (Mehlich, 1953).

[x]Mehlich-1 method used to measure extractable macronutrients from saturated extract (Mehlich, 1953).

[z]Hydrometer method (Bouyoucos, 1962) used to determine water availability (cm^3 water/cm^3 soil) based on percentages of sand, silt, and clay particles.

Table 5. Visual ratings of *Rhododendron austrinum* root growth in run 3, based on percentage quadrant coverage in soil and substrate layers by plant roots. Plants were grown in Horhizotrons from 25 Feb. 2009 to 9 Jul. 2009 (133 DAP) in a greenhouse at Auburn University in Auburn, Ala.

Substrate	Visual Rating[z]
Pine bark	2.3ab[y]
Coconut coir	1.7b
Chipped Pine Trees	2.8ab
Peat moss	3.4a

[z]Roots were rated using a scale of 0-5 [0 = no roots visible; 1 = 1-10% quadrant coverage by roots; 2 = 11-20% quadrant coverage by roots; 3 = 21-30% quadrant coverage by roots; 4 = 31-50% quadrant coverage by roots; 5 = 51-80% quadrant coverage by roots (greatest density of root growth proliferation)].

[y]Letters denote means separation among treatments using LSD at $\alpha = 0.05$ (SAS Institute, 2004).

Table 6. Effect of organic matter type on horizontal root length (length measurement parallel to ground, HRL) of *Hydrangea quercifolia* 'Alice'. Plants were grown in Horhizotrons from 21 Feb. 2008 to 6 May 2008 (run 1), 22 Aug. 2008 to 15 Oct. 2008 (run 2), and 25 Feb. 2009 – 29 Apr. 2009 (run 3) in a greenhouse at Auburn University in Auburn, Ala. Plants were planted in soil [10 cm (4 in) depth] with one of four organic matter types (treatments) layered on top [10 cm (3.9 in)]: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

21 February 2008 - 6 May 2008 (run 1)

Substrate[z]	Final HRL (cm)
PB	18.2
CC	21.3
PT	20.9
PM	17.9

22 August 2008 - 15 October 2008 (run 2)

Substrate	Final HRL (cm)	Equation	R^2	P-value
PB	15.9b	y = 0.35x + 0.31	0.98	<0.0001
CC	17.1b	y = 0.37x + 0.84	0.99	<0.0001
PT	20.6a	y = 0.39x + 3.62	0.97	<0.0001
PM	11.2c	y = 0.25x + 0.13	0.99	<0.0001

Significance	P-value
Substrate	<0.0001
DAP[w]	<0.0001
Substrate x DAP	0.0084

25 February 2009 – 29 April 2009 (run 3)

Substrate	Final HRL (cm)	Equation	R^2	P-value
$PB_{substrate}$[v]	16.4a	y = 0.45x – 11.04	0.99	<0.0001
$CC_{substrate}$	18.3a	y = 0.36x – 3.97	0.97	<0.0001
$PT_{substrate}$	16.4a	y = 0.46x – 11.62	0.99	<0.0001
$PM_{substrate}$	13.6b	y = 0.37x – 8.88	0.99	<0.0001
PB_{soil}	14.7ab	y = 0.43x – 11.96	0.96	<0.0001
CC_{soil}	16.5a	y = 0.38x – 7.01	0.94	<0.0001
PT_{soil}	13.6b	y = 0.39x – 10.61	0.98	<0.0001
PM_{soil}	14.9ab	y = 0.36x – 6.99	0.99	<0.0001

Significance	P-value
Substrate	<0.0001
DAP	<0.0001
Substrate x DAP	0.0003

[z]Substrates included: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

[y] y = HRL, x = days after planting.

[x]Letters denote means separation among treatments using Tukey's at $\alpha = 0.05$ (SAS Institute, 2004). Letters are omitted if there are no differences.
[w]DAP = days after planting.
[v]HRL measurements for run 3 recorded separately for roots growing in soil portions (X_{soil}) and substrate portions ($X_{substrate}$) of each quadrant (treatment).

Table 7. Effect of organic matter type on horizontal root length (length measurement parallel to ground, HRL) of *Chionanthus virginicus*. Plants were grown in Horhizotrons from 21 Feb. 2008 to 18 Jun. 2008 (run 1), 23 Jul. 2008 to 15 Oct. 2008 (run 2), and 25 Feb. 2009 to 29 Jun. 2009 (run 3) in a greenhouse at Auburn University in Auburn, Ala. Plants were planted in soil [10 cm (4 in) depth] with one of four organic matter types (treatments) layered on top [10 cm (3.9 in)]: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

21 February 2008 - 18 June 2008 (run 1)

Substrate[z]	Final HRL (cm)	Equation[y]	R^2	P-value
PB	19.7b[x]	y = 0.28x – 13.98	0.98	<0.0001
CC	19.5b	y = 0.27x – 13.63	0.96	<0.0001
PT	21.3ab	y = 0.33x – 16.84	0.95	<0.0001
PM	22.7a	y = 0.33x – 16.18	0.97	<0.0001

Significance	P-value
Substrate	<0.0001
DAP[w]	<0.0001
Substrate x DAP	<0.0001

23 July 2008 - 15 October 2008 (run 2)

Substrate	Final HRL (cm)
PB	15.8
CC	14.1
PT	14.5
PM	15.6

25 February 2009 - 29 June 2009 (run 3)

Substrate	Final HRL (cm)	Equation	R^2	P-value
$PB_{substrate}$[v]	12.6	y = 0.20x – 8.74	0.99	<0.0001
$CC_{substrate}$	15.0	y = 0.27x – 13.62	0.98	<0.0001
$PT_{substrate}$	13.5	y = 0.25x – 11.09	0.99	<0.0001
$PM_{susbstrate}$	14.7	y = 0.356x – 18.48	0.98	<0.0001
PB_{soil}	15.6ab	y = 0.22x – 9.58	0.95	<0.0001
CC_{soil}	18.8a	y = 0.29x – 14.83	0.99	<0.0001
PT_{soil}	16.1ab	y = 0.27x – 13.62	0.99	<0.0001
PM_{soil}	14.1b	y = 0.24x – 11.21	0.99	<0.0001

Significance	P-value
Substrate	<0.0001
DAP	<0.0001
Substrate x DAP	0.0005

[z]Substrates included: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

[y] y = HRL, x = days after planting.

[x]Letters denote means separation among treatments using Tukey's at $\alpha = 0.05$ (SAS Institute, 2004). Letters are omitted if there are no differences.
[w]DAP = days after planting.
[v]HRL measurements for run 3 recorded separately for roots growing in soil portions (X_{soil}) and substrate portions ($X_{substrate}$) of each quadrant (treatment).

Table 8. Effect of organic matter type on horizontal root length (length measurement parallel to ground, HRL) of *Rhododendron austrinum*. Plants were grown in Horhizotrons from 21 Feb. 2008 to 1 Jul. 2008 (run 1), 23 Jul. 2008 to 19 Nov. 2008 (run 2), and 25 Feb. 2009 to 9 Jul. 2009 (run 3) in a greenhouse at Auburn University in Auburn, Ala. Plants were planted in soil [10 cm (4 in) depth] with one of four organic matter types (treatments) layered on top [10 cm (3.9 in)]: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

21 February 2008 - 1 July 2008 (run 1)

Substrate[z]	Final HRL (cm)	Equation[y]	R^2	P-value
PB	17.2c[x]	y = 0.19x – 7.33	0.98	<0.0001
CC	19.7b	y = 0.18x – 6.18	0.99	<0.0001
PT	16.7c	y = 0.20x – 6.89	0.99	<0.0001
PM	23.7a	y = 0.24x – 8.13	0.99	<0.0001

Significance	P-value
Substrate	<0.0001
DAP[w]	<0.0001
Substrate x DAP	<0.0001

22 August 2008 - 15 October 2008 (run 2)

Substrate	Final HRL (cm)	Equation	R^2	P-value
PB	19.2c	y = 0.18x + 2.34	0.99	<0.0001
CC	19.5c	y = 0.18x + 2.34	0.99	<0.0001
PT	20.9a	y = 0.20x + 1.90	0.99	<0.0001
PM	19.3b	y = 0.19x + 2.11	0.99	<0.0001

Significance	P-value
Substrate	<0.0001
DAP	<0.0001
Substrate x DAP	<0.0001

25 February 2009 – 29 April 2009 (run 3)

Substrate	Final HRL (cm)	Equation	R^2	P-value
$PB_{substrate}$[v]	6.6b	y = 0.10x – 4.20	0.99	<0.0001
$CC_{substrate}$	4.0c	y = 0.06x – 1.77	0.99	<0.0001
$PT_{substrate}$	6.7b	y = 0.11x – 4.74	0.97	<0.0001
$PM_{substrate}$	9.2a	y = 0.14x – 5.82	0.99	<0.0001
PB_{soil}	6.6ab	y = 0.09x – 2.12	0.99	<0.0001
CC_{soil}	4.9b	y = 0.06x – 0.36	0.93	<0.0001
PT_{soil}	8.8a	y = 0.11x – 2.40	0.99	<0.0001
PM_{soil}	8.4a	y = 0.12x – 3.83	0.99	<0.0001

Significance	P-value
Substrate	<0.0001
DAP	<0.0001
Substrate x DAP	<0.0001

[z]Substrates included: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).
[y] y = HRL, x = days after planting.
[x]Letters denote means separation among treatments using Tukey's at $\alpha = 0.05$ (SAS Institute, 2004). Letters are omitted if there are no differences.
[w]DAP = days after planting.
[v]HRL measurements for run 3 recorded separately for roots growing in soil portions (X_{soil}) and substrate portions ($X_{substrate}$) of each quadrant (treatment).

Figure 1. Effect of organic matter type on horizontal root length (length measured parallel to ground, HRL) of *Hydrangea quercifolia* 'Alice' in **(A)** run 1, **(B)** run 2, and **(C-F)** run 3, measured in substrate and soil (separately for substrate and soil layers in run 3 only) as visible through glass quadrant faces of Horhizotrons in a greenhouse in Auburn, Ala. Plants were planted in soil [10 cm (4 in) depth] with one of four organic matter types (treatments) layered on top [10 cm (4 in)]: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

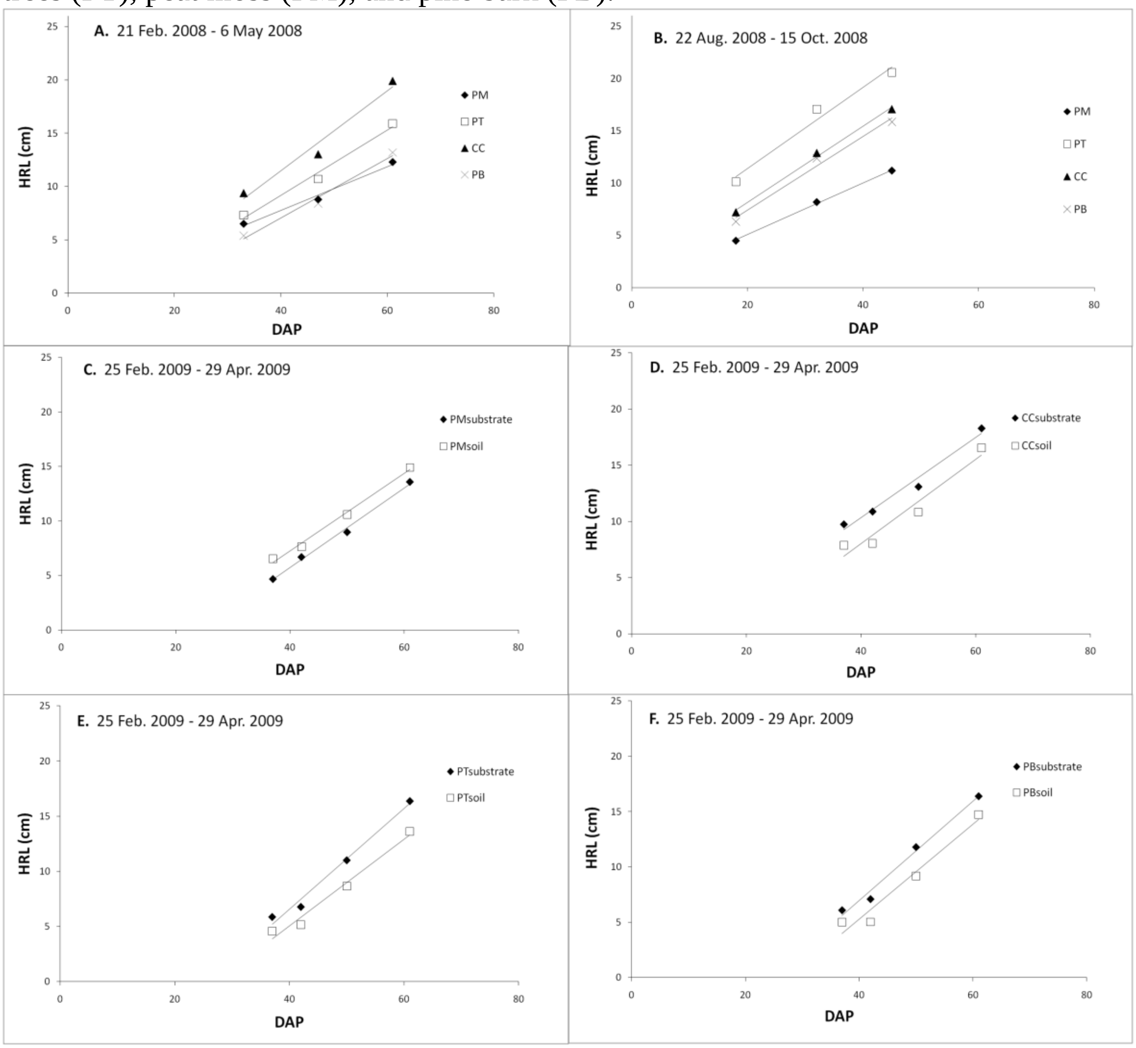


Figure 2. Effect of organic matter type on horizontal root length (length measured parallel to ground, HRL) of *Chionanthus virginicus* in **(A)** run 1, **(B)** run 2, and **(C-F)** run 3, measured in substrate and soil (separately for substrate and soil layers in run 3 only) as visible through glass quadrant faces of Horhizotrons in a greenhouse in Auburn, Ala. Plants were planted in soil [10 cm (4 in) depth] with one of four organic matter types (treatments) layered on top [10 cm (4 in)]: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

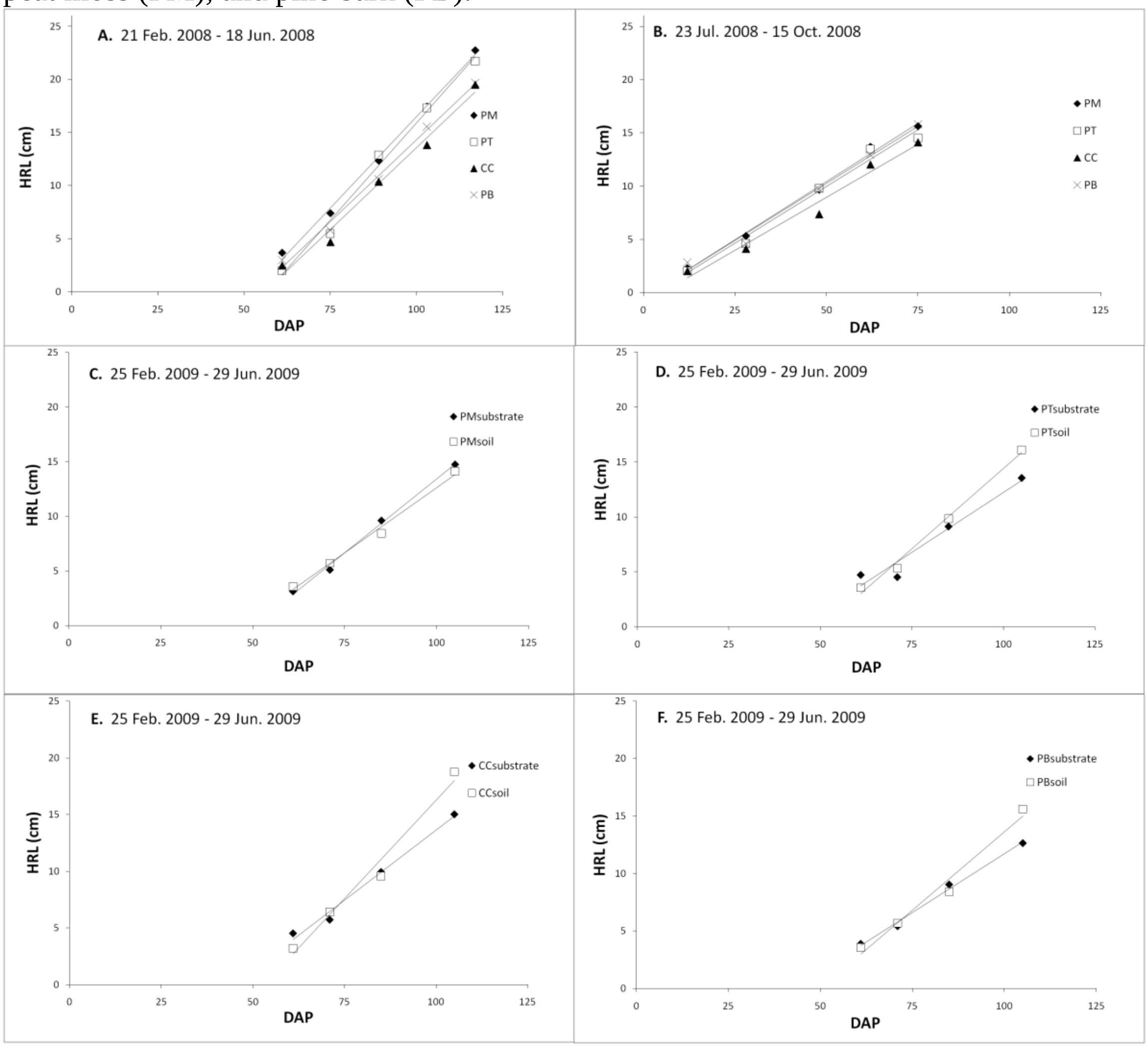


Figure 3. Effect of organic matter type on horizontal root length (length measured parallel to ground, HRL) of *Rhododendron austrinum* in **(A)** Run 1, **(B)** Run 2, and **(C-F)** Run 3, measured in substrate and soil (separately for substrate and soil layers in run 3 only) as visible through glass quadrant faces of Horhizotrons in a greenhouse in Auburn, Ala. Plants were planted in soil [10 cm (4 in) depth] with one of four organic matter types (treatments) layered on top [10 cm (4 in)]: coconut coir (CC), chipped pine trees (PT), peat moss (PM), and pine bark (PB).

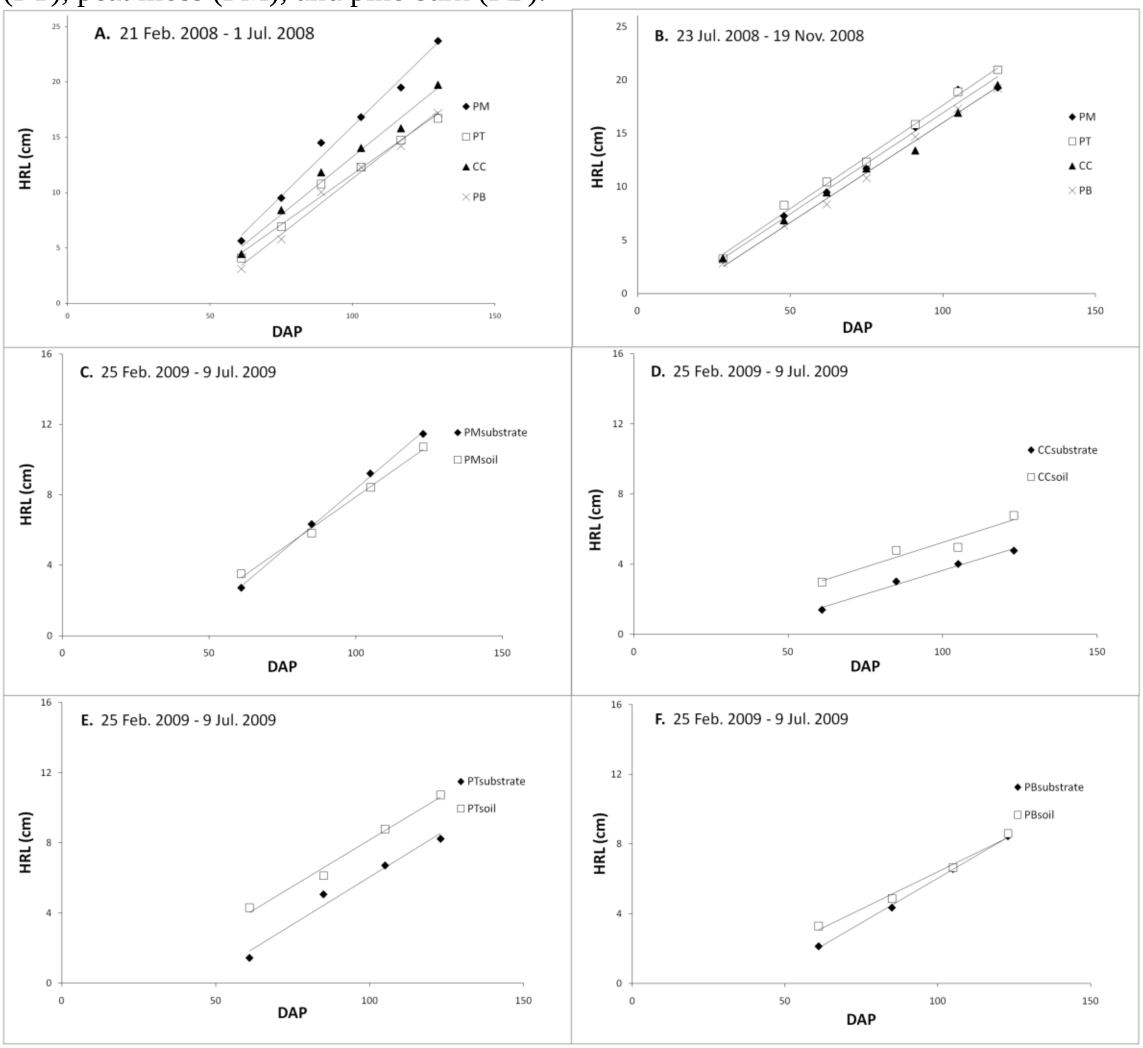


Figure 4. Effect of organic matter type on root dry weight (RDW) *Hydrangea quercifolia* 'Alice' roots separated into soil and organic matter portions for **(A)** run 1, **(B)** run 2, and **(C)** run 3. Plants were grown in Horhizotrons in a greenhouse at Auburn University, Ala. Plants were grown in soil with one of four organic matter types layered on top of soil: coconut coir (CC), chipped pine trees (PT), peat moss (PM), or pine bark (PB). Letters on top of bars indicate differences in total (soil + substrate portions) RDW among treatments, while letters inside bars indicate differences among substrate RDW (open bar) or soil RDW (filled bar) within a treatment (Tukey's, $P<0.05$).

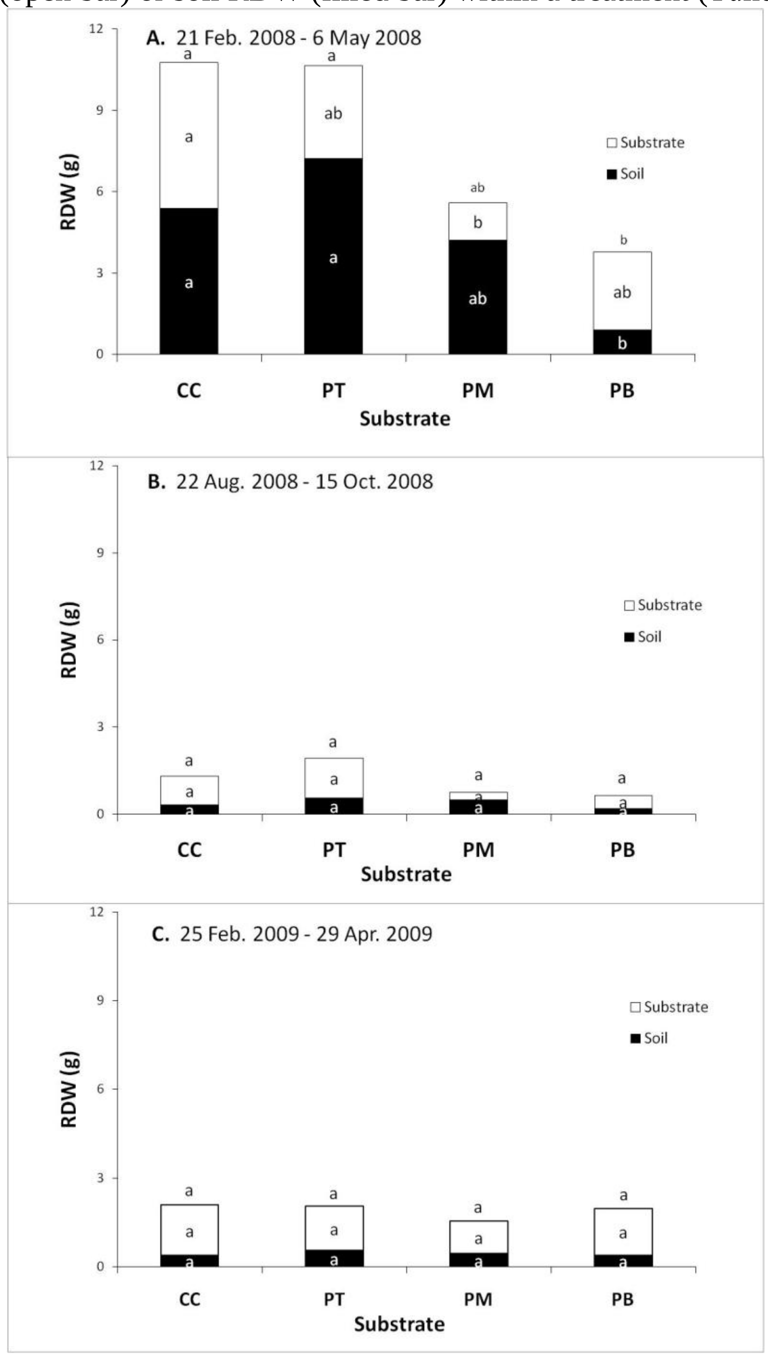
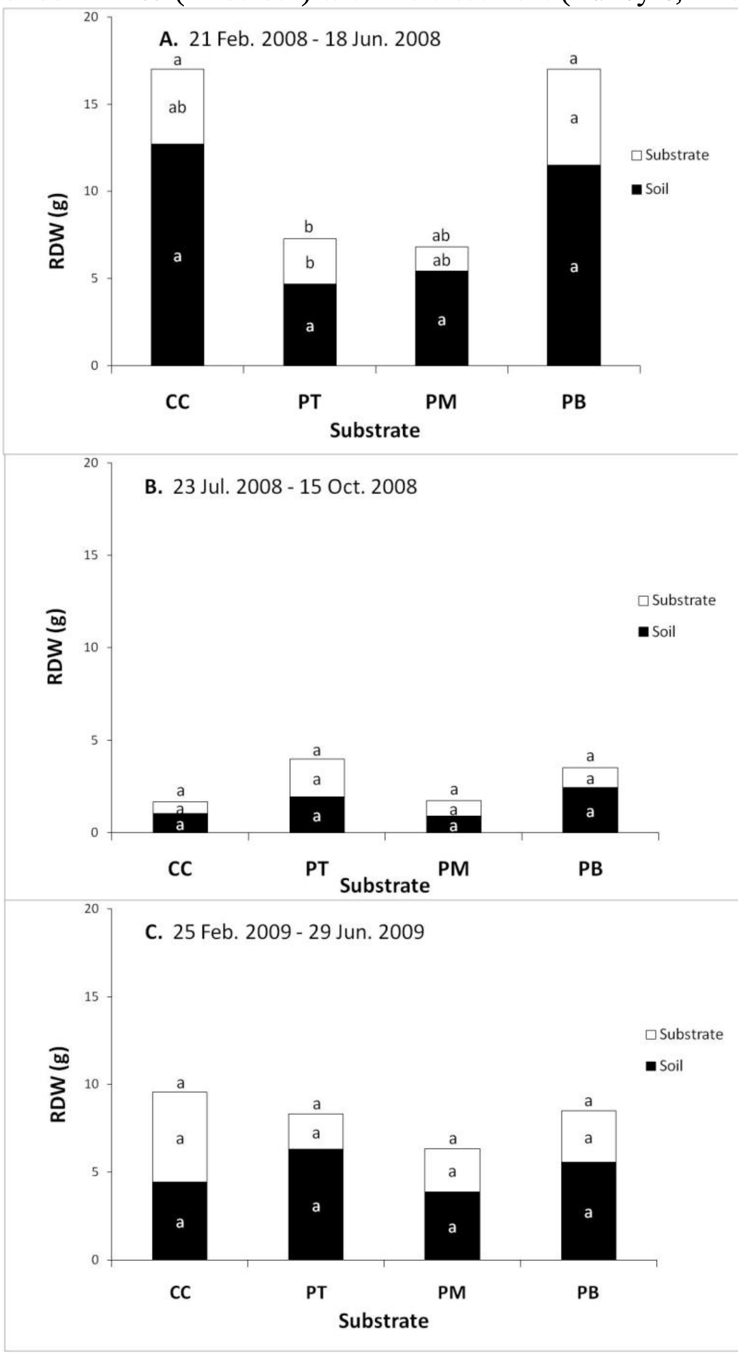


Figure 5. Effect of organic matter type on root dry weight (RDW) *Chionanthus virginicus* roots separated into soil and organic matter portions for **(A)** run 1, **(B)** run 2, and **(C)** run 3. Plants were grown in Horhizotrons in a greenhouse at Auburn University, Ala. Plants were grown in soil with one of four organic matter types layered on top of soil: coconut coir (CC), chipped pine trees (PT), peat moss (PM), or pine bark (PB). Letters on top of bars indicate differences in total (soil + substrate portions) RDW among treatments, while letters inside bars indicate differences among substrate RDW (open bar) or soil RDW (filled bar) within a treatment (Tukey's, P<0.05).



CHAPTER III

GROWTH AND PHOTOSYNTHESIS OF SELECTED NATIVE SHRUBS PLANTED ABOVE-GRADE WITH ORGANIC MATTER

Additional index words. substrate, *Chionanthus virginicus, Rhododendron austrinum, Hydrangea quercifolia* 'Alice', landscape, establishment

Abstract

Field experiments were conducted to evaluate planting above-grade with organic matter. On 17 March 2008, plants of *Chionanthus virginicus* L., *Rhododendron austrinum* Rehd., and *Hydrangea quercifolia* Bartr. 'Alice' were planted under shade in field plots, and the planting hole was backfilled to soil grade with existing soil. Plants were planted at-grade with no organic matter (NOM) or above-grade with one of four organic substrates: coconut coir (CC), chipped pine trees (PT), peat moss (PM), or pine bark (PB). Net photosynthesis (Ps) and stem water potential (SWP) were measured. Growth index (GI) was recorded at planting (17 March 2008), on 23 Oct. 2008, and on 6 Jul. 2009 (final GI was recorded 18 Jul. 2009 for *H. quercifolia* 'Alice'). All *C. virginicus* and *R. austrinum* plants survived; however, seven *H. quercifolia* 'Alice' plants died due to *Phytophthora* spp. infection. Survival of *H. quercifolia* 'Alice' plants appeared highest in PM, PT, and CC substrates. GI increased linearly for *C. virginicus*

and *R. austrinum*, and GI for *H. quercifolia* 'Alice' either increased linearly (PT and CC) or increased then decreased quadratically (NOM, PM, and PB). In *C. virginicus*, there were no differences among treatments in GI. In *R. austrinum*, GI did not differ among treatments at 473 DAP but was highest in CC and lowest in PT at 217 DAP. There were no GI differences among treatments in *H. quercifolia* 'Alice' until final GI, which was highest in PT and lowest in NOM and PB. Visual ratings (VR) and root ball diameter (RBD) for *C. virginicus* and VR for *H. quercifolia* 'Alice' were similar among treatments, but VR and RBD in *R. austrinum* were higher in PM than in NOM treatments. Previous experimentation suggested *R. austrinum* had the slowest root growth rate among taxa; therefore, planting above-grade with organic matter may be beneficial particularly for taxa with slower root growth. Although there was no apparent effect of above-grade planting on shoot growth, there was no detriment from above-grade planting for these taxa. Ps in summer 2008 was similar among treatments but different among taxa. Ps in summer 2009 was lowest in PB for *C. virginicus*, whereas for *R. austrinum* it was highest in PM and lowest in CC and PB. There was no difference in Ps before and after irrigation. Variations in Ps are likely due to differences in internal nitrogen concentrations among taxa and over time. In *C. virginicus* and *R. austrinum*, positive Ps corresponded with growth increases. SWP in *C. virginicus* was highest in CC and PB and lowest in NOM. There were no SWP differences among treatments for *R. austrinum*. SWP averaged across all treatments was higher after irrigating than before. Planting these taxa in this modified above-grade planting technique and utilizing substrates produced a post-transplant shoot growth response comparable to or better than planting at-grade in field soil. All substrates appeared to be suitable for use in this planting technique with these taxa.

Introduction

Soils, especially in urban settings, are often compacted and lack organic matter (Craul, 1985; Montagu et al., 2001). Planting above-grade with organic matter is one way to remediate these poor soil conditions and increase post-transplant root and shoot growth for shrubs and trees (Arnold et al., 2005; Guckenberger and Wright, 2007; Smith, 1998; Wright et al., 2007). In this modified above-grade planting technique, plants are positioned such that the top one-third of the root ball remains above soil grade, then the planting hole is backfilled to grade with existing soil, and organic matter is mounded around the above-grade portion of the root ball. The mounded organic matter replaces the organic matter layer that would accumulate naturally from leaf litter and other debris in upper soil horizons (Sayer, 2006). This organic layer has a low bulk density that promotes root growth after transplanting (Kozlowski, 1999). When altering planting depth, some species are more sensitive to changes in planting depth than others, so it is important to determine species-specific responses to this modified, above-grade planting technique (Will and Burch, 1988). While pine bark and peat moss are common landscape soil amendments, other organic substrates may be suitable for use in this technique, as substrate performance varies with site conditions and species cultural requirements (Bilderback et al., 2005; Guérin et al., 2001). Coconut coir is one substrate demonstrating potential to replace peat because of its similar rewetting properties, and ground or chipped loblolly pine trees are also suitable for horticultural use (Abad et al., 2005; Fornes et al., 2003; Noguera et al., 2001; Wright et al., 2008). Determining which substrates encourage the most post-transplant growth for a variety of taxa could improve the effectiveness of the above-grade planting technique. Therefore, the objective of this study was to evaluate organic matter substrates for use in above-grade planting of three native deciduous shrubs.

Materials and Methods

Dormant plants in 11.4 L (3 gal) containers were obtained from local nurseries in Feb. 2008. *Chionanthus virginicus* L. (white fringetree) plants were obtained from Dodd & Dodd Nursery Inc. in Semmes, Ala. (2-year old liners, propagated from seed at Superior Trees in Lee, Fla. And grown in 100% pine bark substrate). *Rhododendron austrinum* Rehd. (Florida flame azalea) plants were obtained from Moore & Davis Nursery in Shorter, Ala. (2-year old liners, propagated from stem cuttings taken from existing nursery stock and grown in 9:1 pine bark:sand substrate). *Hydrangea quercifolia* Bartr. 'Alice' ('Alice' oakleaf hydrangea) plants were obtained from Southern Growers Nursery in Montgomery, Ala. (2-year old liners, propagated from stem cuttings taken from existing nursery stock and grown in 9:1 pine bark:sand substrate).

Soil analysis (AU Soil Testing Lab) at planting indicated that no fertilizer amendments were necessary. Physical properties (porosity, water-holding capacity, air space, bulk density, etc.) of all substrates were determined at Auburn University (Auburn, Ala.) using the NCSU Porometer™ method (Fonteno et al., 1981) and compared to measurements published by North Carolina State University's Horticultural Substrates Lab (Raleigh, NC). Subsamples of each substrate (same batch of production) were sent to Quality Analytical Laboratories (Panama City, Fla.) to analyze the same physical properties as a comparison (Ch. 2: Table 1). Substrate and soil chemical properties (nutrient concentrations, EC, soluble salts, and pH) and soil physical properties (particle size and texture) were determined by Auburn University Soil Testing Laboratory (Auburn, Ala.) (Ch. 2: Tables 3-4).

Shrubs were planted in horticulture field research plots on the campus of Auburn University, Auburn, Ala., on 17 Mar. 2008 in three plots, with each plot measuring 6.1 x 7.6 m (20 x 25 ft), and with one taxon per plot. Plants of *C. virginicus* and *H. quercifolia* were planted under 30% shade, and plants of *R. austrinum* were planted under 47% shade. Planting holes were spaced 1.2 m (4 ft) on-center, with 100% field soil used as backfill to soil grade level for each plant. Twenty-five plants of each taxon were planted with a total of 5 plants for each treatment in a taxon. In one treatment, plants were planted at-grade with no organic matter (NOM). Plants in the four other treatments were planted with the top 10 cm (4 in) of the root ball above soil grade, and 100% pine bark, 100% peat moss, 100% coconut coir, or 100% chipped pine trees substrate was mounded up around the above-grade portion of the root ball to the height of the top of the root ball, forming a tapered mound extending from the root ball outward to a distance of 30 cm (12 in) from the stem. To prepare coconut coir (FibreDust LLC, Glastonbury, Conn.) for use, 26.5 L (7 gal) of tap water was added to a 5 kg (11 lb) block and mixed to yield approximately 0.07 m^3 (2.5 ft^3) of coir substrate. Pine tree substrate was created from *Pinus taeda* L. (loblolly pine) logs harvested 21 Jan. 2008 from Virginia Tech's Southern Piedmont Agriculture Research & Extension Center in Blackstone, Va. The chipped pine tree substrate was coarsely chipped on 13 Feb. 2008 with a 1996 Bandit Model 200 Chipper, then hammered with 25% by volume pine bark on the same day with a Mills 25 hp hammer-mill to a size of 0.5 cm (0.2 in). Peat moss (Fafard Inc. in Agawam, Mass.), pine bark (Pineywoods Mulch Co., Alexander City, Ala.), and pine tree substrates were thoroughly moistened with tap water before applying to root balls. For weed control and to keep substrates from washing away, pine straw mulch [*Pinus palustris* P. Mill. (longleaf pine)] was applied to a depth of 7 cm (3 in) on top of substrates and throughout the entire plot for each taxon. Pine straw mulch was re-applied 23 Mar. 2009 to the same depth. Hand weeding and Razor® Pro (Nufarm Inc., Burr Ridge, Ill.) glyphosate herbicide applications were used (recommended rates for broadleaf control) as needed for weed control throughout the duration of this study, spraying between plant rows and around the perimeter of field plots.

Two rain gauges were installed in each plot, and date and amount of each precipitation event were recorded as an average of all rain gauge readings. A ML2X Theta Probe (Dynamax Inc., Houston, Tx.) was used to measure substrate volumetric moisture content (using the standard 'organic' calibration) for above-grade treatments and soil volumetric content (using the standard 'mineral' calibration) in the at-grade (NOM) treatment. Each taxon was irrigated separately when volumetric moisture content of substrate (above-grade treatments) or soil (at-grade treatments) immediately surrounding the original containerized root ball reached 20%. Within each taxon, treatments were irrigated separately. Plants received 2.5 cm (1 in) water applied by hand individually to each root ball and surrounding substrate and soil to a radius of 30 cm (12 in) from the main stem [0.3 m^2 (0.4 yd^2)]. Pine bark initially dried faster than other substrates, but as plants in all substrates grew, all five treatments reached target percent moisture for irrigation every 2-3 days (data not shown). Therefore, beginning on 6 Jun. 2008, moisture content of pine bark was used to determine if a taxon required irrigation, and mini Wobbler® (Senninger in Clermont, Fla.) overhead sprinklers were used to provide 2.5 cm water (1 in) at each irrigation (confirmed by rain gauges) to all plants within a taxon at one time.

On 19 Sept. 2008 (summer 2008), photosynthesis (Ps) was measured on one most recently expanded leaf from each plant of *C. virginicus* and *R. austrinum* using a LI-COR 6400 (Li-Cor Biosciences, Lincoln, NE) set to ambient temperature and humidity, with the leaf fan at fast speed, stomatal ratio set to 0, flow rate set to 500 ml/min, CO_2 set to 400 µmol/m^2/sec, and PAR set at 1800 µmol photons/m^2/sec. Leaves were selected by starting at the highest growing point of the plant and following the branch down to the first set of fully expanded leaves, choosing the best leaf of the pair for Ps measurements. Ps measurements were initiated at 10:00 AM and completed before 1:00 PM. Ps was measured before irrigation on 2 Jul. 2009 (summer 2009). After measurements were recorded, plants were irrigated around 3:00 PM on the same day, and on 3 Jul. 2009, Ps measurements were repeated to compare Ps measurements before and after irrigation of *C. virginicus* and *R. austrinum*.

A Scholander pressure bomb (PMS 1000; Corvallis, Ore.) was used to measure stem water potential (SWP) of *C. virginicus* and *R. austrinum* plants. SWP was recorded before irrigating plants on 2 Jul. 2009 and on 3 Jul. 2009. On both days SWP was measured between 1:00 PM and 2:00 PM, during which one 10 cm (4 in) terminal stem section was removed from each plant for a total of five stems per substrate per taxon. Cuttings were placed in a plastic bag and placed in a cooler with ice, and samples were immediately transported to a lab where stems were re-cut to 7.6 cm (3 in) and SWP was measured.

Growth indices (GI) [(widest width + perpendicular width + height)/3] of all plants were recorded at experiment initiation (17 Mar. 2008) and on 23 Oct. 2008 and 6 Jul. 2009. Final GI measurements for *H. quercifolia* 'Alice' were recorded 18 Jul. 2009. Plant visual ratings were evaluated (based on a scale of 1 through 5, where 1=lowest visual quality and 5=highest visual quality) (Table 1) 18 Jul. 2009. A soil-borne outbreak of *Phythopthora* spp. combined with bacterial leaf spot (*Colletotrichum* spp.) and fungal stem cankers (*Botryosphaeria* spp.), which could not be controlled by fungicidal applications due to the severity of the outbreak, caused several plants to die and visual ratings (VR) to be low (Table 1). Five *C. virginicus* plants which were in close proximity to infected *H. quercifolia* 'Alice' plants appeared very stunted and had few leaves remaining; therefore, these plants were not included in VR and GI analysis.

To quantify effects of substrates on root growth of *C. virginicus* and *R. austrinum*, root balls were excavated at experiment termination. To accomplish this, the pine straw layer was removed and a shovel was used to estimate where new root growth ended by carefully piercing the soil, starting 1.2 m (4 ft) away from the main stem and working inwards until distinguishable new roots were exposed. Cuts were made in this fashion circling around and digging inwards towards the main stem to excavate root balls. Root ball diameter (RBD) was measured at the widest point of the excavated root ball and at the width perpendicular to that measurement, and these values were averaged to determine RBD. Due to complications from infection of *H. quercifolia* 'Alice' by *Phythopthora* spp., RBD, Ps, and SWP were not quantified for this taxon.

Within each plot (taxon), treatments were arranged in a randomized complete block design with five blocks. Each taxon represented a separate experiment. Data were analyzed using GLM procedures, regression analysis, and PDIFF means separation at α = 0.05 (SAS Institute, 2003).

Results

Chionanthus virginicus

Growth index (GI) increased linearly in all substrate treatments, and there were no differences among treatments in GI at any measurement date (Table 2, Fig. 1A). Visual rating (VR) and root ball diameter (RBD) were also similar among treatments (Table 1). All *C. virginicus* plants survived.

Photosynthesis (Ps) of *C. virginicus* in 2008 was not different among treatments (Table 3) and intermediate among taxa (data not shown). Ps was higher in *C. virginicus* than in *R. austrinum* in 2009 (data not shown). When measurements taken before and after irrigation were combined within each treatment, Ps in 2009 was lowest in PB and similar among all other treatments (Table 3, Fig. 2A). There were no differences in Ps before or after irrigation within each treatment or averaged across all treatments (Fig. 2A).

When stem water potential (SWP) data taken before and after irrigation were combined within each treatment, SWP was highest in CC and PB, intermediate in PM and PT, and lowest in NOM (Table 3, Fig. 3A). There were no differences in SWP before and after irrigation within individual treatments; however, SWP averaged across all treatments was higher after irrigation than before (data not shown) (Table 3, Fig. 3A).

Rhododendron austrinum

GI increased linearly over time (Table 2, Fig. 1B). There were no differences among substrates for final GI, but GI at 217 DAP was highest in CC, lowest in PT, and intermediate in PB, PM, and NOM. VR was highest in PM and CC, intermediate in PB and PT, and lowest in NOM (Table 1). RBD in *R. austrinum* was highest in PM, lowest in NOM, and intermediate in other substrates (Table 1). All *R. austrinum* plants survived.

Ps in 2008 was not different among substrates (Table 3), and was highest among taxa (data not shown). Ps in 2009 was lower in *R. austrinum* than in *C. virginicus* (data not shown). Ps in 2009 was highest in PM, intermediate in PT and NOM, and lowest in CC and PB (Table 3, Fig. 2). There was no difference in Ps before or after irrigation within a treatment or averaged across all treatments (Table 3, Fig. 2B).

When averaged over time (before and after irrigation) within each treatment, SWP was not different among treatments. SWP was higher after irrigation than before in NOM, CC, and PM, and was similar before and after irrigation in PB and PT (Table 3, Fig. 3B). When averaged across all treatments, SWP was higher after irrigation than before (Table 3, Fig. 3B).

Hydrangea quercifolia 'Alice'

At experiment termination, seven of the 25 plants (28%) had died. Three of the 17 surviving plants had only a few leaves, all of which appeared unhealthy (VR=2), and six plants appeared unlikely to survive (VR=1). Three of the seven *H. quercifolia* 'Alice' plants that died were in NOM treatments, and half of the plants receiving a VR of 1 were in NOM or PB treatments.

Among living plants, GI increased linearly over time in PT and CC (Table 2, Fig. 1C) and changed quadratically over time in NOM, PB, and PM (Table 2, Fig. 1C), increasing from planting to 217 DAP then decreasing as the experiment continued (Table 2, Fig. 1C). GI was not different among treatments at 217 DAP. Final GI was highest in PT, intermediate in PB, PM, and CC, and lowest in NOM (Table 2, Fig. 1C). Ps in 2008 was not different among substrates and was lowest in *H. quercifolia* 'Alice' among taxa (Table 3).

Discussion

Although all plants for the experiment were initially obtained as 11.4 L (3 gal) containers, *R. austrinum* plants appeared to have the largest canopies (Fig. 1) and most developed root systems (visual observation) at planting, followed by *H. quercifolia* 'Alice' and *C. virginicus*, respectively. Within each taxon plants were of a similar size and shape at planting (no GI differences at 0 DAP) (Fig. 1). Different sized canopies among taxa associated with similar size containers may have meant that plants had different root:shoot ratios at planting, although the root system may not have equaled the container volume. The initially smaller *C. virginicus* plants grew the most relative to their initial size (Table 2, Fig. 1). Root:shoot ratio at planting may have influenced transplant survival and establishment in the landscape (Wright et al., 2004). In *R. austrinum*, the ratio of RBD/Final GI was lowest in NOM and similar among above-grade treatments, while in *C. virginicus*, RBD/Final GI was highest in PT, intermediate in PB, PM, and NOM, and lowest in CC. Above-grade planting treatments may have been more beneficial to *R. austrinum*, as RBD/Final GI was higher in this taxon for above-grade treatments, while this was not observed in *C. virginicus*.

All taxa demonstrated the largest shoot growth increase during the first season (Table 2, Fig. 1). In *R. austrinum*, planting above-grade with organic matter may have a primary effect on growth, as RBD was higher in all above-grade planting treatments than when planted at-grade with NOM. The impact of this planting technique on root growth of *R. austrinum* is not surprising, given results from Chapter Two, which demonstrate the slower root growth rates of *R. austrinum* compared to *C. virginicus*. This suggest that planting above-grade with organic matter may be particularly important for taxa with slower rates of root growth. Faster rates of root growth in *C. virginicus* may have led to less differences between at- or above-grade planting treatments for this taxon. Although planting above-grade with organic matter did not appear to impact above-ground growth of *C. virginicus*, there was also no detriment from this practice. Roots generally grew through substrate mounds in above-grade plantings (visual observation). Root mass was generally more evenly distributed in the finer root systems of *R. austrinum*, while coarse roots were not even and root mass was more one-sided or unevenly distributed in *C. virginicus*. RBD was more variable as a result in *C. virginicus* than in *R. austrinum*, making quantification of a treatment effect difficult for *C. virginicus*. Results do suggest, once again, species specific responses to this planting technique.

Ps in 2008 was highest in *R. austrinum*, lowest in *H. quercifolia* 'Alice', and intermediate in *C. virginicus* (Table 3). Ps in 2009 was higher in *C. virginicus* than in *R. austrinum*, even though final GI was intermediate among taxa (Table 2), and Ps may not reflect growth rates (Agren and Ingestad, 1987). In 2009, Ps of both taxa was lowest in PB. (Table 3, Fig. 2). This is similar to results from Chapter Two in which root growth tended to be less in PB (Ch. 2: Tables 7-8). Since the same substrates were used as in

Chapter Two, Ps differences may be attributed to pH, EC, and water holding capacity of PB. (Ch. 2: Tables 1 and 3). The lack of Ps differences among treatments after the first growing season is similar to the lack of GI differences among treatments in *H. quercifolia* 'Alice' and *C. virginicus* (Tables 2-3). Following a second season's growth, taxa generally showed a lack of correlation between Ps and GI data, but higher Ps in 2009 of *R. austrinum* in PM corresponds with high VR and RBD in the same substrate (Tables 1-3; Fig. 1, Fig. 2B). In *C. virginicus* and *R. austrinum*, positive Ps corresponds with growth increases, as large decreases in Ps would indicate that plant growth has slowed or stopped and the plant is under stress (Herms and Mattson, 1992) (Tables 2-3).

For *C. virginicus*, SWP (highest in PB and CC) and Ps in 2009 (lowest in PB) do not appear to be correlated (Fig. 2A, Fig. 3A). The lack of differences in Ps and SWP following irrigation suggest that these taxa are able to maintain Ps and remain hydrated even when substrate mounds and surrounding soil dry to 20% moisture (by volume) (Table 3, Figs. 2-3). This is not surprising, since 20% moisture (by volume) has been used with success as a threshold for scheduling irrigation.

Low VR in NOM treatments for *H. quercifolia* 'Alice' is not surprising, considering that *Phythopthora* spp. is a soil-borne fungus that attacks plant roots, and planting above-grade with organic matter improves resistance to soil-borne *Phythopthora* spp. (Benson et al., 1982). High rainfall during spring and summer 2009 (Fig. 4) may have contributed to the increased activity of soil-borne pathogens (Murphy et al., 2007). PM is said to have antifunigicidal properties, and beneficial *Trichoderma* spp. and *Streptomyces* spp. populations present in PM may have contributed to the suppression of *Phytophthera* spp., as no plants in PM substrates died (Tahvonen, 1993). Additionally, there were the highest numbers of surviving plants in PT, PM, and CC substrates (4 plants, 5 plants, and 3 plants, respectively). PM, PT, and CC substrates used in these treatments all share similar physical properties (Ch. 2: Tables 1-2), however, chemical properties of substrates may have affected results in *H. quercifolia* ‘Alice’, since PT and CC had the only increases in shoot growth during the second growing season while shoot growth in other substrates declined (Table 2, Fig. 1, Ch. 2: Table 3). In CC especially, damage was likely reduced from *Phythopthora* spp., as CC is also known for its ability to suppress a variety of soil-borne plant pathogens and may outperform PM in this area (Hyder et al., 2008). *H. quercifolia* ‘Alice’ plants grew linearly during the first growing season (Table 2, Fig. 1C), and it is expected that linear growth would continue if plants were not affected by *Phytophthora* spp.; however, it is not clear whether this would result in similar differences among treatments in final GI for this taxon.

Previous research found that planting *Morella cerifera* L. (wax myrtle), *Illicium floridanum* Ellis (Florida anise tree), and *Kalmia latifolia* L. (mountain laurel) utilizing this modified above-grade planting technique with PB or PM substrates reduced post-transplant stress, and improved root growth and establishment compared to planting at grade with no organic matter (Guckenberger and Wright, 2007; Price et al., 2009). Plants appeared to be established by their second growing season, and the lack of treatment differences could be attributed to ambient rainfall that may have minimized any plant stress (Fig. 4). In this study, planting in somewhat optimized substrate (fertile uncompacted sandy loam soil), light (shade cloth) and moisture (ambient rainfall) likely reduced stress and may have contributed to minimized differences in growth among treatments. Continued evaluation of this above-grade planting technique for a range of native shrubs, substrates, and soil or environmental conditions will hopefully contribute to the successful implementation of native, sustainable landscapes.

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Table 1. Effect of substrate on visual rating of canopy (VR) and root ball diameter (RBD) of *Chionanthus virginicus*, *Rhododendron austrinum*, and *Hydrangea quercifolia* 'Alice' (VR only), planted 17 Mar. 2008 in field plots in Auburn, Ala. Root balls were excavated 18 Jul. 2009.

	C. virginicus		*R. austrinum*		*H. quercifolia* 'Alice'
Substrate[z]	VR[y]	RBD (cm)[x]	VR	RBD (cm)	VR
NOM	4.1	44.8	2.6c[w]	51.0c	1.0
CC	4.0	51.3	4.2a	72.3b	1.8
PB	3.7	61.6	3.8ab	72.7b	1.4
PM	3.4	52.0	4.2a	79.0a	2.0
PT	2.9	56.0	3.0bc	72.0b	3.2

[z]Substrates include: planted at soil-grade level using no organic matter (NOM), planted above-grade using coconut coir (CC), planted above-grade using pine bark (PB), planted above-grade using chipped pine trees (PT), and planted above-grade using peat moss (PM).

[y]Plant size and visual quality were rated by taxon using a scale of 0-5: [0=plant is dead; 1=plant is almost dead with only a few damaged leaves remaining on plant and very little branching; 2=plant is stunted with a majority damaged foliage and some branching; 3=plant foliage quality is intermediate with moderate branching; 4=majority of plant foliage is unaffected with good branching; 5=very little of plant foliage shows any adverse effects and plant has excellent branching formation (highest visual quality)].

[x]RBD = (widest diameter of root ball + perpendicular width)/2.

[w]Letters represent means separation among substrates within species using LSD ($P<0.05$). (Letters omitted when there are no differences among substrates).

Table 2. Effect of substrate on shoot growth index (GI) of *Chionanthus virginicus*, *Rhododendron austrinum*, and *Hydrangea quercifolia* 'Alice' grown in field plots in Auburn, Ala. GI was recorded at planting (17 Mar. 2008), on 23 Oct. 2008 (217 DAP), and on 6 Jul. 2009 (473 DAP) [final GI measurements were recorded 18 Jul. 2009 (485 DAP) for *H. quercifolia* 'Alice'].

C. virginicus

Substrate[z]	Final GI (cm)	Equation[y]	R^2	P-value
NOM	103.3	y = 30.39x – 4.45	0.97	< 0.0001
CC	97.6	y = 43.28x – 24.87	0.99	< 0.0001
PB	98.4	y = 38.03x – 14.43	0.99	< 0.0001
PT	97.1	y = 33.70x – 10.97	0.99	< 0.0001
PM	92.1	y = 34.75x – 15.40	0.99	< 0.0001

R. austrinum

Substrate	Final GI (cm)	Equation	R^2	P-value
NOM	114.8	y = 25.74x + 43.06	0.88	< 0.0001
CC	122.8	y = 27.81x + 44.46	0.91	< 0.0001
PB	122.0	y = 27.04x + 43.92	0.97	< 0.0001
PT	122.4	y = 28.11x + 40.28	0.98	< 0.0001
PM	122.2	y = 27.92x + 42.10	0.95	< 0.0001

H. quercifolia 'Alice'

Substrate	Final GI (cm)	Equation	R^2	P-value
NOM	35.2b[x]	$y = -44.94x^2 + 182.22x – 96.56$	1.00	< 0.0001
CC	67.1ab	y = 14.20x + 34.97	0.69	< 0.0001
PB	52.9b	$y = -15.51x^2 + 65.91x – 2.05$	1.00	< 0.0001
PT	94.2a	y = 26.32x + 20.93	0.97	< 0.0001
PM	66.2ab	$y = -28.60x^2 + 125.66x – 53.46$	1.00	< 0.0001

[z]Substrates include: planted at soil-grade level using no organic matter (NOM), planted above-grade using coconut coir (CC), planted above-grade using pine bark (PB), planted above-grade using chipped pine trees (PT), and planted above-grade using peat moss (PM).

[y] y = GI, x = days after planting (DAP)

[x]Letters represent means separation among substrates within species using LSD (P<0.05). (Letters omitted when there are no differences among substrates).

Table 3. Effect of substrate on net photosynthesis (Ps) ($\mu molCO_2 \cdot m^{-2} \cdot s^{-1}$) and stem water potential (SWP) (MPa) of *Chionanthus virginicus*, *Rhododendron austrinum*, and *Hydrangea quercifolia* 'Alice' grown in field plots in Auburn, Ala. Ps measurements (summer 2008) were recorded 19 Sep. 2008, between 10:00 AM and 1:00 PM for all taxa. SWP and summer 2009 Ps measurements were recorded (*C. virginicus* and *R. austrinum* only) between 1:00 PM and 2:00 PM before and after irrigation 2 Jul. 2009 (251 DAP) – 3 Jul. 2009 (252 DAP), and data presented are an average over both dates.

C. virginicus

Substrate[z]	Ps (Summer 2008)	Ps (Summer 2009)	SWP
NOM	14.00[y]	10.41a	-1.85c
CC	16.84	11.73a	-1.60a
PB	15.14	7.72b	-1.62a
PM	17.40	10.07a	-1.65ab
PT	17.32	10.15a	-1.80bc

R. austrinum

Substrate	Ps (Summer 2008)	Ps (Summer 2009)	SWP
NOM	18.44	5.97ab	-0.91
CC	19.36	5.64b	-0.86
PB	18.25	5.79b	-0.99
PM	16.72	7.14a	-0.87
PT	21.50	6.11ab	-0.84

H. quercifolia 'Alice'

Substrate	
NOM	Ps (Summer 2008)
CC	6.06
PB	6.98
PM	6.82
PT	6.18

[z]Substrates include: planted at soil-grade level using no organic matter (NOM), planted above-grade using coconut coir (CC), planted above-grade using pine bark (PB), planted above-grade using chipped pine trees (PT), and planted above-grade using peat moss (PM).

[y]Letters represent means separation among substrates within species using LSD ($P<0.05$). (Letters omitted when there are no differences among substrates).

Figure 1. Effect of substrate on shoot growth index (GI) over time for (**A**) *Chionanthus virginicus*, (**B**) *Rhododendron austrinum*, and (**C**) *Hydrangea quercifolia* 'Alice' grown in field plots in Auburn, Ala. GI was recorded at planting (17 Mar. 2008), on 23 Oct. 2008 (217 DAP), and on 6 Jul. 2009 (473 DAP) [final GI measurements were recorded 18 Jul. 2009 (485 DAP) for *H. quercifolia* 'Alice']. Treatments include: planted at soil-grade level using no organic matter (NOM), planted above-grade using coconut coir (CC), planted above-grade using pine bark (PB), planted above-grade using chipped pine trees (PT), and planted above-grade using peat moss (PM).

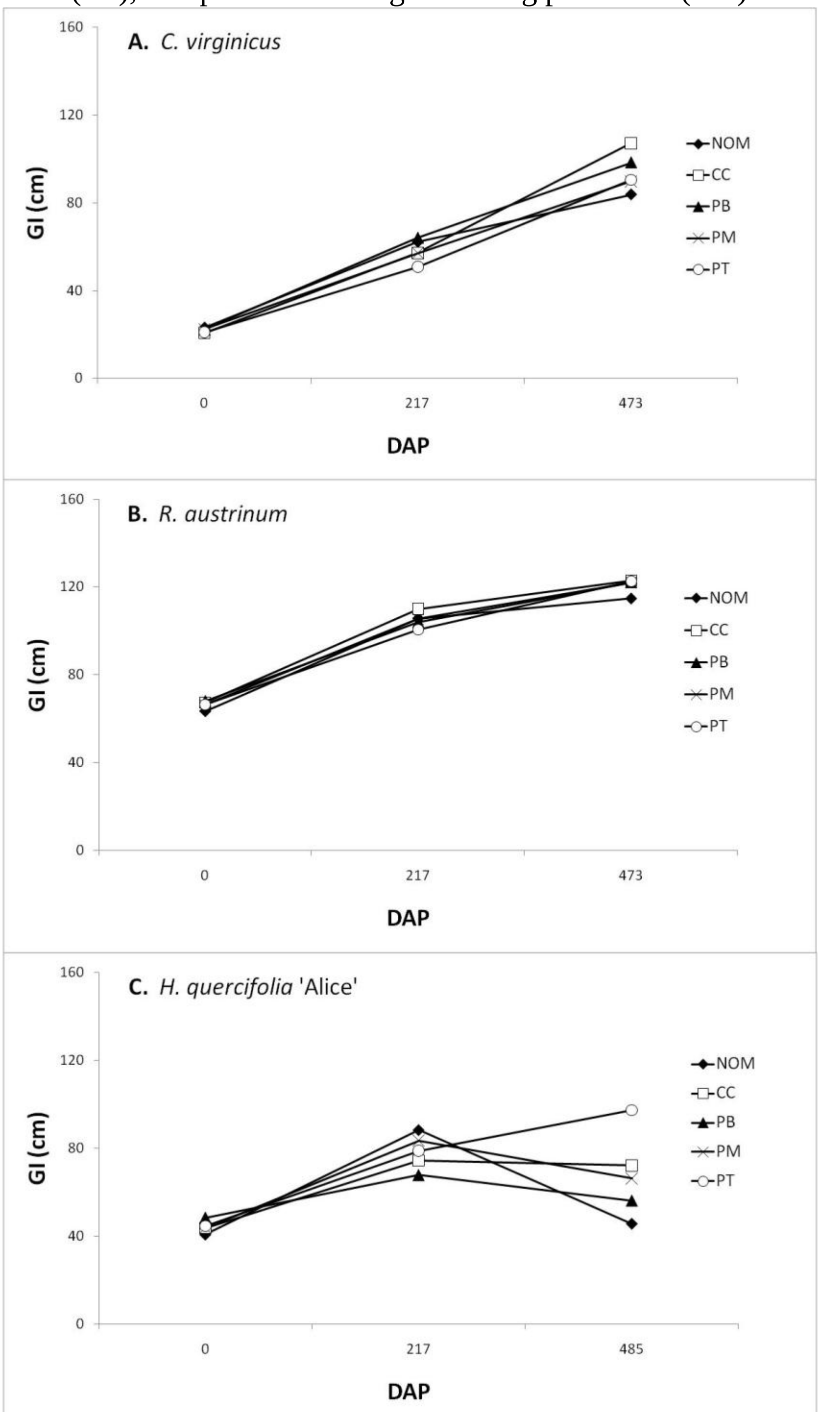

Figure 2. Effect of substrate on net photosynthesis rates (Ps, µmol $CO_2 \cdot m^{-2} \cdot s^{-1}$) of (**A**) *Chionanthus virginicus* and (**B**) *Rhododendron austrinum* grown in field plots in Auburn, Ala. Plants were planted on 17 Mar. 2008 and Ps was measured 2 Jul. 2009 (before irrigation) and 3 Jul. 2009 (after irrigation), between 10:00 AM and 1:00 PM. Substrates include: planted at soil-grade level using no organic matter (NOM), planted above-grade using coconut coir (CC), planted above-grade using pine bark (PB), planted above-grade using chipped pine trees (PT), and planted above-grade using peat moss (PM). Letters denote means separation among substrates within each taxon (averaged over measurements taken before and after irrigation) using LSD (P<0.05).

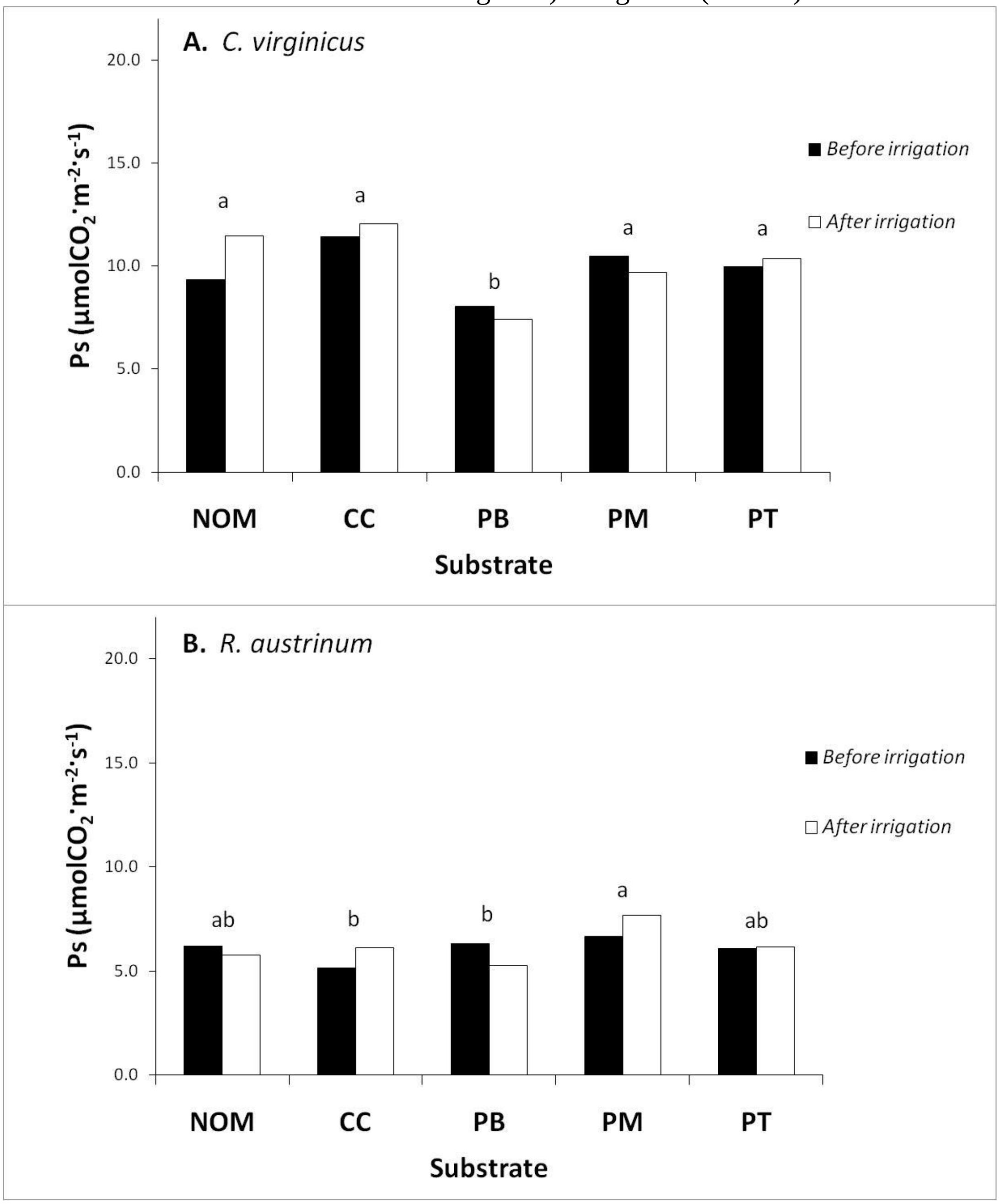

Figure 3. Effect of substrate on stem water potential (SWP, MPa) of (**A**) *Chionanthus virginicus* and (**B**) *Rhododendron austrinum* grown in field plots in Auburn, Ala. Plants were planted on 17 Mar. 2008 and SWP was measured 2 Jul. 2009 (before irrigation) and 3 Jul. 2009 (after irrigation), between 10:00 AM and 1:00 PM. Substrates include: planted at soil-grade level using no organic matter (NOM), planted above-grade using coconut coir (CC), planted above-grade using pine bark (PB), planted above-grade using chipped pine trees (PT), and planted above-grade using peat moss (PM). Letters above substrate bars denote means separation among substrates within each taxon (averaged over measurements taken before and after irrigation), and letters within bars denote means separation within a substrate between before and after irrigation using LSD (P<0.05).

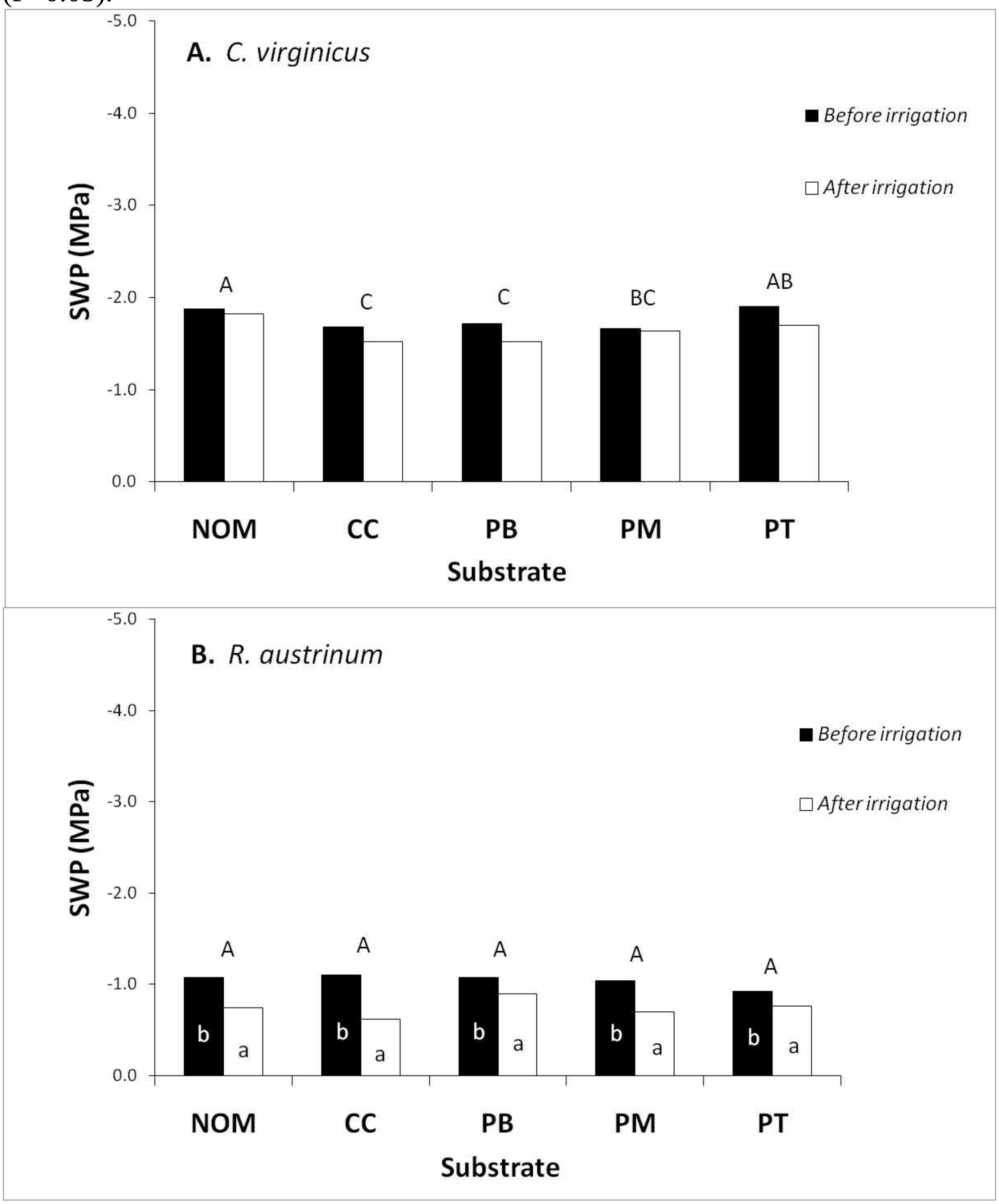

Figure 4. Rainfall amounts from Jun. 2008 – Jun. 2009 for field plots in Auburn, Ala. Rainfall amounts were averaged among 12 rain gauges for this graph.