# ABOVE-GRADE PLANTING WITH ORGANIC MATTER IMPROVES POST-TRANSPLANT ROOT AND SHOOT GROWTH AND PHYSIOLOGY OF NATIVE SHRUBS

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Julie Lynn Guckenberger


Certificate of Approval:

Kenneth M. Tilt
Professor
Horticulture

Amy N. Wright, Chair
Associate Professor
Horticulture

Robert S. Boyd
Professor
Biological Sciences

George T. Flowers
Interim Dean
Graduate School

ABOVE-GRADE PLANTING WITH ORGANIC MATTER IMPROVES POST-TRANSPLANT ROOT AND SHOOT GROWTH AND PHYSIOLOGY OF NATIVE SHRUBS

Julie Lynn Guckenberger

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Julie Lynn Guckenberger



____________________________
Signature of Author

____________________________
Date of Graduation

# VITA

Julie Lynn Guckenberger, daughter of Nancy Marie Turner, was born February 12, 1982 in Dayton, Ohio. She has two brothers, Robert and J.D. She graduated from Henry Clay High School, Lexington, Kentucky in May 2000. Though she entered the Early Music Institute at Indiana University in Bloomington, Indiana, she soon transferred to the University of the South in Sewanee, Tennessee and graduated with a Bachelor of Science degree in Natural Resources in May 2004. Upon graduating, she and her dog, Woody, moved to Jackson, Wyoming so she could work as an intern for the Jackson Hole Land Trust and Woody could swim in the Snake River every day. She returned to Lexington that winter to work for a landscaping company, and soon found that she wanted to go back to school. Julie entered graduate school at Auburn University in January 2005 and pursued a Master of Science degree under the superb guidance and direction of Dr. Amy Noelle Wright, and is very glad that she did. She received her Master of Science degree in Horticulture on December 17, 2007.

THESIS ABSTRACT

ABOVE-GRADE PLANTING WITH ORGANIC MATTER IMPROVES POST-TRANSPLANT ROOT AND SHOOT GROWTH AND PHYSIOLOGY OF NATIVE SHRUBS

Julie Lynn Guckenberger

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*Morella cerifera* (L.) Small (*syn. Myrica cerifera* L.) (wax myrtle)[11.3 L (3 gal)], *Illicium floridanum* Ellis (Florida anise tree)[11.3 L (3 gal)], and *Kalmia latifolia* L. (mountain laurel) [19 L (5 gal)] plants were planted in Horhizotrons in a greenhouse in Auburn, Ala. on 1 Mar. 2006, 6 June 2006, and 3 Jan. 2007, respectively. The experiment was repeated with the same species being planted 18 June 2007. Horhizotrons contained four glass quadrants extending away from the root ball, providing a nondestructive method for measuring growth over time of roots of the same plant into different rhizosphere conditions. Each quadrant was filled with 100% soil (Marvyn sandy loam) in the lower 10 cm (3.9 in). The upper 10 cm (3.9 cm) of the quadrants were filled randomly with either:

1) pine bark (PB), 2) peat (P), 3) cotton gin compost (CGC), or 4) more soil with no organic matter (NOM). Treatments 1-3 were intended to simulate an above-grade planting practice with the lower half of the root ball in soil and upper half in organic matter, and Treatment 4 was intended to simulate traditional at grade planting with no organic matter. Horizontal root lengths (length measured parallel to the ground, HRL) of the five longest roots visible along each side of a quadrant were measured weekly for *M. cerifera* and *I. floridanum*, and biweekly for *K. latifolia*, and when roots of one species reached the end of a quadrant the experiment was terminated for that species. *M. cerifera* had the fastest rate of root growth, followed by *I. floridanum*, and *K. latifolia* had the slowest rate of root growth. In most cases roots grew initially into the organic matter rather than the soil in treatments 1-3. In general, HRL and root dry weight (RDW) of *I. floridanum* and *K. latifolia* were highest in PB and P, while for *M. cerifera* they were highest in P. Differences in root growth among treatments were not as pronounced for *M. cerifera* as for the other species, perhaps due to its faster rate of root growth. Increased root growth in PB and P may be attributed to the ideal physical and chemical properties of these substrates.

*M. cerifera* [11.3 L (3 gal)] and *K. latifolia* [19 L (5 gal)] were planted on 30 Oct. 2006 (Fall planting) and 12 Apr. 2007 (Spring planting) in a shade house in Auburn, Ala. At planting in fall and spring, four plants of each species in a row were randomly assigned one of four treatments. Three of the four treatments utilized a modified above-grade planting technique in which plants were planted such that the top 7.6 cm (3 in) of the root ball remained above the surface of the ground and pine bark (PB), peat (P), or cotton gin compost (CGC) was applied on and around the above grade portion of the root ball, tapering down from the top of the root ball to the ground at a distance of 30.5 cm (12 in) from the stem. In the fourth treatment, plants were planted at grade with no organic matter (NOM) using only the native field soil (Marvyn sandy loam). Net photosynthesis (net Ps) and stem water potential (Ψstem) were measured 15-23 Aug. 2007 for shrubs of each species planted in the fall and spring for all treatments before and after irrigation. Plants were harvested 18 Sept. 2007. Generally, for both species at harvest, shrubs planted in the fall had higher shoot dry weight (SDW) and root ball diameter (RBD) than when planted in spring. Plants also typically had higher RBD when planted in PB or P. *M. cerifera* had higher net Ps than *K. latifolia*, and both species had higher net Ps after irrigation than before. Differences in net Ps before and after irrigation were more pronounced for shrubs planted in the spring than in the fall. Highest net Ps and Ψstem were generally observed for shrubs in PB and P. For easy-to-transplant species (such as *M.* cerifera) and especially for difficult-to-transplant species like *K. latifolia*, fall planting utilizing this modified above-grade planting technique with PB or P may reduce post-transplant stress, improve post-transplant root growth, and speed establishment.

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# CHAPTER I

## LITERATURE REVIEW

Newly transplanted trees and shrubs in urban areas struggle with poor soils, competition for space with underground infrastructure, pollution, excessive heat, high foot traffic, and often neglect in terms of irrigation and fertilization. In such difficult growing situations, many of these plants do not survive (Day et al., 1995). This proves expensive for landscaping companies that, despite careful transplanting techniques and quality plant materials, are ultimately held responsible if plants do not survive. In both horticulture and urban forestry, most research on plant performance in constructed urban landscapes is performed on trees. While this is important, research on successful transplanting of the woody shrubs that constitute the backbone of many landscapes is also imperative.

The key to survival of a newly transplanted tree or shrub is the development of a root system that extends into the surrounding native soil. Until this occurs, the plant must rely on the water and nutrient supplies in the transplanted container media, which may be extremely limited due to the tendency of surrounding soils to pull moisture and nutrients from the root ball because of differences in texture and moisture gradients (Costello and Paul, 1975; Heiskanen and Rikala, 2000; Nelms and Spomer, 1983; Nicolosi, 1981). Upon transplanting, roots must elongate into the backfill soil and eventually penetrate the soil outside the planting hole. There may be air gaps between the root ball and surrounding soil due to careless planting in clumpy soils (Wilson and Clark, 1998). Roots of container grown plants may continue to grow in a circle, only gradually growing outside the planting hole (Ingram and van der Werken, 1978). Also, research with *Euonymus alatus* (Thunb.) Sieb. ‘Compactus’ (burning bush) liners showed that roots growing from lower bulk density substrates, such as the pine bark mixes in which many nursery crops are grown, were less likely to penetrate surrounding higher bulk density soil than roots growing from higher density substrates into similarly high density surroundings (Nicolosi and Fretz, 1980). Further detering post-transplant root growth, the planting hole may become glazed from digging, and this combined with the differing bulk densities of the container substrate and native soil can inhibit root growth and containerize roots within the original planting hole (Pellet, 1971; Schulte and Whitcomb, 1975). The ensuing root restriction can cause symptoms of moisture stress even when there is ample water in the surrounding soil (Krizek et al., 1985). As roots respond to the impedance caused by the containerization, they quickly elicit decreases in leaf elongation and transpiration, independent of nutrient, oxygen, and water availability (Masle and Passioura, 1987).

Mechanical impedance to root growth is natural as roots grow and penetrate the soil, but it is intensified by decreasing soil water content (Passioura, 1988), which is common in post-transplant landcapes that do not receive regular irrigation. With increasing soil impedance, there is a decrease in root elongation (Bengough and Mullins, 1990). Root systems in hard soils appear stunted compared with those in softer soils (Bengough, 2003), the root cap becomes more rounded, and the diameter of the root behind the meristem increases (Atwell, 1990). Hydraulic conductivity of roots has been shown to be inversely related to root diameter (Rieger and Litvin, 1999), and relatively thin roots tend to have greater physiological capacity for nutrient uptake (Eissenstat, 1992). This suggests that thicker roots may not absorb water and nutrients as quickly as fine roots do, as has been shown with *Pinus taeda* L. (loblolly pine) roots (Kramer and Bullock, 1966). While the majority of total water absorption is done by fully differentiated and suberized portions of a plant root system, this is because the majority of the root system is composed of mature portions rather than apical segments and mycorrhizal roots (Kramer and Bullock, 1966). However, thinner, unsuberized new roots still absorb water at nearly five times the rate of older roots (Kramer and Bullock, 1966). This emphasizes the need for speedy fine root proliferation upon transplanting to quickly absorb water and decrease plant moisture stress, which should aid the growth of more roots that mature and establish the plant into its new surroundings.

The shape, size, and pattern of roots are species dependent. In general, trees described as difficult-to-transplant have coarse root systems, while those with finer root systems as easier to transplant (Watson, 1994). This recommendation came from research on field grown trees that were dug out of the ground, wrapped in burlap for transport, and transplanted, also called balled and burlapped. Those with coarse root systems often have a tap root and many woody roots that are severed at digging and require much longer to generate new root tips than trees with more fibrous root systems (Watson, 1994). The opposite may be true for container grown trees and shrubs. Since roots have not been severed prior to transplanting, with proper conditions these plants may not suffer the same period of stress following transplanting that balled and burlapped trees do. Rather, perhaps container grown plants are described as easy- or difficult-to-transplant based on the time between transplanting and new root growth (Harris et al., 1996; Struve et al., 1984; Wright et al., 2004), and the ability of the roots to penetrate the surrounding soil. In a study evaluating the influence of root diameter on the ability of roots to penetrate a compacted subsoil, more thick roots (0.93-1.52mm) than thin roots (0.23-0.46mm) penetrated the subsoil (Materechera et al., 1992). Container grown plants with coarse roots of larger diameters may be better able to exert the growth pressure necessary to deform soil aggregates than those of plants with fine roots of smaller diameters.

The season in which a plant is transplanted may affect the time between transplanting and new root growth, and overall success and survival of the plant. For both trees and shrubs, fall transplanting has proven more successful (in terms of survival) than spring transplanting for some species (Harris et al., 2002; Harris and Bassuk, 1994), but not others (Watson and Himelick, 1982b). The differences between species success by season may be attributed to seasonal potential for root versus shoot growth, or periodicity. It seems that fall is generally underrated by landscapers for transplanting, though the benefits of lower moisture needs because of reduced new shoot growth make excellent conditions for root growth, particularly in the warmer fall of the southern regions of the U.S. *Kalmia latifolia* L. (mountain laurel) has been shown to allocate resources to root growth in the fall months (Wright et al., 2004) and thus may be more suited to fall planting since plants should be transplanted when root growth rates are highest (Kozlowski and Davies, 1975). The majority of research on planting season and root and shoot growth periodicity has been performed on trees, and should be expanded to include shrubs.

Though plants grown in containers do not have their roots severed and therefore may be able to begin post-transplant root growth faster than those grown in the field, they also present their own set of problems. When in the nursery, container grown plants are in ideal substrates for root growth. They are situated in close proximity to one another and so are sheltered from wind, with more than adequate water and nutrients supplied to encourage rapid shoot growth and leaves of high area:mass ratio (Close et al., 2005). The high shoot:root ratio of these plants makes them attractive for purchase and placement into a landscape. However, once transplanted it may be very difficult for a plant to compensate for evapotranspiration from an abnormally large canopy of leaves that increase the potential for stomatal water loss (Wright et al., 2001) using only the resources available in the root ball and without the daily attention typical in a nursery setting. Following transplanting, shoot growth of *P. taeda* seedlings was negatively correlated with shoot:root ratio (Larsen et al., 1988) as the plants struggled to produce roots to support the shoots. *K. latifolia* transplanted into the landscape had highest survival rates for plants with the lowest shoot:root ratio at planting (Wright et al., 2005).

An inevitable consequence of transplanting plants with high shoot:root ratios with little post-transplant care is moisture stress, which often occurs even if a plant is well-watered (Aloni et al., 1991). Water deficits can limit photosynthesis, usually through stomatal closure (Chaves, 1991) in response to low soil and plant water potential. Opening and closing of stomata is controlled by turgor pressure, and low water potential causes the guard cells on either side of a stomate to lose their turgidity and close the stomate. In research with *Glycine max* L. Merr. var. Beeson (soybean), photosynthesis was severely restricted under drought conditions, though leaf respiration was only moderately inhibited (Kramer and Boyer, 1995). The stomata closed, restricting water loss to delay shoot dehydration (Kramer and Boyer, 1995). Respiration can continue with closed stomata, but photosynthesis cannot continue without the external supply of $CO_2$ coming in through the stomata (Kramer and Boyer, 1995). Plant species differ in their response to dehydration, but in general water deficit is the most common factor limiting plant growth following transplanting (Kramer, 1983).

As if all the difficulties plants face upon transplanting were not enough, they also may struggle with the specific environment into which they are planted. Normal undisturbed soils have established horizons, ample pore space, organic matter, and beneficial organisms creating pore space and soil aggregates that allow air, water, and nutrients to penetrate (Perry, 1982). These are ideal conditions for transplanting. Urban areas, where most landscapes are installed, often lack the natural topsoil, and what is remaining is often alkaline and high in clay, with restricted space for root growth, poor aeration, and inadequate drainage, making them less than optimal environments for root growth (Craul, 1985). Once the landscape is installed, regular maintenance procedures often remov leaves and plant waste, depriving the soil of a natural litter layer and incorporation of degrading organic matter. Application of mineral fertilizers may compensate chemically, but there may still be a lack of physical benefits and microbial life from organic matter. A large number of trees in urban environments do not survive the first two years, and the average lifespan of an urban tree is about 10 years (Foster and Blaine, 1978). Much of the problem stems from heavy compaction and disruption of soil horizons by construction equipment. While reducing disturbance of the landscape environment in the first place, rather than trying to salvage it with added drainage and aeration attempts, is the best solution (Day et al., 1995), this is rarely possible. Therefore, every effort must be made to find a planting practice that provides the best chance of survival for a transplant into an unfavorable landscape environment, but that is also easy for landscapers and homeowners to implement.

One common practice when transplanting trees and shrubs is mulching: adding organic matter to the soil surface around a newly transplanted tree or shrub. Studies on the influence of mulching around a transplant report beneficial effects, such as weed suppression (Greenly and Rakow, 1995). Weed suppression is an excellent aesthetic benefit, but may also benefit the woody plant by reducing shallow root competition from weeds (Greenly and Rakow, 1995). Other benefits from surface mulch application include temperature modification, improved soil quality, and increased water absorption and retention (Ashworth and Harrison, 1983; Greenly and Rakow, 1995). Temperature modification may be especially important to root development since higher root-zone temperatures can lead to shorter periods of cell elongation (Beauchamp and Lathwell, 1966) and therefore potentially shorter roots. This is of particular interest for already difficult-to-transplant species that may be even more sensitive to temperature extremes. Another benefit of surface mulch applications is reduction of further soil compaction and damage to roots of plants in high traffic areas (Patterson, 1977), which is essential since the highest densities of roots are in the upper soil horizons (Watson and Himelick, 1982a). More is not always better though, since very thick mulch layers can tie up nutrients, reduce water penetration to underlying soil, cut off oxygen supplies, and induce fermentation (Perry, 1982). Also, mounding mulch against woody tissue may result in damage to bark and phloem tissues (Ball, 1999).

Another common practice to improve transplant success is amending the backfill of the planting hole with organic matter. Since root density is generally higher in soils with more organic matter (Kalisz et al., 1987), addition of organic matter to the backfill should improve root growth relative to using native urban soil. While some studies show positive results from backfill amendments (Ferrini et al., 2005; Day et al., 1995), particularly peat moss additions, often there is no significant consistent improvement from amendments (Corley, 1984; Hummel and Johnson, 1985; Ingram and van der Werken, 1978; Smalley and Wood, 1995; Watson et al., 1993). In some cases, amended backfill may be more detrimental than backfilling with native soil, such as when there is insufficient irrigation (Corley, 1984). Most of the studies referenced above assessed backfill amendment benefits in terms of improved shoot growth and survival and did not document rather root establishment.

A more recent consideration in attempts to improve transplant success in urban soils is planting depth. Transplanting must be done with particular care since it nearly always results in planting depths different from what would have occurred if a seedling had naturally germinated and established itself (Arnold et al., 2005). In urban situations, a tree often is intentionally planted below the surface to reduce conflicts with sidewalks (McPherson et al., 2001) or to increase wind resistance, a practice that can be damaging, particularly with excessive mulch application (Arnold et al., 2002; Minore and Weatherly, 1990). In contrast, studies of planting above-grade have proven it a very successful technique, both with trees (Arnold et al., 2005) and woody shrubs (Wright et al., 2007). With trees, this specialized planting practice leaves a small portion of the root ball exposed above the surface, followed by mounding the remaining soil on and around the root ball and finishing with a shallow mulch application sufficient to suppress weeds. According to Wright et al. (2007), the planting practice most successful in establishing *K. latifolia* was similar: the root ball was left above-grade, but a shallow layer of pine bark (rather than the remaining soil) was applied to the top of the exposed root ball and a thick layer of pine bark was applied around the root ball, tapering from the top of the root ball down to the surrounding soil grade. When plants planted using the above-grade treatment were harvested after three years in the field, the roots had completely grown beyond the original root ball from the container, particularly in the upper portion that had been left above-grade and mounded with pine bark. The other treatments were planting at normal grade with a shallow pine bark mulch application and at normal grade with no mulch. The shrubs planted at normal grade with pine bark had slightly more root growth in the upper portion than those with no pine bark, but both treatments had grown few roots outside of the original root ball.

This study intends to expand on the successful specialized planting practice of Wright et al. (2007) by experimenting with other native woody shrubs and types of organic matter. This technique should most effectively encourage root growth of transplanted shrubs, perhaps because the layer of organic matter simulates the litter layer found in natural environments, encouraging the natural proliferation of roots in this layer and upper soil horizons. Plants in cultivation have less than half the root:shoot ratio of those in natural areas (Robinson et al., 2003), possibly because they lack this natural litter layer. The layer of organic matter has a low bulk density, making it much easier for roots to penetrate than surrounding soils, particularly under dry conditions in which dry soils become hard. This should therefore reduce plant stress and improve survival and overall transplanting success.

This study will use three native evergreen shrub species chosen for their variable survival rates in adverse conditions. *Morella cerifera* (L.) Small (syn.

*Myrica cerifera)* (wax myrtle; bayberry) is found on the east coast from New Jersey to Florida, and in the south grows west to Texas (Dirr, 1998). *M. cerifera* grows in full sun and generally has the highest transplant survival rate of the three species, possibly due to its high drought tolerance and ability to fix atmospheric nitrogen (Dirr, 1998). *M. cerifera* has minimal flowers and fruit, but is an excellent low maintenance shrub for mass plantings and borders, and has an interesting branch pattern and attractive bark when limbed up to small tree form. *Illicium floridanum* Ellis (Florida anisetree) is also a low maintenance landscape plant that prefers shade and may even grow in saturated conditions. It is found in Louisiana, Mississippi, Alabama, Georgia, and Florida (DIrr, 1998). With dark green leaves and single dark pink flowers borne on a 1/2" to 2" long pedicel (Dirr, 1998), *I. floridanum* is an outstanding shrub for shady parts of the landscape. *K. latifolia* tends to be a more difficult-to-transplant species with a fibrous, slow growing root system requiring cool, acid, well-drained soil. *K. latifolia* is native on the east coast from Maine to Florida, and west to Illinois down to Louisiana (Dirr, 1998). *K. latifolia* has rustic gnarly mature branches, attractive glossy green foliage prone to leaf spot, and phenomenal flowers ranging from white to shades of pink with purple markings, borne in terminal corymbs (Dirr, 1998). There has been an increased interest in the horticultural industry in using native shrubs, both to combat overuse of attractive nonnative species and because native plants might be more suited to the soils and climate their native regions than nonnative species. This may make native species more successful in poor transplanting situations like urban areas, requiring fewer inputs such as fertilizer and water.

Pine bark, peat, and cotton gin compost (CGC) will be studied for use as organic matter type in the above grade planting practice to determine which most effectively promotes root growth as well as how they compare to the standard planting practice (at grade with no organic matter). Pine bark and peat moss are commonly used in horticulture production as container substrates, and in the landscape as mulches and soil amendments. CGC is a more recent addition to horticulture research in an attempt to find alternatives to nonrenewable sources like peat and to make use of waste materials (Chen et al., 2002; Jackson et al., 2005). CGC has proven successful in production scenarios (Jackson et al., 2005), having naturally high nutrient levels, suitable pH around 6.0, and initially very high EC that improves with irrigation and subsequent leaching. When applied to the landscape, composts like CGC may reduce compaction and increase fertility (Patterson, 1977), which are ideal conditions for this study.

Many techniques of determining root growth in the field have been developed: excavation, monoliths, needleboards, growth cages, in-ground glass walls, plant injection, soil cores, and many more. The choice of best method depends mostly on the research aim, but also very much on time. Many of the above techniques are extremely time consuming and may require extensive construction before an experiment is even installed (Böhm, 1979), and also require intense labor and destruction of the plant (Wright and Wright, 2004). For smaller plants (such as shrubs) that have only been growing for a few seasons after transplanting, often the plant can simply be lifted out of the ground with shovels, and the extent of root growth beyond the original container is evident. This has proved sufficient to demonstrate the effectiveness of different planting techniques in encouraging post-transplant root growth (Wright et al., 2007).

To supplement the field experiment and further assess root growth following transplanting, this project will also utilize the Horhizotron™, an instrument that can be used to nondestructively view root growth over time under different rhizospheric conditions (Wright and Wright, 2004). The Horhizotron will be used in the greenhouse to simulate the field practice of planting above grade and applying organic matter on and around the exposed root ball. The Horhizotron has four quadrants made from two glass panes that extend away from the root ball (removed from its container) and can be filled with different substrates. Root growth over time from the root ball into the quadrants can be observed through the glass panes. This root growth measurement represents horizontal root growth into the surrounding substrate following transplanting in the field, thus allowing quantitative measurement of root growth under different conditions to complement the visual ratings and pictures of root balls from field grown plants. The Horhizotron is especially suited to this experiment, as comparisons of simulated conditions to field conditions can be made.

To begin to identify the stresses being imposed on plants under different environmental conditions, it is important to be able to measure plant water status and photosynthetic capability. Water potential is the best way to describe plant water status. The components of total water potential are effects of solutes, pressure, solids, and gravity on cell water potential (Kramer and Boyer, 1995). Generally, gravitational effects can be ignored unless the plant being assessed is a very tall tree, and the effects of solids (expressed through water molecules that adhere to solid and porous cellular matrices) are negligible unless plant tissues are extremely dry (Kramer and Boyer, 1995). Total water potential is most easily measured using a pressure chamber (Spomer, 1985). One method is to place a freshly excised terminal stem section inside the airtight chamber, and it is sealed with the cut surface extending out. When the sample was cut, xylem sap withdrew from the surface to surrounding cells. The chamber fills with compressed gas, applying pressure to the plant section inside the chamber and causing the water in the section to move back into the xylem and become visible on the cut surface. When the sap is visible, the pressure applied equals that of the tension within the xylem vessels and the reading can be made (Spomer, 1985).

Photosynthesis can be measured in the field using the LI- 6400 Portable Photosynthesis Machine (Li-Cor Biosciences, Lincoln, NE). This is an open system, frequently used to measure the gas exchange of a single leaf. The leaf is clamped in a cuvette that controls the environment around the leaf. The LI-6400 passes a reference air stream with a steady state level of carbon dioxide through the cuvette. As a result of leaf activity, the air exiting the cuvette will have a different level of carbon dioxide and water than the reference. The difference in the two carbon dioxide concentrations represents the net photosynthesis of the leaf at that time (Mitchell, 1992). The machine is also equipped with a light that allows photosynthesis measurements to be taken at variable light intensity, regardless of the time of day outside the cuvette.

Since shrubs may face many difficulties after transplanting, it is important to find reliable planting techniques that encourage root growth in adverse conditions, particularly for difficult-to-transplant species. Along with assessments of shoot and root growth, net photosynthesis and stem water potential are two parameters that may provide insight into plant responses to stress. Therefore, the objective of this research is to combine greenhouse and field studies to determine the effect of organic matter type in the modified above-grade planting technique of Wright et al. (2007) on root and shoot growth and physiology of three native shrub species.

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## CHAPTER II

## ORGANIC MATTER APPLICATION IMPROVES POST-TRANSPLANT ROOT GROWTH OF NATIVE WOODY SHRUBS

***Additional index words.*** landscape, establishment, *Morella cerifera,* wax myrtle, *Illicium floridanum,* Florida anise tree, *Kalmia latifolia,* mountain laurel

**Abstract.** Development of a root system into the surrounding soil is essential for survival of transplanted container-grown plants. The need for reliable planting techniques that encourage root growth in adverse conditions has prompted research into planting above grade. *Morella cerifera* (L.) Small (*syn. Myrica cerifera* L.) (wax myrtle)[11.3 L (3 gal)], *Illicium floridanum* Ellis (Florida anise tree)[11.3 L (3 gal)], and *Kalmia latifolia* L. (mountain laurel) [19 L (5 gal)] plants were planted in Horhizotrons in a greenhouse in Auburn, Ala. on 1 Mar. 2006, 6 June 2006, and 3 Jan. 2007, respectively. The experiment was repeated with the same species being planted 18 June 2007. Horhizotrons contained four glass quadrants extending away from the root ball, providing a nondestructive method for measuring growth of roots of the same plant into different rhizosphere conditions. Each quadrant was filled with 100% soil (Marvyn sandy loam) in the lower 10 cm (3.9 in). The upper 10 cm (3.9 cm) of the quadrants were filled randomly with either: 1) pine bark (PB), 2) peat (P), 3) cotton gin compost (CGC),

or 4) more soil with no organic matter (NOM). Treatments 1-3 were intended to simulate an above grade planting practice with the lower half the root ball in soil and upper half in organic matter, and Treatment 4 was intended to simulate traditional at grade planting with no organic matter. Horizontal root lengths (length measured parallel to the ground, HRL) of the five longest roots visible along each side of a quadrant were measured weekly for *M. cerifera* and *I. floridanum*, and biweekly for *K. latifolia*, and when roots of one species had reached the end of the quadrant the experiment was terminated for that species. *M. cerifera* had the fastest rate of root growth, followed by *I. floridanum*, and then by *K. latifolia*. In most cases, roots grew initially into the organic matter rather than the soil in treatments 1-3. In general, HRL and root dry weight (RDW) of *I. floridanum* and *K. latifolia* were highest in PB and P, while for *M. cerifera* these were highest in P. Differences in root growth among treatments were not as pronounced for *M. cerifera* as for the other species, perhaps due to its faster rates of root growth. Increased root growth in PB and P may be attributed to the ideal physical and chemical properties of these substrates. Results suggest that planting above-grade with organic matter may increase post-transplant root growth compared to planting at grade with no organic matter.

**Introduction**

The key to survival of a newly transplanted tree or shrub is the development of a root system that extends into surrounding native soil. Until this occurs, the plant must rely on the water and nutrient supplies in the transplanted container media, which may be extremely limited due to the tendency of surrounding soils to pull moisture and nutrients from the root ball due to texture and moisture gradients (Heiskanen and Rikala, 2000).

Container grown woody plants are described as easy- or difficult-to-transplant based on the time between transplanting and new root growth (Harris et al., 1996) and the ability of the roots to penetrate the surrounding soil. Container grown plants with coarse roots of larger diameters (0.9-1.5 mm) may be better able to exert the growth pressure necessary to deform soil aggregates than those of plants with fine roots of smaller diameters (0.2-0.5 mm) (Materechera et al., 1992). Thus container-grown plants with fine roots may be classified as difficult-to-transplant due to slower post-transplant root growth.

Newly transplanted shrubs may also struggle with the specific environment into which they are planted. Normal undisturbed soils have established horizons, ample pore space, ample organic matter, and beneficial organisms that create the pore space and soil aggregates that allow air, water, and nutrients to penetrate (Perry, 1982). Urban areas, where most landscapes are installed, often lack the natural topsoil, and what is remaining is often alkaline and high in clay. These areas also have restricted space for root growth, poor aeration, and inadequate drainage, making them less than optimal environments for root growth (Craul, 1985). Once a landscape is installed, regular maintenance procedures often remove leaves and plant waste, depriving the soil of a natural litter layer and incorporation of degrading organic matter. Application of mineral fertilizers may compensate chemically, but there may still be a lack of physical benefits and microbial life from organic matter. Therefore, every effort must be made to find a planting practice that provides the best chance of survival for a plant transplanted into an unfavorable landscape environment, but that is also easy for landscapers and homeowners to implement.

A common practice to improve transplant success is amending the backfill of the planting hole with organic matter, but studies show there is no consistent improvement from this (Day et al., 1995; Ferrini et al., 2005; Smalley and Wood, 1995; Watson et al., 1993). However, studies of planting above grade have proven it a very successful technique, both with trees (Arnold et al., 2005) and woody shrubs (Wright et al., 2007). According to Wright et al. (2007), the modified above-grade planting technique most successful in establishing *Kalmia latifolia* L. (mountain laurel) was leaving a small portion of the root ball exposed above the surface, then applying a shallow layer of pine bark to the top of the exposed root ball and a thick layer of pine bark around the root ball, tapering from the top of the root ball down to the surrounding soil grade.

The Horhizotron™ is an instrument that can be used to nondestructively view root growth under different rhizospheric conditions (Wright and Wright, 2004). The Horhizotron™ can be used in the greenhouse to simulate field planting practices. The Horhizotron has four quadrants made from two glass panes that extend away from the root ball (removed from its container) and can be filled with different substrates. Root growth from the root ball into the quadrants can be observed through the glass panes. This root growth measurement represents horizontal root growth into the surrounding substrate following transplanting in the field, thus allowing a quantitative measurement of root growth under different conditions.

Recently there has been an increased interest in native plants because they may be better suited to the soils and climate of their native region than nonnative species. This may make them more successful in poor transplanting situations while requiring fewer inputs of fertilizer and water. This study intends to expand on the successful specialized planting practice of Wright et al. (2007) by experimenting with other native woody shrubs chosen for their varied descriptions of transplanting success (Dirr, 1998) and other kinds of organic matter. This technique should most effectively encourage root growth of transplanted shrubs, because the layer of organic matter simulates the litter layer found in natural environments, encouraging the natural proliferation of roots in this layer and upper soil horizons. Therefore, the objective of this study was to determine the effect of organic matter type on post-transplant root growth of three native landscape shrubs in simulated above-grade planting conditions.

## Materials and Methods

### *Experiment I*

On 1 Mar. and 6 June 2006 and 3 Jan. 2007, respectively, five *Morella cerifera* (L.) Small (*syn. Myrica cerifera* L.) (wax myrtle) [11.3 L (3 gal)] from Moore and Davis, LLC in Shorter, Ala., five *Illicium floridanum* Ellis (Florida anisetree) [11.3 L (3 gal)] from Greene Hill Nursery, Inc. in Waverly, Ala., and five seedling *Kalmia latifolia* L. (mountain laurel) [19 L (5 gal)] from Dodd and Dodd Nursery, Inc. in Semmes, Ala. were removed from their containers and placed in the center of Horhizotrons (Wright and Wright, 2004) with one plant per Horhizotron. Each Horhizotron consisted of four wedge-shaped quadrants 3.7 L (0.84 gal) each made from two 0.3 cm (0.12 in)-thick glass panes [20.3 cm x 26.7 cm (7.99 in x 10.51 in)] extending from the root ball. The quadrants rested on a 0.6 m x 0.6 m x 0.3 cm (0.24 in x 0.24 in x 0.12 in) sheet of aluminum attached to a wooden frame made from 5.1 x 5.1 cm (2 x 2 in) treated lumber and the entire structure was enclosed by a box and lid of 1.9 cm (0.75 in) thick foam insulation board. In each Horhizotron, the four quadrants were filled with field soil (Marvyn sandy loam) in the lower half [10 cm (3.9 in)]. The upper half [10 cm (3.9 in)] of the four quadrants was randomly filled with: 1) pine bark (PB), 2) peat moss (P), 3) cotton gin compost (CGC), or 4) more soil with no organic matter (NOM) so each Horhizotron had one of each treatments 1 through 4. Treatments 1 through 3 were intended to mimic an above-grade planting technique that utilized different kinds of organic matter mounded around the above-grade portion of the root ball, and treatment 4 simulated traditional at-grade planting without organic matter. Marvyn sandy loam is the local field soil at the horticulture research facility in Auburn, Ala. CGC was obtained from cotton gin trash produced by Milstead Farm Group, Inc., in Shorter, Ala. and composted at E.V. Smith Research Center, also in Shorter. PB came from Pineywoods Mulch Company from trees grown in Roanoke, Ala., and P was supplied by Cassco, Montgomery, Ala.

The Horhizotrons were placed on greenhouse benches at the Paterson Horticulture Greenhouse Complex, Auburn University, Auburn, Ala. [day/night temperatures set at 26/21°C (79/70°F)], initial plant growth indices [(height + widest width + width perpendicular to widest width)/3] were determined, and root balls and quadrants were hand watered as needed with tap water. Once per week, the horizontal root lengths (HRL, measured parallel to the ground) of the five longest roots visible on each glass pane (two panes per quadrant) were recorded. HRL represents root penetration into the landscape soil and mounded organic matter following transplanting. All plants of a species were removed from their Horhizotrons when roots in one treatment reached the end of a quadrant (26 cm), and final growth indices of the canopies were recorded. Roots in each quadrant were cut from the original root ball, and for *M. cerifera*, roots were washed to remove substrate and soil, dried for 48 hours at 66°C (150°F), and weighed to determine root dry weight (RDW). For *I. floridanum*, roots from treatments 1-3 were separated into those from the organic matter and soil portions at experiment termination, then washed and dried in order to quantify RDW into soil and organic matter portions separately. Due to the extreme difficulty of washing organic matter from the fine, hairlike roots of *K. latifolia,* rather than washing the roots a visual rating of 0 to 5 was recorded for each side of a quadrant, with 0 being no root growth and 5 being the most dense proliferation relative to all other observations. On the first and last day of the study, the pour-through nutrient extraction procedure (Wright, 1986) was used to obtain leachate samples from six 3.8 L (1 gal) containers of soil or each substrate (without soil) to determine soil or substrate pH and EC. Physical properties of organic matter substrates were determined using the NCSU Porometer™

(Fontento et al., 1981), and chemical properties of organic matter substrates and soil were determined from saturated extracts at the Auburn University Soil Testing Laboratory, Auburn, Ala.

This study was a randomized complete block design with each Horhizotron representing an individual block with five blocks for each species. *M. cerifera* was harvested 44 days after planting (DAP), *I. floridanum* 97 DAP, and *K. latifolia* 136 DAP. Data were analyzed separately by species using GLM procedures with means separation by date using PDIFF at P = 0.05 and regression analysis of root growth over time to compare the rates of root growth among substrate treatments within each species (SAS Institute, Inc., 2004).

*Experiment II*

In Experiment II, all three species listed above were planted as described above on 18 June 2007. All procedures were the same as for Experiment I, and at experiment termination, roots of both *M. cerifera* and *I. floridanum* were separated into soil and organic matter portions before washing and drying. Additionally a Theta moisture probe (Delta- T Devices Ltd., Cambridge, England) was utilized to determine percent moisture by volume in each quadrant. To more accurately control percent moisture, when percent moisture by volume fell below 10%, that quadrant was rewatered with 400 mL tap water (the amount needed to fully hydrate the substrate in one quadrant). *M. cerifera* was harvested 43 DAP, *I. floridanum* 80 DAP, and *K. latifolia* 127 DAP. When *K. latifolia* was terminated, data from all taxa were analyzed together using GLM procedures and regression analysis of root growth over time to compare rates of root growth among species.

Due to a significant interaction between species, treatment, and DAP, species were then analyzed separately using GLM procedures with means separation by date using PDIFF at P = 0.05 and regression analysis of root growth over time to compare the rates of root growth among substrate treatments within each species (SAS Institute, Inc., 2004).

**Results**

*Experiment I*

Though the significance of linear, quadratic, and cubic trends were investigated, horizontal root length (HRL) of *M. cerifera* increased linearly in all treatments (Table 1, Fig. 1A). From the first measurement date, 21 days after planting (DAP), roots were longest in CGC and P, and this trend continued for every measurement following. With the exception of the first date when roots in CGC and P were similar lengths, CGC had significantly higher HRL than the other treatments. Roots in P were significantly longer than those in NOM and PB on all measurement dates. Root dry weights (RDW) were similar in all treatments (Fig. 2A). *I. floridanum* HRL increased linearly in all treatments (Table 1, Fig. 1B). HRL in PB and P was similarly higher than other treatments from the first measurement date until 71 DAP, when root lengths in PB surpassed those in P and all other treatments (Fig. 1B). Roots in P were significantly longer than those in CGC and NOM on all measurement dates (Fig. 1B). Root lengths in CGC and NOM were similar until 63 DAP when HRL in CGC exceeded that in NOM (Fig. 1B). RDW for *I. floridanum* (Fig. 2B) reflected HRL measurements and demonstrates that the majority of roots grew into the organic matter layers when present. For *K. latifolia*, HRL increased linearly in all treatments except CGC, in which very limited root growth made a trend difficult to ascertain (Table 1, Fig. 1C). On every measurement date, HRL was highest in P, followed closely but with significantly lower HRL by PB (Fig. 1C). Roots in P and PB were significantly longer than those in NOM on all measurement dates (Fig. 1C). Root visual ratings were similar to root growth trends (Table 2), with the highest ratings in PB and P.

*Experiment II*

As in Experiment I, root length of both *M. cerifera* and *I. floridanum* increased linearly in all treatments (Table 3, Fig. 3A and B). HRL in P was higher than all other treatments on every DAP and for both species, except for the last measurement day of *M. cerifera*, 42 DAP, when NOM and P had similar HRL (Fig. 3A and B). Roots of *M. cerifera* in PB and NOM had similar HRL from 15 DAP until 42 DAP, when roots in NOM were significantly longer (Fig. 3A). *I. floridanum* roots in PB and NOM were similar on the first measurement date (31 DAP) but roots in PB were significantly longer than those in NOM on every date thereafter (Fig. 3B). Both *M. cerifera* and *I. floridanum* had the lowest HRL in CGC on all measurement dates (Fig. 3A and B). The relative pattern of RDW measurements was generally similar to HRL measurements for both species (Fig. 2C and D). Roots of *K. latifolia* had limited growth in CGC and NOM, which made a trend difficult to determine. HRL of roots of *K. latifolia* in PB and P increased linearly and were higher than those in CGC and NOM on all measurement dates.

For both experiments, EC in solutions extracted from substrates or soil was highest in CGC (Table 4). NOM had the highest pH, PB and CGC had similar pH, and P had the lowest (Table 4). CGC was the most elementally rich substrate, with the highest concentration of almost every nutrient (Table 5). CGC also had the highest water holding capacity and lowest air space of the substrates (Table 6). NOM had the highest bulk density (Table 6).

**Discussion**

While the two experiments yielded a few comparative differences, in general the outcomes were the same, with more root growth occurring in PB and P than CGC or NOM. In both studies, roots of *M. cerifera* grew faster than those of the other species. Root dry weights (RDW) or visual ratings generally followed HRL trends in both experiments. The variation between HRL and RDW (or inability to separate roots of species like *K. latifolia* from substrates) illustrates the importance of measuring HRL to determine the rate of root growth and extent of root development laterally into the surrounding substrate or backfill as well as RDW. Observations from monitoring percent moisture in Exp. II simply reflected physical properties of the substrates (Table 6): percent moisture was nearly always highest in CGC and lowest in PB, and therefore PB had to be watered most often (data not shown).

In Experiment I, the slope of the trend line for increase of *M. cerifera* root length over time in CGC (the fastest growing roots) were almost three times that of *I. floridanum* roots in PB, the most rapidly growing roots of *I. floridanum* (Table 1, Figure 1). In Experiment II, the slope of the trend line for the fastest growing roots of *M. cerifera* were more than five times that of *K. latifolia* roots in PB, the highest for *K. latifolia* (Table 3, Fig. 3). This demonstrates the varied speed of post-transplant root growth of the three species, whether planted in different seasons (Exp. I) or at the same time of year (Exp. II). Even though roots of *M. cerifera* grew rapidly and eventually grew into the soil portion (Marvyn sandy loam) of each quadrant, in most quadrants the majority of roots, particularly in the first few weeks, were in the layer of organic matter if present (visual observation). The majority of roots of *I. floridanum* and *K. latifolia* grew into the organic matter layer only over the entire measurement period (visual observation). This contrast in root growth into difference substrates is further demonstrated by rates of root growth of one species into different treatments. The slope of the trend line for roots of *K. latifolia* growing into PB was ten times that of the line for roots growing into NOM (Table 1, 3).

Root growth did not correlate with pH since the pH values of solutions extracted from CGC and PB were similar but those substrates yielded very different HRL measurements (Tables 1, 3). However, physical properties and nutrient concentration appeared to influence post-transplant root growth. CGC had lower air space and higher water holding capacity than the other types of organic matter (Table 6), which may not have allowed enough oxygen necessary for root respiration. This, combined with high EC and salts, particularly Na, K, and $NO_3$ (Tables 4, 5), indicates that CGC may not be the best organic matter to use when transplanting even slightly difficult-to-transplant species (such as *I. floridanum*). Though CGC has been shown successful in horticultural production

(Jackson et al., 2005), it may not be suitable for landscape purposes since the salts Table 5) do not leach as readily in the landscape as in the daily watering scenarios of container production (Jackson et al., 2005). Species with fine root systems (e.g. *K. latifolia*) are particularly vulnerable to high salt levels that may be common in composts (Sæbø and Ferrini, 2006). Conversely, bulk density was generally lowest, and other physical and chemical properties more favorable, for PB and P (Tables 4-6), in which the highest HRL and generally the highest RDW or visual ratings were found for all species (Tables 1-3; Figs. 1-3).

While mature roots are responsible for the majority of nutrient and water uptake, thinner, unsuberized new roots still absorb water at nearly five times the rate of older roots (Kramer and Bullock, 1966). This emphasizes the need for speedy fine root proliferation upon transplanting to quickly absorb water and decrease plant moisture stress, which should aid the growth of more roots that mature and establish the plant into its new surroundings. Consequently, this modified above- grade planting technique using PB or P may be effective since it simulates the upper organic layer found in natural environments, providing ideal physical and chemical environments for post-transplant root growth. Plants in cultivation have less than half the root:shoot ratio of those in natural areas (Robinson et al., 2003), possibly because they lack a natural litter layer. This planting practice may not be as important for easy-to-transplant species like *M. cerifera* that quickly grow roots after transplanting, but may be very important for others like *K. latifolia* that require a hospitable post-transplant environment in which they may grow roots and establish themselves. Planting above-grade with

PB or P should therefore reduce post-transplant stress and improve survival and overall success of both difficult- and easy-to-transplant shrubs by increasing post-transplant root growth.

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**Table 1. Experiment I.** Effect of organic matter type (treatment) on final horizontal root length (HRL[z]) of *M. cerifera, I. floridanum,* and *K. latifolia* (49, 97, and 136 DAP[y], respectively) growing in Horhizotrons in a greenhouse in Auburn, AL, regression equations for change in HRL over time with corresponding $R^2$ term and significance of regression equation (P-value), and significance of treatment main effects and interactions for HRL. *M. cerifera* were grown 1 Mar. 1 - 13 Apr. 2006, *I. floridanum* were grown 6 June - 6 Oct. 2006, and *K. latifolia* were grown 3 Jan. - 24 May 2007.

| | *M. cerifera* | | | |
|---|---|---|---|---|
| Treatment[x] | HRL (cm) | Equation[w] | $R^2$ | P-value |
| Pine bark (PB) | 20.8d[v] | y = 0.61x - 9.36 | 0.86 | <0.0001 |
| Peat (P) | 24.1b | y = 0.67x - 7.72 | 0.76 | <0.0001 |
| Cotton gin compost (CGC) | 25.2a | y = 0.70x - 7.57 | 0.81 | <0.0001 |
| No organic matter (NOM) | 22.9c | y = 0.67x - 11.31 | 0.77 | <0.0001 |

| Significance | P-value |
|---|---|
| Treatment | 0.0013 |
| DAP | <0.0001 |
| Treatment x DAP | <0.0001 |

| | *I. floridanum* | | | |
|---|---|---|---|---|
| Treatment[x] | HRL (cm) | Equation[w] | $R^2$ | P-value |
| Pine bark (PB) | 22.0a | y = 0.27x - 1.82 | 0.92 | <0.0001 |
| Peat (P) | 20.1b | y = 0.25x - 1.18 | 0.86 | <0.0001 |
| Cotton gin compost (CGC) | 11.3c | y = 0.14x - 0.55 | 0.76 | <0.0001 |
| No organic matter (NOM) | 9.0d | y = 0.09x + 1.22 | 0.24 | <0.0001 |

| Significance | P-value |
|---|---|
| Treatment | <0.0001 |
| DAP | <0.0001 |
| Treatment x DAP | <0.0001 |

| | *K. latifolia* | | | |
|---|---|---|---|---|
| Treatment[x] | HRL (cm) | Equation[w] | $R^2$ | P-value |
| Pine bark (PB) | 15.9b | y = 0.14x - 2.10 | 0.79 | <0.0001 |
| Peat (P) | 17.5a | y = 0.12x + 1.19 | 0.81 | <0.0001 |
| Cotton gin compost (CGC) | 1.3d | y = 0.01x + 0.01 | 0.06 | <0.0001 |
| No organic matter (NOM) | 5.1c | y = 0.04x - 0.30 | 0.14 | <0.0001 |

| Significance | P-value |
|---|---|
| Treatment | <0.0001 |
| DAP | <0.0001 |
| Treatment x DAP | <0.0001 |

[z]HRL = root length measured parallel to the ground.
[y]DAP = days after planting in Horhizotron (Wright and Wright, 2004).
[x]Treatments were soil in bottom 10 cm (3.9 in) and pine bark, peat, or cotton gin compost in upper 10 cm (3.9 in) or 100% soil (no organic matter) in Horhizotron quadrants.
[w]y = HRL, x = DAP.
[v]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at P<0.05 (SAS Institute, Inc., 2004).

**Table 2.** Visual ratings of *K. latifolia* root proliferation in four substrates at experiment termination. Plants were planted in Horhizotrons in a greenhouse in Auburn, Ala. on 3 Jan. (Experiment I) and 18 June (Experiment II) 2007 and grew to 136 and 127 days after planting, respectively.

| | Visual Rating[z] | |
|---|---|---|
| | Experiment I | Experiment II |
| Pine bark (PB) | 2.8b[y] | 2.2a |
| Peat (P) | 4.8a | 2.0a |
| Cotton gin compost (CGC) | 0.0d | 0.3b |
| No organic matter (NOM) | 0.6c | 0.2b |

[z]Roots were evaluated visually using a scale of 0-5 [0 = no root growth; 1 = 10% of the quadrant was filled with roots; 2 = 20% of the quadrant was filled with roots; 3 = 30% of the quadrant was filled with roots; 4 = 40% of the quadrant was filled with roots; 5 = 50% of the quadrant was filled with roots (the most dense proliferation of any treatment)].

[y]Means separation within experiment using PDIFF at P = 0.05 (SAS institute, Inc., 2004).

**Table 3. Experiment II.** Effect of organic matter type (treatment) on final horizontal root length (HRL[z]) of *M. cerifera, I. floridanum,* and *K. latifolia* (42, 81, and 127 DAP[y], respectively) growing in Horhizotrons in a greenhouse in Auburn, AL, regression equations for change in HRL over time with corresponding $R^2$ term and significance of regression equation (P-value), and significance of treatment main effects and interactions for HRL. *M. cerifera* were grown 19 June - 1 Aug. 2007, *I. floridanum* were grown 19 June - 6 Sept. 2007, and *K. latifolia* were grown 19 June - 23 Oct. 2007.

| | *M. cerifera* | | | |
|---|---|---|---|---|
| Treatment[x] | HRL (cm) | Equation[w] | $R^2$ | P-value |
| Pine bark (PB) | 24.7b[v] | y = 0.69x - 3.68 | 0.84 | <0.0001 |
| Peat (P) | 25.8a | y = 0.69x - 1.87 | 0.92 | <0.0001 |
| Cotton gin compost (CGC) | 19.2c | y = 0.54x - 3.60 | 0.69 | <0.0001 |
| No organic matter (NOM) | 24.9ab | y = 0.68x - 2.93 | 0.85 | <0.0001 |

| Significance | P-value |
|---|---|
| Treatment | <0.0001 |
| DAP | <0.0001 |
| Treatment x DAP | <0.0001 |

| | *I. floridanum* | | | |
|---|---|---|---|---|
| Treatment[x] | HRL (cm) | Equation[w] | $R^2$ | P-value |
| Pine bark (PB) | 16.8b | y = 0.27x - 5.15 | 0.81 | <0.0001 |
| Peat (P) | 19.5a | y = 0.28x - 3.19 | 0.84 | <0.0001 |
| Cotton gin compost (CGC) | 3.0d | y = 0.04x - 0.10 | 0.11 | <0.0001 |
| No organic matter (NOM) | 12.7c | y = 0.19x - 3.10 | 0.72 | <0.0001 |

| Significance | P-value |
|---|---|
| Treatment | <0.0001 |
| DAP | <0.0001 |
| Treatment x DAP | <0.0001 |

| | *K. latifolia* | | | |
|---|---|---|---|---|
| Treatment[x] | HRL (cm) | Equation[w] | $R^2$ | P-value |
| Pine bark (PB) | 9.9a | y = 0.13x - 5.75 | 0.27 | <0.0001 |
| Peat (P) | 6.7b | y = 0.09x - 4.52 | 0.12 | <0.0001 |
| Cotton gin compost (CGC) | 0.6c | y = 0.01x - 0.74 | 0.06 | 0.0005 |
| No organic matter (NOM) | 0.8c | y = 0.01x - 0.51 | 0.03 | 0.014 |

| Significance | P-value |
|---|---|
| Treatment | 0.0041 |
| DAP | <0.0001 |
| Treatment x DAP | <0.0001 |

[z]HRL = root length measured parallel to the ground.

[y]DAP = days after planting in Horhizotron (Wright and Wright, 2004).

[x]Treatments were soil in bottom 10 cm (3.9 in) and pine bark, peat, or cotton gin compost in upper 10 cm (3.9 in) or 100% soil (no organic matter) in Horhizotron quadrants.

[w]y = HRL, x = DAP.

[v]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at P<0.05 (SAS Institute, Inc., 2004).

**Table 4.** Initial and final pH and EC[z] of soil and substrate solutions.

| | Experiment I | | | |
|---|---|---|---|---|
| | pH | | EC | |
| | Initial | Final | Initial | Final |
| Pine bark (PB) | 6.4b[y] | 6.3b | 0.1b | 0.2b |
| Peat (P) | 3.9d | 3.9c | 0.2b | 0.2b |
| Cotton gin compost (CGC) | 5.8c | 6.5b | 2.7a | 0.6a |
| No organic matter (NOM) | 7.1a | 6.8a | 0.1b | 0.2b |
| | Experiment II | | | |
| | pH | | EC | |
| | Initial | Final | Initial | Final |
| Pine bark (PB) | 4.7c | 6.5a | 0.3b | 0.2b |
| Peat (P) | 3.8d | 5.7b | 0.2b | 0.3b |
| Cotton gin compost (CGC) | 5.2b | 5.7b | 1.9a | 1.8a |
| No organic matter (NOM) | 7.1a | 7.0a | 0.3b | 0.5b |

[z]Solutions extracted using pour-through nutrient extraction procedure (Wright, 1986).

[y]Means separated using LSD at P = 0.05 (SAS Institute, Inc., 2004).

**Table 5.** Concentration (ppm) of Minerals, Ammonium-Nitrogen, and Nitrate-Nitrogen of saturated extract[z].

| | Ca | K | Mg | P | Al | B | Cd | Cr | Zn |
|---|---|---|---|---|---|---|---|---|---|
| Pine bark (PB) | 13.7b[y] | 64b | 17b | 7.4b | 26a | 0.3b | <0.1 | <0.1 | 0.5a |
| Peat (P) | 31.0b | 0.6c | 0.4d | 0.2c | 0.1b | <0.1c | <0.1 | <0.1 | 0.1b |
| Cotton gin compost (CGC) | 306a | 99a | 48a | 24a | 0.3b | 0.5a | <0.1 | <0.1 | <0.1c |
| No organic matter (NOM) | 1.10b | 2.4c | 2.9c | 0.2c | 0.1b | <0.1c | <0.1 | <0.1 | <0.1c |

| | Cu | Fe | Mn | Na | Ni | Pb | $NH_4$-N | $NO_3$-N |
|---|---|---|---|---|---|---|---|---|
| Pine bark (PB) | 0.2 | 1.1b | 1.8a | 2.2b | <0.1 | <0.1 | 0.1c | 4.2b |
| Peat (P) | 0.3 | <0.1c | <0.1b | 2.3b | <0.1 | <0.1 | 3.9a | 0.9b |
| Cotton gin compost (CGC) | 0.2 | <0.1c | <0.1b | 3.6a | <0.1 | <0.1 | 1.1b | 520a |
| No organic matter (NOM) | 0.1 | 1.9a | <0.1b | 3.3a | <0.1 | <0.1 | 0.1c | 7.7b |

[z]Soil and media analysis by saturated extraction, Auburn University Soil Testing Laboratory, Auburn, Ala.

[y]Means separated using PDIFF at P = 0.05 (SAS Institute, Inc., 2004).

**Table 6 .** Physical properties of substrates and soil[z].

| | Water holding capacity (%) | Air space (%) | Total porosity (%) | Bulk density (g-cm$^{-3}$) |
|---|---|---|---|---|
| Pine bark (PB) | 53.2b[y] | 18.5a | 71.7b | 0.2 |
| Peat (P) | 49.8b | 20.1a | 68.7b | 0.1 |
| Cotton gin compost (CGC) | 69.1a | 12.4b | 81.5a | 0.3 |
| No organic matter (NOM) | n/a | n/a | n/a | 1.5 |

[z]Properties were determined using the NCSU Porometer™ (Fontento et al., 1981).

[y]Means separation within columns using LSD at P = 0.05 (SAS Institute, Inc., 2004).

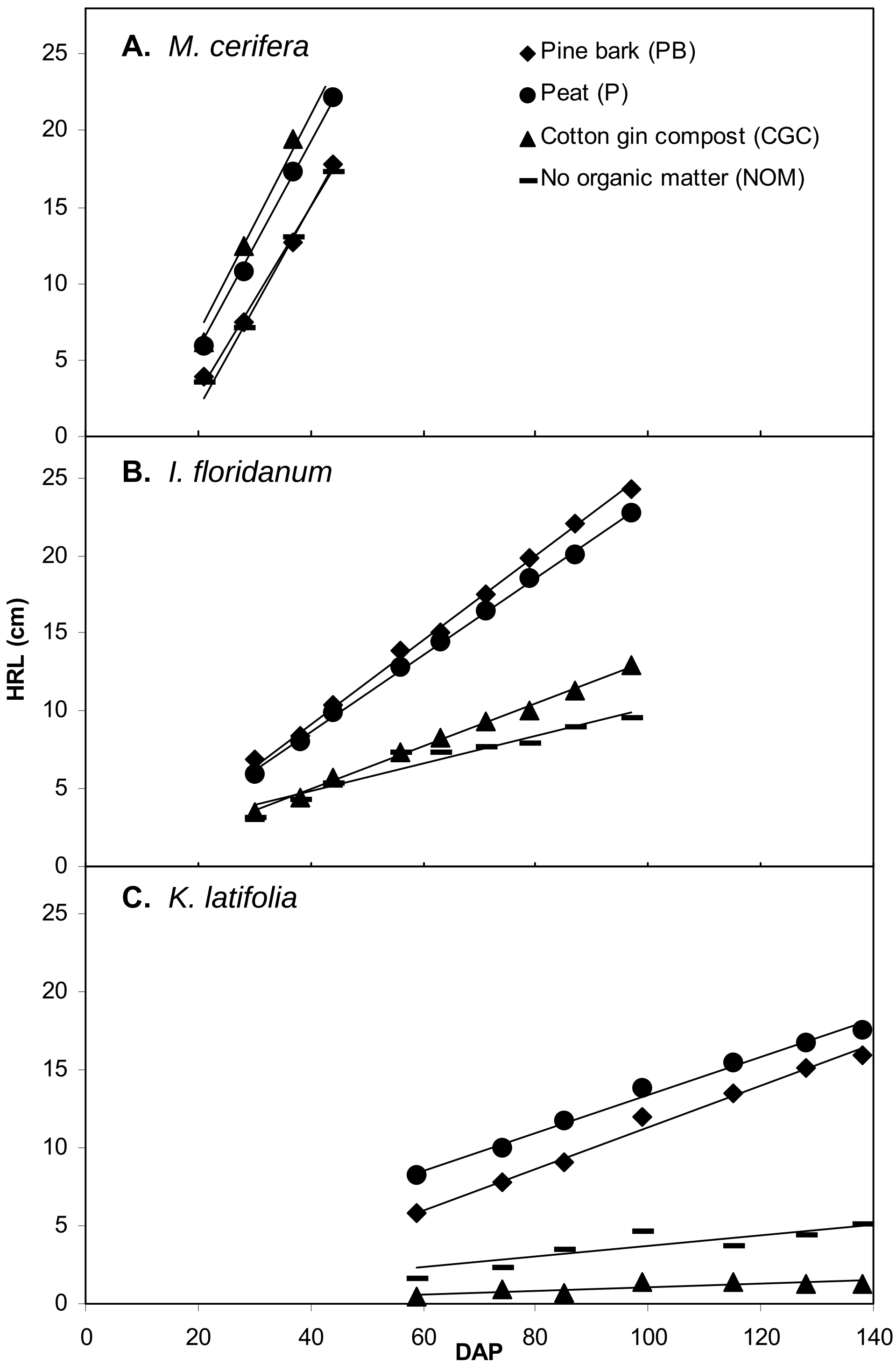


**Figure 1. Experiment I.** Effect of organic matter type on horizontal root length (length measured parallel to the ground, HRL) of **(A)** *M. cerifera* measured 21 to 44 days after planting (DAP), **(B)** *I. floridanum* measured 30 to 97 DAP, and **(C)** *K. latifolia* measured 59 to 138 DAP. Plants were planted 1 Mar. 2006, 6 June 2006 and 3 Jan. 2007, respectively, in a greenhouse at Auburn University in Auburn, Ala.

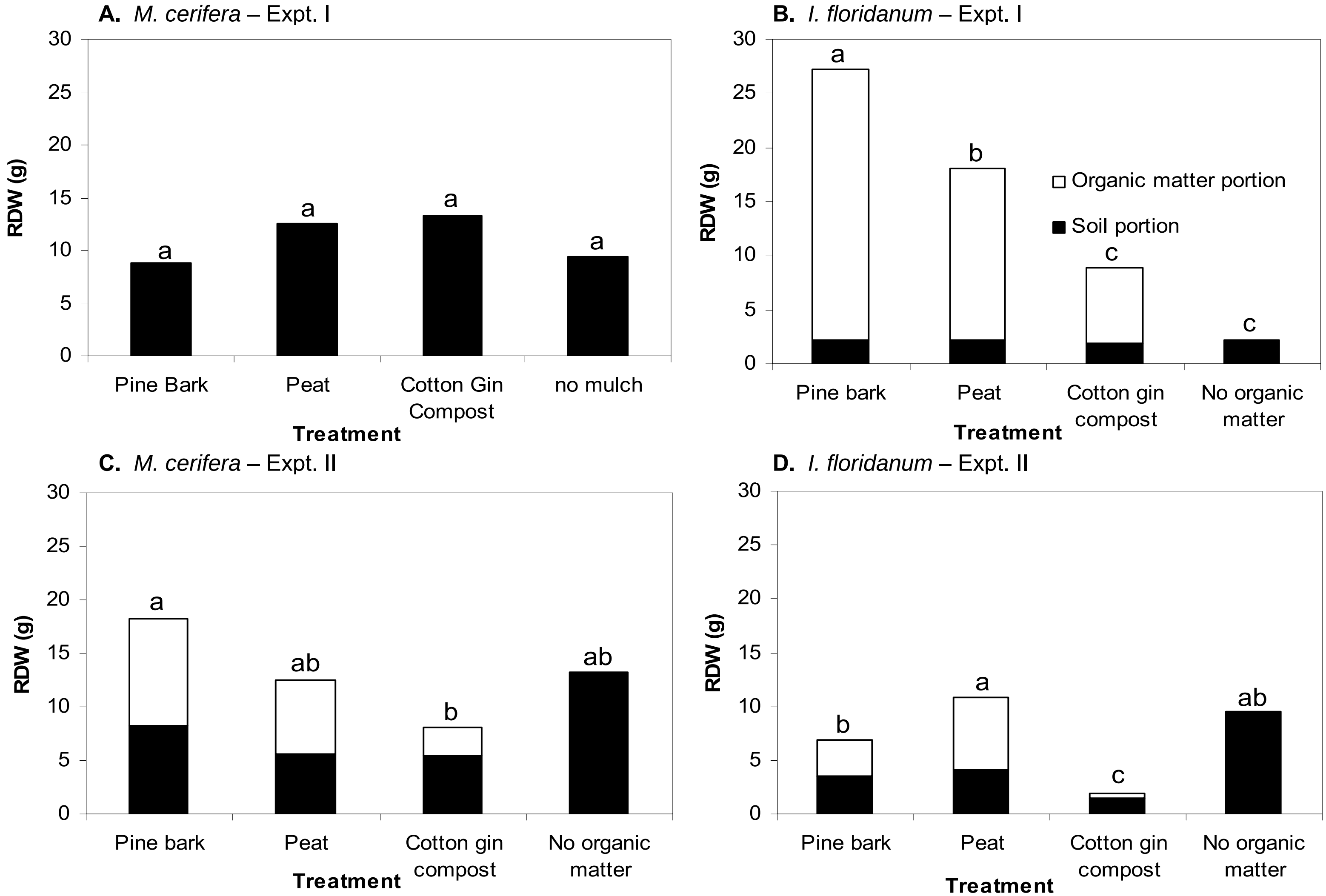


**Figure 2.** Mean root dry weight (RDW) of *M. cerifera* **(A, C)** and *I. floridanum* **(B, D)** from Experiment I (**A, B**) and Experiment II **(C, D).** Roots of **B, C, D** were divided into soil and organic matter portions in treatments pine bark, peat, and cotton gin compost and washed separately to determine root growth preference. Lowercase letters denote means separation for total RDW (n=5) among treatments within location by PDIFF at P = 0.05 (SAS Institute, Inc., 2004). All plants were grown in Horhizotrons in a greenhouse in Auburn, Ala. During Experiment I, M. cerifera and I. floridanum were grown 1 Mar. 1 - 13 Apr. and 6 June - 6 Oct. 2006, respectively. During Experiment II. *M. cerifera* and *I. floridanum* were grown 19 June - 1 Aug. and 19 June - 6 Sept. 2007, respectively.

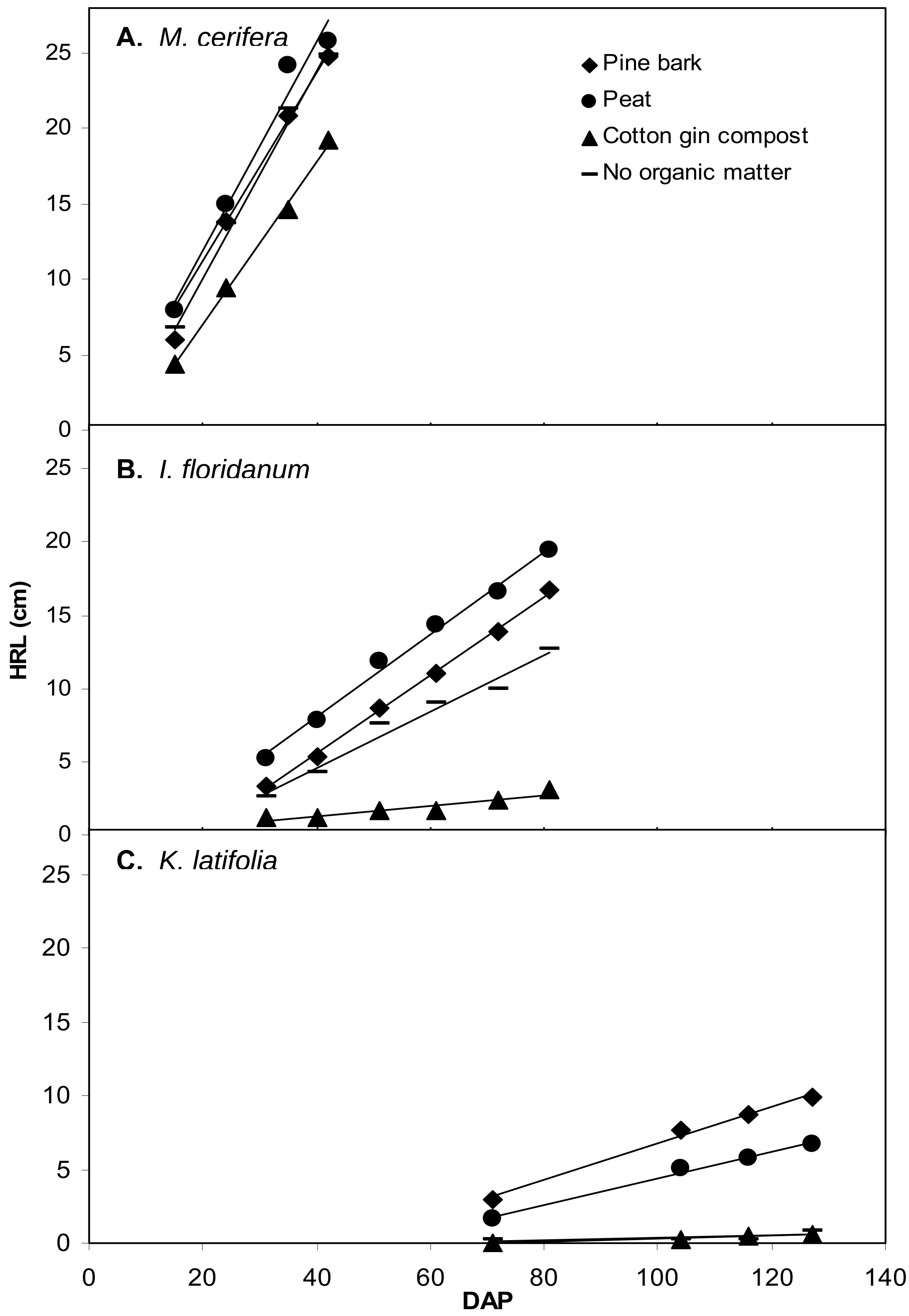


**Figure 3. Experiment II.** Effect of organic matter type on horizontal root length (length measured parallel to the ground, HRL) of **(A)** *M. cerifera* measured 24 to 42 days after planting (DAP), **(B)** *I. floridanum* measured 31 to 81 DAP, and **(C)** *K. latifolia* measured 71 to 127 DAP. Plants were planted 19 June 2007 in a greenhouse at Auburn University in Auburn, Ala.

## CHAPTER III

## ABOVE-GRADE PLANTING WITH ORGANIC MATTER IMPROVES POST-TRANSPLANT ROOT AND SHOOT GROWTH AND PHYSIOLOGY OF NATIVE SHRUBS

***Additional index words.*** landscape, establishment, stem water potential, net photosynthesis, *Morella cerifera*, wax myrtle, *Kalmia latifolia*, mountain laurel

**Abstract.** When a plant is transplanted into the landscape, often it struggles with poor soils, competition for space with underground infrastructure, pollution, excessive heat, foot traffic, and neglect in terms of irrigation and fertilization. Root growth into the surrounding soil is vital to its survival and establishment, so every effort must be made to improve post-transplant root growth. Studies of planting above grade have shown it to be a very successful technique, both with trees (Arnold et al., 2005) and woody shrubs (Wright et al., 2007). With trees, this specialized planting practice leaves a small portion of the root ball exposed above the surface, followed by mounding the remaining soil on and around the root ball and finishing with a shallow mulch application sufficient to suppress weeds. According to Wright et al. (2007), the planting practice most successful in establishing *K. latifolia* was similar: the root ball was left above grade, but rather than the remaining soil, a shallow layer of pine bark was applied to the top of the exposed root ball and a thick layer of pine bark was applied around the

root ball, tapering from the root ball down to the surrounding soil grade. To further investigate this technique, *Morella cerifera* (L.) Small (*syn. Myrica cerifera* L.) (wax myrtle) [11.3 L (3 gal)] and *Kalmia latifolia* L. (mountain laurel) [19 L (5 gal)] were planted on 30 Oct. 2006 (Fall planting) and 12 Apr. 2007 (Spring planting) in a shade house in Auburn, Ala. At planting in fall and spring, four plants of each species in a row were randomly assigned one of four treatments. Three of the four treatments utilized a modified above-grade planting technique in which plants were planted such that the top 7.6 cm (3 in) of the root ball remained above the surface of the ground. Organic matter was applied around the above grade portion of the root ball, tapering down from the top of the root ball to the ground at a distance of 30.5 cm (12 in) from the stem. Also, 1.3 cm (0.5 in) of organic matter was applied on the top of the root ball. Organic matter was either pine bark (PB), peat (P), or cotton gin compost (CGC). In the fourth treatment, plants were planted at grade with no organic matter (NOM) using only the native field soil (Marvyn sandy loam). Net photosynthesis (net Ps) and stem water potential (Ψstem) were measured 15-23 Aug. 2007 for shrubs of each species planted in the fall and spring for all treatments before and after irrigation. Plants were harvested 18 Sept. 2007. Generally, for both species at harvest, shrubs planted in the fall had higher shoot dry weight (SDW) and root ball diameter (RBD) than when planted in spring. Plants also typically had higher RBD when planted in PB or P. *M. cerifera* had higher net Ps than *K. latifolia*, and both species had higher net Ps after irrigation than before. Differences in net Ps before and after irrigation were more pronounced for shrubs planted in the spring than in the fall.  Highest net Ps and Ψstem were generally observed for shrubs in PB and P.  Growth data for *K. latifolia* were best correlated to values of Ψstem while *M. cerifera* growth responses were better correlated to net Ps.  For easy-to-transplant species (such as *M.* cerifera) and especially for difficult-to-transplant species like *K. latifolia*, fall planting utilizing this modified above-grade planting technique with PB or P may reduce post-transplant stress, improve post-transplant root growth, and speed establishment.

**Introduction**

Newly transplanted trees and shrubs in urban areas struggle with poor soils, competition for space with underground infrastructure, pollution, excessive heat, high foot traffic, and often neglect in terms of irrigation and fertilization.  In such difficult growing situations, many of these plants do not survive (Day et al., 1995).  In both horticulture and urban forestry, most research on plant performance in constructed urban landscapes is performed on trees.  While this is important, research on successful transplanting of the woody shrubs that constitute the backbone of many landscapes is also imperative.

When a plant is transplanted into the landscape, root growth into the surrounding soil is vital to its survival and establishment.  Until this occurs, the plant has only the water and nutrient supplies in the transplanted container substrate from which to draw, and these may be extremely limited due to the tendency of surrounding soils to pull moisture and nutrients from the root ball due to texture and moisture gradients (Costello and Paul, 1975).  Also, research with *Euonymus alatus* (Thunb.) Sieb.  'Compactus' (burning bush) liners showed that roots growing from lower bulk density substrates, such as the pine bark mixes in which many nursery crops are grown, were less likely to penetrate surrounding higher bulk density soil than roots growing from higher density substrates into similarly high density surroundings (Nicolosi and Fretz, 1980). This, combined with the frequent glazing of the planting hole from digging and common tendency of roots of container grown plants to continue growing in a circle (Ingram and van der Werken, 1978), may effectively inhibit root growth and containerize roots within the original planting hole (Schulte and Whitcomb, 1975).

The time between transplanting and new root growth as well as the ability of roots to penetrate the surrounding soil may explain why some container grown plants are described as either easy- or difficult-to-transplant (Harris et al., 1996). Container grown plants with coarser roots of larger diameters may be better able to exert the growth pressure necessary to deform soil aggregates than those of plants with finer roots of smaller diameters, so container-grown plants with finer roots systems may be more difficult to transplant due to slower post-transplant root growth. The season in which a plant is transplanted may affect the time between transplanting and new root growth, as well as overall success and survival of the plant. The differences between species success by season may be attributed to seasonal potential for root versus shoot growth, or periodicity.

When in the nursery, container grown plants are in ideal substrates for root growth. They are situated in close proximity to one another and so are sheltered from wind, with more than adequate water and nutrients supplied to encourage the rapid shoot growth that makes the plants attractive for purchase and placement into a landscape. However, once transplanted it may be very difficult for a plant to compensate for evapotranspiration from an abnormally large canopy of leaves that increases the potential for stomatal water loss (Wright et al., 2001) using only the resources available in the root ball and without the daily attention typical in a nursery setting. A likely consequence of transplanting plants with high shoot:root ratios followed by little post-transplant care is moisture stress, which often occurs even if a plant is well-watered (Aloni et al., 1991) and can limit photosynthesis. Plant species differ in their response to dehydration, but in general water deficit is the most common factor limiting plant growth following transplanting (Kramer, 1983). Net photosynthesis and stem water potential are two parameters that may provide insight into the post-transplant stress level of a plant.

Because of all the difficulties facing a plant upon transplanting, every effort must be made to find a planting practice that provides the best chance of survival for a plant transplanted into an unfavorable landscape environment, but that is also easy for landscapers and homeowners to implement. Often the backfill from a planting hole is amended with organic matter in an attempt to improve post-transplant conditions, but studies show there is no significant consistent improvement from this practice (Watson et al., 1993; Day et al., 1995; Smalley and Wood, 1995; Ferrini et al., 2005). However, planting above-grade has proven very successful, both with trees (Arnold et al., 2005) and woody shrubs (Wright et al., 2007). By leaving a small portion of the root ball exposed above the surface, then applying shallow layer of pine bark to the top of the exposed root ball and a thick layer of pine bark around the root ball, tapering from the top of the root ball down to the surrounding soil grade, Wright et al. (2007) encouraged the most post-transplant root growth of the very difficult-to-transplant species *Kalmia latifolia* L. (mountain laurel). Once established, the majority of water and nutrient uptake is performed by large, mature roots, but thinner, unsuberized new roots absorb water at nearly five times the rate of older roots (Kramer and Bullock, 1966). This emphasizes the need for speedy fine root proliferation upon transplanting to quickly absorb water and decrease plant moisture stress, which should aid the growth of more roots that mature and establish the plant into its new surroundings.

The technique of Wright et al. (2007) should most effectively encourage post-transplant root growth of container-grown shrubs, perhaps because the layer of organic matter simulates the litter layer found in natural environments, encouraging the natural proliferation of roots in this layer and upper soil horizons. Species native to the region may be more suited to the soils and climate, and therefore may be successful in poor transplanting situations while requiring fewer inputs such as fertilizer and water. The objective of this study was to use this above grade planting technique to determine the effect of organic matter type on post-transplant root growth of two native landscape shrubs selected for their reported differing success after transplanting (Dirr, 1998).

**Materials and Methods**

On 30 Oct. 2006 (hereafter referred to as fall planting) and 12 Apr. 2007 (hereafter referred to as spring planting), 24 plants each of 11.3 L (3 gal) *Morella* *cerifera* (L.) Small (*syn. Myrica cerifera* L.) (wax myrtle) (Moore and Davis Nursery, Shorter, Ala.) and 19 L (5 gal) *Kalmia latifolia* 'Olympic Wedding' (mountain laurel) (Historyland Nursery, Warsaw, Va.) obtained at the same time were planted in six rows (blocks) in a 15.2 x 9.1 m (50 x 30 ft) shade house in Auburn, Ala. covered with 47% shade cloth. Spring-planted shrubs overwintered on a nursery pad with daily irrigation and winter cover. Each row contained eight plants of each species, four planted in fall and four in spring, for a total of ninety-six plants. At planting in fall and spring, four plants of each species in a row were randomly assigned one of four treatments. Three of the four treatments utilized a modified above-grade planting technique in which plants were planted such that the top 7.6 cm (3 in) of the root ball remained above the surface of the ground. Organic matter was applied around the above grade portion of the root ball, tapering down from the top of the root ball to the ground at a distance of 30.5 cm (12 in) from the stem. Also, 1.3 cm (0.5 in) of organic matter was applied on the top of the root ball. Organic matter was either pine bark (PB), peat (P), or cotton gin compost (CGC). In the fourth treatment, plants were planted at grade with no organic matter (NOM) using only the native field soil (Marvyn sandy loam). Each plant was fertilized with 95.3 g (3.4 oz) of encapsulated slow-release fertilizer (12 month 18N-6$P_2O_5$-12$K_2O$; Polyon®, Pursell Industries, Sylacauga, Ala.). A 7.6 cm (3 in) layer of pine straw (*Pinus palustris* P. Mill., longleaf pine) was applied on top of organic matter and to the ground between plants and rows.

Plant growth indices [(height + widest width + width perpendicular to widest width)/3] of all planted shrubs were recorded at both planting dates.

Three additional (non-planted) plants of each species were harvested for leaf area (LA) [measured using an LI-3100 Area Meter (Li-Cor BioSciences, Lincoln, Nebr.)] and shoot dry weight (SDW) [shoots cut from the root ball and dried for 48 hours at 66°C (150°F)] at both planting dates. From these non-planted shrubs, three leaf tissue samples were taken from the most recently matured leaves of each shrub at planting in Fall 2006 and Spring 2007 for tissue nutrient analysis (Auburn University Soil Testing Laboratory, Auburn, Ala.). Also, at planting in Spring 2007, three recently matured leaf tissue samples from those shrubs planted in Fall 2006 were collected from three plants of each treatment for tissue nutrient analysis (Auburn University Soil Testing Laboratory, Auburn, Ala.). Three rain gauges were installed, each at a different location within the shade house, and precipitation and irrigation events (frequency and volume) were recorded throughout the experiment. All plants were irrigated with one inch of water from overhead irrigation (#4 Nozzle mini-Wobbler®, Senninger Irrigation, Inc., Clermont, Fla.) when mean percent moisture in any treatment fell below 10%. Percent moisture was measured weekly using a Theta moisture probe (Delta- T Devices Ltd., Cambridge, England) inserted into the organic matter (treatments 1-3) or soil (treatment 4) around each root ball, approximately 20.3 cm (8 in) from the stem. From 13 to 23 Aug. 2007, net photosynthesis (Ps, μmol $CO_2/m^2/sec$) was measured at photosynthetically active radiations (PAR) of 0, 200, 500, 800, 1000, 1200, 1500, 1800, 2000, and 2200 μmol photons/$m^2$/sec in order to construct light response curves (LRC). Measurements were made using two LI- 6400 portable photosynthesis systems (Li-Cor Biosciences, Lincoln, Nebr.) on four plants of each treatment within each species and planting date both before and after irrigation. The first week, 13-16 Aug. 2007 was considered "dry" as the shrubs had not received rain or irrigation the previous two weeks when percent moisture measurements of the substrates and soil indicated irrigation should be have been applied. Ps LRC measurements were conducted separately by species and planting season to minimize variation among these factors and highlight variations among treatments. Measurements of *M. cerifera* planted in Fall 2006 were recorded 13 Aug., *M. cerifera* planted in Spring 2007 on 14 Aug., *K. latifolia* planted in Fall 2006 on 15 Aug., and *K. latifolia* planted in Spring 2007 on 16 Aug. The following week plants received irrigation and therefore were considered "well-watered." Measurements were recorded Aug. 20-23 in the same order as the previous week, with irrigation on 19 Aug. and 21 Aug., so both species were well-watered when measurements were recorded. On each measurement day, plants in all treatments were measured by both LI-6400 systems, and the order of treatment measurement was randomized so one treatment was not always measured earlier or later in the day than another treatmentr. Measurements were recorded from about 10:00 AM to 2:00 PM. Stem water potential ($\Psi_{stem}$, MPa) was measured for each plant at two times on the same day that Ps LRC measurements were recorded for that plant. At 11:00 AM and 3:00 PM a single, terminal stem section was removed from each of the four plants within each treatment for which Ps LRC was measured that day. Upon removal from the plant, all stem sections were placed in a portable cooler on ice, and taken immediately to the lab. Each stem section was recut to 10.2

cm (4 in), the basal 2.5 cm (1 in) of foliage was removed, and $\Psi_{stem}$ was determined using a Model 1000 Pressure Chamber (PMS Instrument Company, Albany, Ore.). Physical properties of each organic matter type were determined using the NCSU Porometer™ (Fontento et al., 1981), and chemical properties of substrates and soil were determined from saturated extracts at the Auburn University Soil Testing Laboratory, Auburn, Ala.

All plants were harvested 18 Sept. 2007. Final growth indices were taken, and canopy quality was rated visually from 0 to 5, with 0 being no live tissue and 5 being no visible tissue death or disease. Plant canopies were cut from the root ball, dried for 48 hours at 66°C (150°F), and weighed to determine shoot dry weight (SDW), and from these oven-dried samples a nutrient analysis was performed on three plants from each species within each treatment and planting season. Plant root balls were excavated by inserting a shovel around the plant at a 30.48 cm (12 in) radius from the stem and carefully lifting each from the surrounding soil to determine the extent of root growth beyond the original root ball. Root ball diameter (RBD) [widest diameter + width perpendicular to widest diameter)/2] was recorded for all plants.

This study was a randomized complete block design with each of the six blocks (rows) containing one plant of each species subjected to each treatment and from each planting season. Data were analyzed using GLM procedures to determine main effects and interactions in order to perform mean separations using PDIFF at $P = 0.05$ (SAS Institute, Inc., 2004). Regression analysis of photosynthetic light response curves was performed separately by species and by planting season for each treatment before and after watering.

**Results**

Survival rate of shrubs was 100% with the exception of a 67% rate for *K. latifolia* planted in the spring in CGC. Mean shoot dry weight (SDW) of non-planted *M. cerifera* harvested at planting was higher for those planted in Spring 2007 (0.172 kg) than for those planted in Fall 2006 (0.120 kg). SDW:Root ball diameter (RBD) was lower for fall-planted shrubs (0.011 kg/cm) than for spring-planted shrubs (0.016 kg/cm). By experiment termination in Fall 2007, the shrubs planted the previous fall had higher SDW than those planted in spring (P <0.0001) (Table 1A). There were no differences in final SDW of *M. cerifera* among treatments. Initial *K. latifolia* SDW was higher for spring-planted shrubs (0.33 kg) than fall-planted shrubs (0.29 kg), but SDW/RBD was similar. Fall-planted *K. latifolia* had higher SDW than those planted in spring (P = 0.0005) by the end of the experiment (Table 1B). A significant interaction between season and treatment (P = 0.0475) showed that SDW of fall planted *K. latifolia* was highest when grown in pine bark (PB) or peat (P), while SDW of those planted in spring was highest in PB, P, or at grade with no organic matter (NOM). Final growth index (GI) was higher for *M. cerifera* planted in fall (P <0.0001), but there were no differences among treatments within season (Table 1A). Visual ratings of canopies of *M. cerifera* were unaffected by planting season or treatment. *K. latifolia* GI was higher for those planted in fall (P = 0.0003) and there was an interaction of treatment and season (P = 0.0433) showing that those planted in spring in CGC had lower GI than all other treatments (Table 1B). *K. latifolia* visual ratings reflect these findings (Table 1B).

Final root ball diameter (RBD) appeared to follow the results for SDW, with additional differences in RBD for *M. cerifera* that were not apparent above ground. *M. cerifera* RBD was largest in PB and P regardless of planting season (P <0.0001) (Table 1A). Roots of *M. cerifera* growing into the soil below organic matter layers were thicker and fewer than the many fine roots in organic matter layers (visual observation). *K. latifolia* RBD was affected by both treatment (P <0.0001) and season (P = 0.0062), with plants planted in fall and grown with PB and P having the largest root balls at experiment termination (Table 1B).

For both species, photosynthetic light response curve (Ps LRC) data are presented separately by season, treatment, and before and after irrigation (water status) since the four way interaction of these variables and PAR was significant (P <0.0001), and stem water potential ($\Psi_{stem}$) data are presented similarly due to a significant interaction between season, treatment, water status, and time of day (P = 0.0007 and P = 0.0228 for *M. cerifera* and *I. floridanum*, respectively) (Figs. 1-3). Under both dry and well-watered conditions (before and after watering), Ps LRC and $\Psi_{stem}$ of the two species were significantly different (all P <0.0001), so data are presented separately by species.

Overall, Ps LRC for *M. cerifera* were higher after watering than before (P = 0.0026) and when planted in fall versus spring (P = 0.0348) (Fig. 1). The largest difference in *M. cerifera* Ps LRC before and after watering was for spring-planted shrubs (Fig. 1). Within planting date and water status, Ps LRC were similar among treatments for *M. cerifera* (Table 2; Fig. 1). *K. latifolia* had higher Ps LRC after watering than before (P = 0.0431) (Fig. 2), and the differences between before and after watering were more pronounced for those shrubs planted in spring. Before watering, *K. latifolia* planted in the fall had highest Ps LRC when planted in CGC, and spring-planted shrubs in PB and P had highest Ps LRC before watering (Table 3; Fig. 2).

*M. cerifera* had higher $\Psi_{stem}$ when planted in the fall than in the spring (P <0.0001) and also before watering than after (P <0.0001) (Fig. 3). The time of day was only significant for those planted in spring, with higher $\Psi_{stem}$ at 11:00 AM (P <0.0001) (Fig. 3). When planted in the fall, and if measured before watering, $\Psi_{stem}$ was higher in shrubs planted in PB than all other treatments (Fig. 3). *K. latifolia* $\Psi_{stem}$ was higher after watering than before for spring-planted shrubs (P = 0.0021) (Fig. 3). After watering *K. latifolia* planted in spring, Ψstem was higher in shrubs in PB than all other treatments at 11:00 AM (P = 0.0021), while at 3:00 PM those in PB and P had higher Ψstem than those in CGC, though plants in NOM had Ψstem similar to those in P and CGC (P = 0.0497) (Fig. 3). Percent moisture near root balls of both species was typically lowest in PB and highest in P (Fig. 4). Percent moisture was higher near root balls of *K. latifolia* than those of *M. cerifera,* and for both species, there were larger differences between treatments for shrubs planted in the spring.

**Discussion**

Though fall planted shrubs of both species were smaller at planting than those planted in the spring, they had a smaller shoot:root ratio and therefore, relative to their root systems, had a smaller canopy to support. The fall-planted shrubs of both species were able to grow roots in the winter months, and by experiment termination had become established enough to develop significantly larger canopies than their spring-planted counterparts (Table 1). The vigorous growth of fall-planted shrubs is also evident in larger RBD and higher visual ratings (Table 1). Spring-planted *K. latifolia* had lower overall visual ratings and larger treatment differences than those planted in fall (Table 1), showing that organic matter selection affected these less established spring-planted shrubs more than fall-planted shrubs. In addition, for both species, percent moisture around root balls varied by treatment more for spring-planted shrubs than fall, showing that fall-planted shrubs had better established roots systems regardless of treatment (Fig. 4). Lower daily fluctuation of $\Psi_{stem}$ and higher Ps LRC for fall-planted shrubs of both species provide physiological evidence of establishment (Figs. 1-3). The larger differences in Ps LRC between before and after watering for spring-planted shrubs of both species indicate more extreme fluctuations between dry and well-watered environments resulting from lack of root system development into the surrounding soil. This would be explained by the fact that, until establishment, a plant has only the transplanted container substrate from which to draw water (Heiskanen and Rikala, 2000). Perhaps spring-planted shrubs had already allocated much of their resources into new shoot growth, and by harvest may not have been able to develop roots into the surrounding soil and grow shoots as rapidly as fall-planted shrubs. The season in which a shrub is planted may be of particular importance, especially for already difficult-to-transplant species like *K. latifolia*, which has been shown to allocate resources to root growth in the fall months (Wright et al., 2004) and thus may be more suited to fall planting since plants should be transplanted when root growth rates are highest (Kozlowski and Davies, 1975).

Differences in Ps LCR were better correlated to establishment of *M. cerifera* than $\Psi_{stem}$ since shrubs of this species developed extensive root systems quickly and possessed large canopies. *K. latifolia* performance was better correlated to $\Psi_{stem}$ results because the plants were smaller and roots were thinner. *M. cerifera* became larger and more photosynthetically active when planted in the fall. Also, generally lower percent moisture values around the root balls for fall-planted than spring-planted shrubs can be explained by the more extensive root growth of fall-planted shrubs.

When measured before irrigation, *K. latiolia* $\Psi_{stem}$ was higher for fall planted than spring planted shrubs, showing a better ability of fall planted shrubs to accommodate dry conditions than the less established spring planted shrubs. After irrigation, spring planted *K. latifolia* recovered to higher $\Psi_{stem}$ more quickly when planted with PB and P than in other treatments. This result, along with higher SDW, GI, visual rating, and RBD, demonstrate that it is of benefit for *K. latiolia* to be planted using this technique, and PB or P is recommended over CGC. PB and P used in above grade planting may contribute to speedier establishment because the layer of organic matter simulates a natural litter layer. This layer has a low bulk density (see Ch. II, Table 6), making it much easier for roots to penetrate than surrounding soils, particularly under dry conditions in which soils become dry and hard.  Plants in cultivation have less than half the root to shoot ratio of those in natural areas (Robinson et al., 2003), possibly because they lack this organic matter layer that simulates a natural litter layer.

Treatment differences were not as important for *M. cerifera*, an easy-to-transplant species, though CGC is not recommended due to limited root growth perhaps due to high EC and salts (Tables 4 and 5 in Ch. II).    Though it may not be as important for easy-to-transplant species like *M. cerifera,* this above-grade planting technique with PB or P was still beneficial and was in no way detrimental.  Even after one year, the organic matter applied on and around the exposed root balls stayed in place under the pine straw mulch, demonstrating that this technique requires little maintenance.  Though *M. cerifera* had a 100% survival rate, *K. latifolia* planted in the spring with CGC had only a 67% survival rate.  For species like *K. latifolia* that may be particularly sensitive to high salt levels (see Ch. II, Tables 4 and 5), CGC is not recommended.  Composts like CGC should only be used in urban areas when heavily diluted in mixes with soil or other organic matter (Sæbø and Ferrini, 2006).  This field experiment comparing two native species, and the previous chapter that examined root growth of these two as well as another native species (*I. floridanum*) under simulated above-grade conditions, demonstrate the benefit of this technique with PB or P.  These experiments show that this technique with PB or P could possibly be used when transplanting native shrub species from diverse habitats to encourage post-transplant root growth, decrease moisture stress, and contribute to establishment of the shrubs to develop attractive, low-maintenance landscapes.

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**Table 1.** Effect of organic matter and planting season on shoot dry weight (SDW), growth index (GI), visual rating, and root ball diameter (RBD) of *M. cerifera* **(A)** and *K. latifolia* **(B)** planted on 30 Oct. 2006 **(Fall)** and 12 Apr. 2007 **(Spring).** Plants were harvested 18 Sept. 2007.

**A.** *M. cerifera*

| | **Fall-planted** | | | | |
|---|---|---|---|---|---|
| | | **GI (cm)[z]** | | | |
| **Treatment[y]** | **Final SDW (kg)** | **Spring 2007** | **Final** | **Final visual rating[w]** | **Final RBD(cm)[v]** |
| PB | 1.89a[x] | 84a | 183a | 5.0a | 47a |
| P | 1.87a | 81a | 173a | 5.0a | 52a |
| CGC | 1.60a | 78a | 171a | 4.7a | 35b |
| NOM | 1.69a | 80a | 171a | 5.0a | 34b |
| | **Spring-planted** | | | | |
| PB | 0.69a | - | 125a | 5.0a | 47a |
| P | 0.73a | - | 121a | 5.0a | 53a |
| CGC | 0.61a | - | 119a | 4.7a | 28c |
| NOM | 0.68a | - | 119a | 5.0a | 39b |

**B.** *K. latifolia*

| | **Fall-planted** | | | | |
|---|---|---|---|---|---|
| | | **GI (cm)[y]** | | | |
| **Treatment[z]** | **Final SDW (kg)** | **Spring 2007** | **Final** | **Final visual rating[x]** | **Final RBD(cm)[v]** |
| PB | 0.50a | 60a | 75a | 4.3a | 40a |
| P | 0.42ab | 56ab | 76a | 4.0a | 40a |
| CGC | 0.35b | 58ab | 71a | 3.5a | 29b |
| NOM | 0.36b | 55b | 70a | 3.5a | 28b |
| | **Spring-planted** | | | | |
| PB | 0.36a | - | 65a | 4.2a | 38a |
| P | 0.25a | - | 63a | 3.2a | 32b |
| CGC | 0.10b | - | 40b | 1.2b | 27c |
| NOM | 0.38a | - | 71a | 4.0a | 28c |

[z]GI = (height + widest width + width perpendicular to widest width)/3.

[y]Treatments were planted above grade with pine bark (PB), peat (P), or cotton gin compost (CGC) mounded on and around the exposed root ball, or planted at grade with no organic matter (NOM).

[x]Means within column and season not significantly different when followed by the same letter, separated using PDIFF at P = 0.05 (SAS Institute, Inc., 2004).

[w]Visual Ratings were assessed using scale 0 = no live tissue, 1 = 1-25% live tissue, 2 = 26-50% live tissue, 3 = 51-75% live tissue, 4 = 76-100% live tissue but visible stem dieback or leaf spot, 5 = 100% live tissue and no visible symptoms of disease or drought.

[v]Diameter = (widest width + width perpendicular to widest width)/2.

**Table 2.** Regression equations for change in net photosynthesis with change in PAR[z] for *M. cerifera* planted in fall and spring and before and after irrigation with corresponding $R^2$ term and significance of regression equation (P-value) (SAS Institute, Inc., 2004). *M. cerifera* were grown from 30 Oct. 2006 (fall planted) or 12 Apr. 2007 (spring planted) to 18 Sept., 2007. Measurements were taken 13-23 Aug. 2007 using an LI- 6400 portable photosynthesis system (Li-Cor Biosciences, Lincoln, Nebr.)

| | Fall | | | | | |
|---|---|---|---|---|---|---|
| | Before[y] | | | After[y] | | |
| Treatment[x] | Equation[w] | $R^2$ | P-value | Equation[w] | $R^2$ | P-value |
| Pine bark | $y = -4.56E\text{-}06x^2 + 0.016x - 1.38$ | 0.82 | <0.0001 | $y = -6.79E\text{-}06x^2 + 0.024x - 0.865$ | 0.872 | <0.0001 |
| Peat | $y = -4.39E\text{-}06x^2 + 0.017x - 0.78$ | 0.76 | 0.0004 | $y = -6.91E\text{-}06x^2 + 0.026x - 1.249$ | 0.745 | 0.0003 |
| Cotton gin compost | $y = -5.32E\text{-}06x^2 + 0.017x - 3.05$ | 0.37 | 0.0221 | $y = -6.99E\text{-}06x^2 + 0.025x - 1.033$ | 0.692 | 0.0005 |
| No organic matter | $y = -5.42E\text{-}06x^2 + 0.019x - 1.66$ | 0.44 | 0.0301 | $y = -6.83E\text{-}06x^2 + 0.026x - 1.709$ | 0.618 | 0.0071 |

| | Spring | | | | | |
|---|---|---|---|---|---|---|
| | Before | | | After | | |
| Treatment | Equation | $R^2$ | P-value | Equation | $R^2$ | P-value |
| Pine bark | $y = -2.91E\text{-}06x^2 + 0.011x - 1.94$ | 0.42 | 0.0527 | $y = -7.10E\text{-}06x^2 + 0.028x - 2.91$ | 0.75 | 0.0010 |
| Peat | $y = -4.39E\text{-}06x^2 + 0.015x - 1.82$ | 0.48 | 0.0134 | $y = -6.20E\text{-}06x^2 + 0.022x - 1.31$ | 0.83 | <0.0001 |
| Cotton gin compost | $y = -5.09E\text{-}06x^2 + 0.016x - 3.22$ | 0.70 | <0.0001 | $y = -5.59E\text{-}06x^2 + 0.021x - 2.27$ | 0.73 | 0.0005 |
| No organic matter | $y = -2.70E\text{-}06x^2 + 0.011x - 1.62$ | 0.50 | 0.0555 | $y = -6.06E\text{-}06x^2 + 0.021x - 1.51$ | 0.73 | 0.0001 |

[z]Net photosynthetic rates was measured over photosynthetically active radiation (PAR) 0, 200, 500, 800, 1000, 1200, 1500, 1800, 2000, 2200 µmol photons/$m^2$/sec.

[y]Measurements were taken before and after irrigation.

[x]Treatments were planted above grade with pine bark, peat, or cotton gin compost mounded on and around the exposed root ball, or planted at grade with no organic matter.

[w]y = net photosynthesis (µmol $CO_2/m^2$/sec), x = PAR (µmol photons/$m^2$/sec).

**Table 3.** Regression equations for net photosynthesis with change in PAR[z] for *K. latifolia* planted in fall and spring and before and after irrigation with corresponding $R^2$ term and significance of regression equation (P-value) (SAS Institute, Inc., 2004). *K. latifolia* were grown from 30 Oct. 2006 (fall planted) or 12 Apr. 2007 (spring planted) to 18 Sept., 2007. Measurements were taken 13-23 Aug. 2007 using an LI- 6400 portable photosynthesis system (Li-Cor Biosciences, Lincoln, Nebr.)

| | Fall | | | | | |
|---|---|---|---|---|---|---|
| | Before[y] | | | After[y] | | |
| Treatment[x] | Equation[w] | $R^2$ | P-value | Equation[w] | $R^2$ | P-value |
| Pine bark | $y = -1.81E\text{-}06x^2 + 0.006x - 3.68$ | 0.33 | 0.0192 | $y = -4.40E\text{-}06x^2 + 0.016x - 3.76$ | 0.61 | 0.0025 |
| Peat | $y = -1.60E\text{-}06x^2 + 0.005x - 4.35$ | 0.42 | 0.0049 | $y = -4.40E\text{-}06x^2 + 0.016x - 3.76$ | 0.71 | <0.0001 |
| Cotton gin compost | $y = -8.56E\text{-}07x^2 + 0.003x - 2.05$ | 0.49 | 0.0314 | $y = -4.40E\text{-}06x^2 + 0.016x - 3.77$ | 0.54 | 0.0024 |
| No organic matter | $y = -1.73E\text{-}06x^2 + 0.006x - 4.93$ | 0.34 | 0.0304 | $y = -4.40E\text{-}06x^2 + 0.016x - 3.77$ | 0.65 | 0.0035 |

| | Spring | | | | | |
|---|---|---|---|---|---|---|
| | Before | | | After | | |
| Treatment | Equation | $R^2$ | P-value | Equation | $R^2$ | P-value |
| Pine bark | $y = -1.45E\text{-}06x^2 + 0.005x - 3.92$ | 0.32 | 0.0449 | $y = -4.27E\text{-}06x^2 + 0.017x - 5.21$ | 0.66 | 0.0079 |
| Peat | $y = -1.45E\text{-}06x^2 + 0.005x - 3.34$ | 0.29 | 0.0627 | $y = -4.60E\text{-}06x^2 + 0.016x - 5.41$ | 0.36 | 0.0600 |
| Cotton gin compost | $y = -1.58E\text{-}06x^2 + 0.006x - 5.86$ | 0.4 | 0.1029 | $y = -6.02E\text{-}06x^2 + 0.022x - 7.35$ | 0.84 | <0.0001 |
| No organic matter | $y = 1.94E\text{-}06x^2 + 0.006x - 4.47$ | 0.41 | 0.0055 | $y = -5.06E\text{-}06x^2 + 0.020x - 6.21$ | 0.77 | 0.0006 |

[z]Net photosynthesis was measured over photosynthetically active radiation (PAR) 0, 200, 500, 800, 1000, 1200, 1500, 1800, 2000, 2200 μmol photons/$m^2$/sec.

[y]Measurements were taken before and after irrigation.

[x]Treatments were planted above grade with pine bark, peat, or cotton gin compost mounded on and around the exposed root ball, or planted at grade with no organic matter.

[w]y = net photosynthesis (μmol $CO_2$/$m^2$/sec), x = PAR (μmol photons/$m^2$/sec).

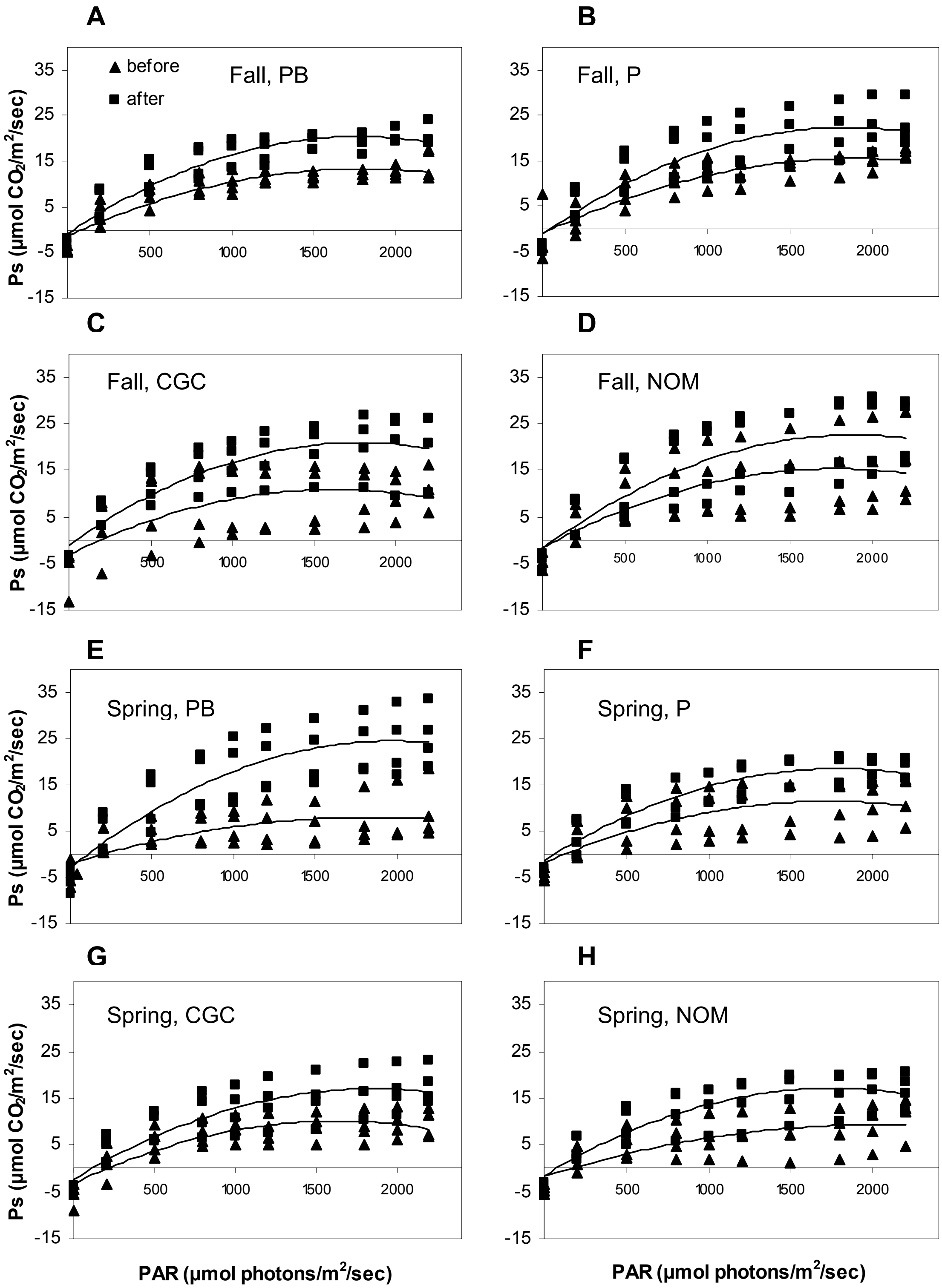


**Figure 1.** Net photosynthesis of *M. cerifera* planted in the fall **(A-D)** and spring **(E-H)**. Shrubs were planted on 30 Oct. 2006 (Fall) and 12 Apr. 2007 (Spring) using a modified above grade planting technique using pine bark (PB) **(A, E)**, peat (P) **(B, F)**, cotton gin compost (CGC) **(C, G)**, or at grade with no organic matter (NOM) **(D, H)**. Ps was measured before and after watering and over a light response curve of PAR ranging from 0 to 2200 from 13-23 Aug. 2007. Measurements were taken using an LI- 6400 portable photosynthesis system (Li-Cor Biosciences, Lincoln, Nebr.).

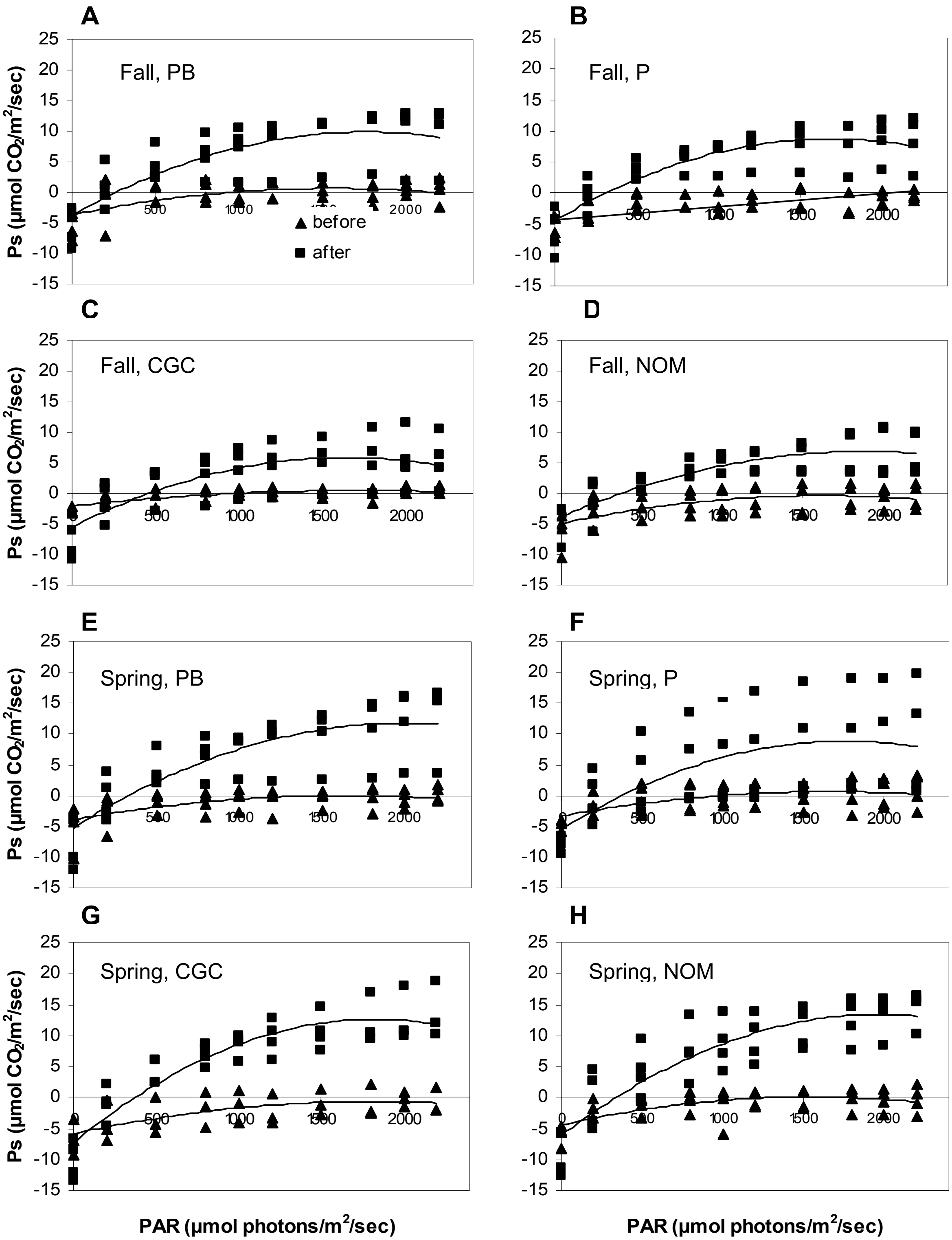


**Figure 2.** Net photosynthesis of *K. latifolia* planted in the fall **(A-D)** and spring **(E-H)**. Shrubs were planted on 30 Oct. 2006 (Fall) and 12 Apr. 2007 (Spring) using a modified above grade planting technique using pine bark (PB) **(A, E)**, peat (P) **(B, F)**, cotton gin compost (CGC) **(C, G)**, or at grade with no organic matter (NOM) **(D, H)**. Ps was measured before and after watering and over a light response curve of PAR ranging from 0 to 2200 from 13-23 Aug. 2007. Measurements were taken using an LI- 6400 portable photosynthesis system (Li-Cor Biosciences, Lincoln, Nebr.).

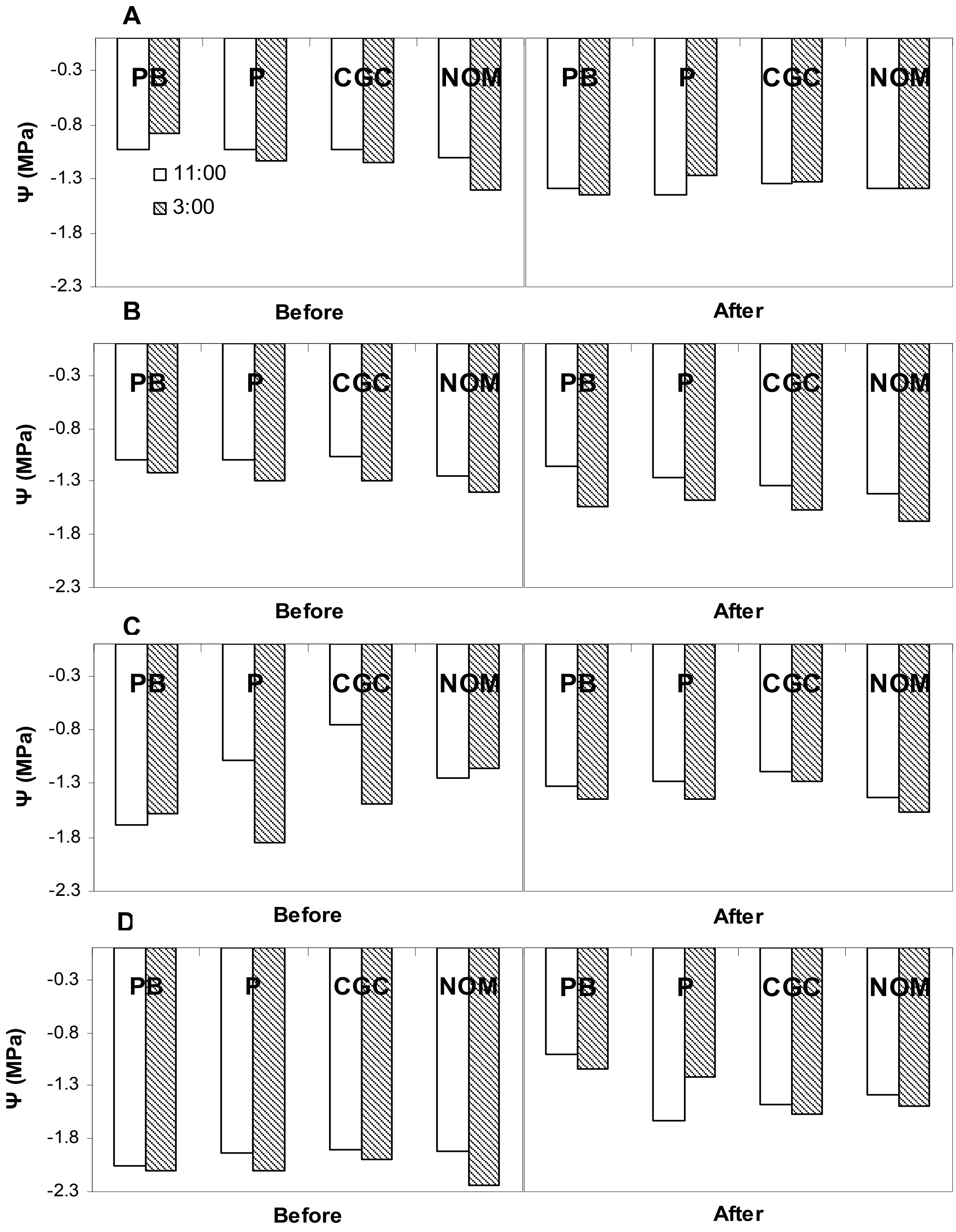


**Fig 3.** Stem water potential (Ψ) in MPa before and after irrigation of *M. cerifera* **(A,B)** and *K. latifolia* **(C,D)**. Treatments included above-grade planting using pine bark **(PB)**, peat **(P)**, cotton gin compost **(CGC)**, or at grade with no organic matter **(NOM)**. Species were planted in the fall **(A,C)** and spring **(B,D)**. Shrubs were planted on 30 Oct. 2006 (Fall) and 12 Apr. 2007 (Spring). Measurements were taken 13-23 Aug. 2007 using a Model 1000 Pressure Chamber (PMS Instrument Company, Albany, OR). Means separation by time within season and water status using PDIFF; if letters present, differences were significant at P = 0.05 (SAS Institute, Inc., 2004).

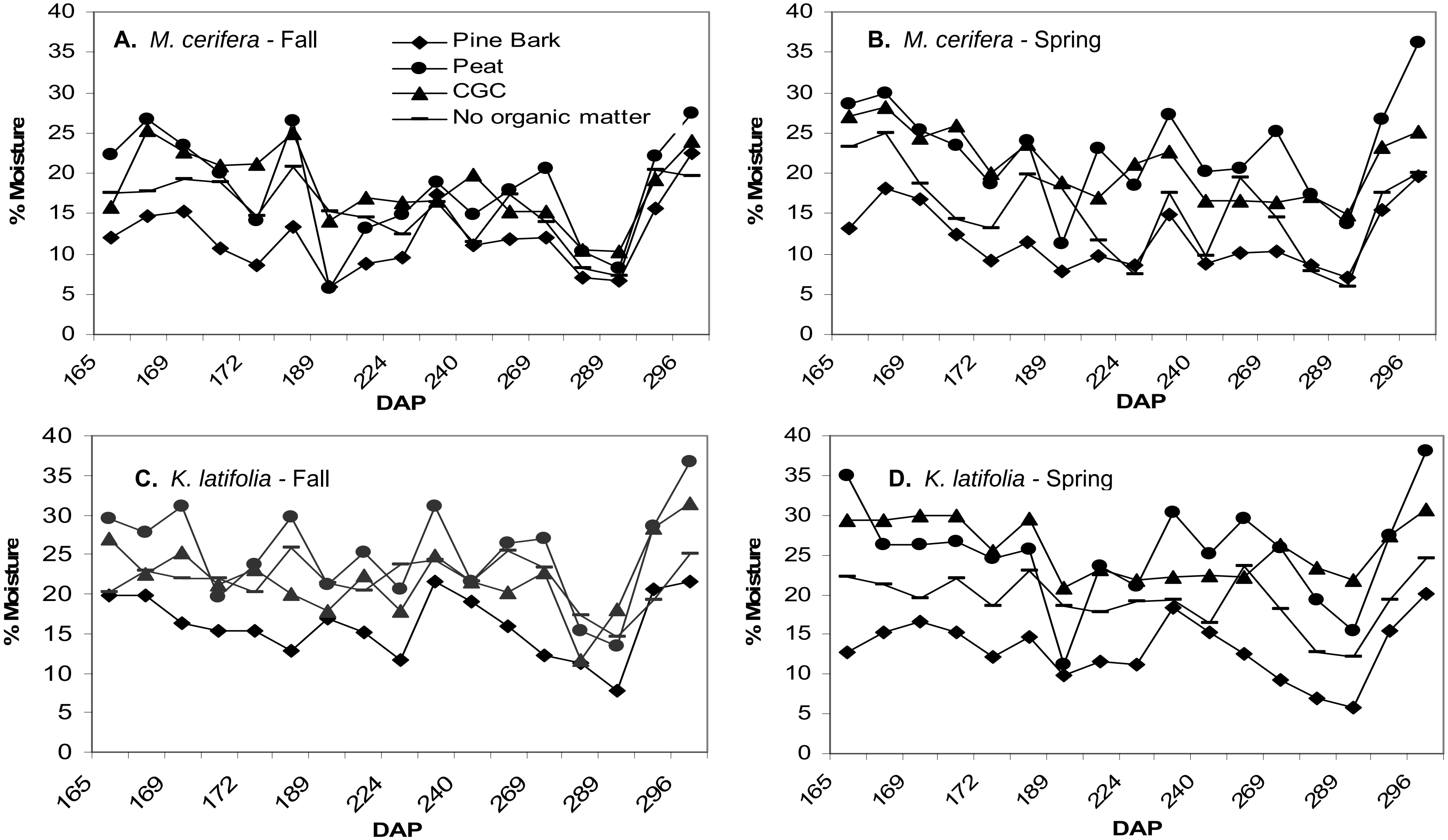


**Figure 4.** Percent moisture (by volume) of organic matter and soil around the rootballs of *M. cerifera* planted in the fall **(A)** and spring **(B)** and *K. latifolia* planted in the fall **(C)** and spring **(D).** Shrubs were planted on 30 Oct. 2006 (Fall) and 12 Apr. 2007 (Spring) and harvested 18 Sept. 2007. Treatments included above-grade planting using pine bark **(PB)**, peat **(P)**, cotton gin compost **(CGC)**, or at grade with no organic matter **(NOM)**. Measurements were taken using a Theta moisture probe (Delta- T Devices, Ltd., Cambridge, England).