Effects of Transplant Season and Container Size on Landscape Establishment of *Kalmia latifolia* L.

Anne-Marie Hanson

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APPROVED:

James R. Harris, Chair

Alex X. Niemiera

Robert D. Wright

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(Abstract)

Mountain laurel (*Kalmia latifolia* L.) is relatively difficult to establish in landscapes. One experiment tested the effect of container size on the water relations of pinebark substrate embedded in field soil. Two other experiments tested the effects of transplant season and container size on landscape establishment of nursery-produced mountain laurel. Experiment one compared volumetric water content of embedded substrate of five sizes (4-L to 100-L) to adjacent field soil at two depths with time domain reflectometry (TDR) during a dry down cycle. Available water was calculated by subtracting unavailable water (estimated with pressure plates) from volumetric water content (TDR measurements). Adjacent soil contained more available water than embedded substrate. The middle depth held more water than the top. Larger pinebark substrate volumes retained higher volumetric water content than smaller volumes. The second experiment consisted of 7.6- and 19-L containers of *Kalmia latifolia* L. 'Olympic Wedding', transplanted into field soil in October or May. Larger container plants generally had lower xylem potential than smaller plants, but better visual ratings. Root growth into surrounding soil was negligible for all treatments. Leaf area was higher for spring transplants than fall transplants. Experiment three was a rhizotron study with 19-L plants, transplanted in October or May. Canopy growth of spring transplants was greater than fall transplants, but fall transplants had longer roots into the backfill. Overall, our data suggest that fall transplanting will potentially allow faster plant establishment than spring transplanting. The effect of container size on plant establishment could not be determined.

Acknowledgments

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I would like to specifically dedicate this thesis to my dad, Gary Hanson. He has always known I can do anything I set my mind on and has never lost hope in me.

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Chapter One

Introduction

Mountain laurel (*Kalmia latifolia L.*) is undoubtedly one of the most spectacular flowering shrubs in the Eastern United States. This species has even been touted by some as “the perfect shrub” for its beauty, the extent of its range, and economic value to the nursery industry (Jaynes 1997). Mountain laurel is a broad-leaved evergreen shrub in the Ericaceae family, sometimes attaining a height of 2.4 meters in the Blue Ridge Mountains in the Eastern U.S. Mountain laurel is native from Northern Florida to Maine. This species can be found on various soil types and growing in a wide range of environmental conditions (Jaynes 1975).

Mountain laurel is a valuable understory shrub in the forest due to its ability to reduce rainfall runoff (Jaynes 1975). Lipscomb and Nilsen (1990a and 1990b) conducted a two-part study of mountain laurel and two species of rhododendron (*Rhododendron maximum* and *Rhododendron periclymenoides*) on Brush Mountain in the southern Appalachian Mountains, approximately 3.1km from Blacksburg, VA. They found mountain laurel growing mostly on hot and dry southwest slopes. Plant water use efficiency and photosynthetic capacity were lower when mountain laurel was found growing on cooler and wetter northeast slopes, compared to southwest slopes (Lipscomb and Nilsen 1990a). Monk et al. (1985) discovered that there were structural differences between mountain laurel on north- and south-facing slopes. Northern slopes produced mountain laurel that were taller, and “less distorted” than those on southern slopes and mountain laurel on south-facing slopes had small, yet very open and sparse canopies and twisted branches that hung low to the ground. Mountain laurel can apparently adjust to extreme growing conditions in the wild, in part because of a physiological mechanism to conserve water. When leaf water potential is low, the amount of water flowing through the xylem is decreased (Lipscomb and Nilsen 1990b). Lipscomb and Nilsen (1990b) found that mountain laurel is able to adapt to both a low amount of available soil water and a high transpiration rate. Monk et al. (1985) found a positive correlation between the abundance of mountain laurel and its distance from a water source, the greater frequency occurring the farther the plant is from a water source. However, Muller (1991) found that mountain laurel distribution in the wild was not a function of water stress.

Natural propagation of mountain laurel is by seedlings, layering, and suckering, with great variability in growth habit and flower color (Robinette 1974). Over the past twenty years, container production of tissue culture-propagated mountain laurel has produced approximately 50 cultivars ranging in flower color from white to pink to dark red and burgundy, with all combinations in between, most with compact growth (Dirr 1998). However, once plants are planted in a landscape, they often decline and die within a few years (Bir and Conner 1991). Thus a strategy is needed to increase the post-transplant survival of mountain laurel. How can we get mountain laurel to establish in the landscape? Can we get better establishment with fall vs. traditional spring transplanting? Can we get better establishment with smaller plants? My overall hypothesis is that transplanting smaller containers in the fall will improve first-year establishment vs. traditional spring transplanting with larger containers.

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Chapter Two

Literature Review

Transplant Timing:

Poor transplant timing is probably the most common mistake homeowners make when attempting to establish landscape plants (Koller 1977). Spring and fall are both recognized as beneficial times to transplant, with the fall being recommended for most plants due to the potential to produce new roots into the backfill in the fall or in the early spring, when more prolific root growth will develop as the soil warms up (Koller 1977). The best time to transplant trees is in the spring if the area gets deep freezes, is windy, and water availability is sparse (Kozlowski & Davies 1975). Lindstrom (1992) found cold hardiness in early winter in Georgia was enhanced by field-transplanting Leyland cypress (X *Cupressocyparis leylandii*) from August to November, while cold hardiness in spring was enhanced by transplanting in midwinter. Harris et al. (1996) found that balled and burlapped (B&B) fringe tree (*Chionanthus virginicus* L.) planted in fall had larger leaves and canopies a month after bud set than for spring-transplanted trees. In a study on bare-root shade trees in upstate New York (USDA plant hardiness zone 5a), Harris and Bassuk (1994) found that the success of a transplant could not be predicted by the periodicity of root growth and that trees that do not successfully transplant in early fall or late spring tend to have a small amount of time in the fall for successful transplanting. Harris et al. (2001) looked at the root growth of seasonally transplanted Turkish hazelnut (*Corylus colurna* L.) and found no fall root growth in fall-transplanted trees in Virginia (USDA plant hardiness zone 6a). Watson and Himelick (1982) studied the seasonal growth of Norway maple (*Acer platanoides* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and ginkgo (*Ginkgo biloba* L.) and found that root growth of Norway maples was more than green ash or ginkgo as a result of spring transplanting. Kozlowski and Davies (1975) suggested that broad-leaved evergreens transplant best in the spring; however, fall transplanting is possible if planting takes place before the ground freezes deeply. This phenomenon of root growth seasonality has not been studied in mountain laurel (Jaynes 1997).

Transplant Size:

A few studies have explored the effect of woody plant transplant-size on post-transplant growth. Lauderdale et al. (1995) transplanted 3.8-cm or 7.6-cm trunk diameter October Glory® red maples (*Acer rubrum* L.) in May. Smaller trees had higher leaf conductance, water use efficiency, and shoot elongation on every date measured for the next two years, indicating less transplant stress than larger trees. They concluded that smaller plants can adjust to transplant shock quicker and are cheaper to replace than larger plants. Beeson (1994), however, found that with live oaks (*Quercus virginiana* Mill.), plants 133-L and 247-L container had similar post-transplant tissue water status.

Water Relations of Transplanted Rootballs:

Transplanting trees and shrubs into the landscape is a timely and expensive process. Certain aspects must be addressed to insure the health and longevity of the plant. Of utmost importance are post-transplant rootball water relations. Costello and Paul (1975) cite improper irrigation volume and frequency as the number one reason for post-transplant death.

A transplanted container-grown plant usually requires more irrigation after transplanting than before (Costello and Paul 1975). This is because a contained rootball has a higher water content before the container is removed and the effect of the perched water table is reduced after the container is removed (Nelms and Spomer 1983). From the bottom to the top of a container, the tension of water being held by substrate particles increases by 0.1 kPa with each centimeter (Argo 1998). Once a plant is planted, the perched water table no longer exists due to drainage into the surrounding soil (Nelms and Spomer 1983). In the experiment by Nelms and Spomer (1983), samples of peat and a sand:peat mix were embedded (container removed) into sandy soil with tensiometers placed at different depths within the substrate and soil. The moisture retention of the embedded substrates and the surrounding soil were compared to samples of each held within containers. They found that the embedded substrates evaporated the same amount of water in a couple hours as the substrate in a container evaporated in a few days. After irrigation, the embedded substrates dried down much more rapidly than the contained substrates and the surrounding soil. Costello and Paul (1975) embedded sweet gum trees with and without their container into the ground and measured the tension created by the loss of water in the middle of the rootball. They found that the trees without the container had more negative rootball moisture tension compared to transplants in containers and to surrounding soil. They concluded that new transplants require more water than container plants, at least until the plants are established.

Container Substrate vs. Field Soil:

Commercial container substrates and field soils have very different physical properties. Mineral soils are typically composed of 50% solid material and 50% pore space at field capacity and the pore space is typically 50% air and 50% water. However, soilless mixes have been reported as having as much as 85% to 93% pore space, with water making up 70% at field capacity (Argo 1998). The higher pore space fraction in container substrates vs. field soil results in a greater amount of air or water that the substrate can hold, making the soilless mixes act like sponges when wet.

Pinebark Water Relations:

Milled and composted pinebark is a very popular organic substrate for container production; growers use a 100% pinebark substrate, or amend bark with other materials like sand and peat moss. Pinebark and peat moss, however, can be difficult to rewet (Airhart et al. 1978). Beardsell and Nichols (1982) found that water mostly tunnels through dry pinebark or spills over the edge, avoiding saturation of the substrate. The pinebark absorbed more water through irrigation, etc. when it initially contained a higher percentage of water per volume. Both Airhart et al. (1978) and Beardsell and Nichols (1982) found that after approximately 50% of the pinebark is wetted, the rest of the volume absorbs water quicker than if the substrate was dry. The same principle also holds for peat moss (Airhart et al. 1978). On the other end of the spectrum is the drying rate of pinebark and its impact on other processes. Evaporation and transpiration can be lessened with pinebark compared to other common substrates, which lengthens the time before wilting occurs, as measured in marigold seedlings (Beardsell et al. 1979). Murray et al. (2001) found that the amount of available water in contained pinebark depends on the height of the container, and that time domain reflectometry (TDR) probes need to be calibrated according to container height.

Exposure of Transplanted Mountain Laurel:

Bir and Conner (1991) found that mountain laurel grown in full sun showed a low incidence of leaf spot. They discourage planting mountain laurel in deep shade because flower abundance will decrease. Brand (1997) studied the influences of shade on the success of container-grown mountain laurel and found that there was a difference in how many years the plants were subjected to shade. He concluded that one year of shading the plants did not affect plant size compared to those grown in full sun. However, the second year of shading produced plants that were smaller than those in their second year of full sun. He concluded that to ensure a healthy green leaf color, transplanting to a shady area would be best for the first year. In another study conducted in Raleigh, NC (Wright et al. 2001), mountain laurel located on a northern- or eastern-facing wall had higher visual ratings, based on leaf color, foliage denseness and overall plant quality than plants on southern- and western-facing walls). Smaller container (7.6-L) plants had the highest visual rating overall and a larger increase in growth for two growing seasons compared to plants in 19-L containers.

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Chapter Three

Effects of Container Size and Measurement Depth on Volumetric Water Content of Embedded Pinebark Substrate

Abstract

The effect of pinebark substrate on water relations of transplanted rootballs is unknown. This experiment was undertaken to compare the water relations of field soil to embedded substrate (container removed). A range of common production container sizes, 4-L, 8-L, 20-L, 60-L, and 100-L was used. Water content of the top and middle zones of container substrates was compared to corresponding depths of adjacent mineral soil. Volumetric water content was measured with time domain reflectometry (TDR), and plant-available water was calculated for substrate and soil by subtracting unavailable water (measured with pressure plates) during a dry-down cycle. Pinebark substrate had 34% unavailable water, compared to 6% in the soil. Substrate in the middle portion of the containers contained more water than the substrate in the top portion. The top section of substrate dried very quickly. Larger containers had a higher volumetric water content than that in smaller containers. Our data suggest the need for greater water retention in transplanted rootballs. Frequent irrigation of transplanted, container-grown plants is necessary due to the relatively small amount of water available to plants.

Introduction

The primary causes of post-transplant plant death are improper irrigation volume and frequency (Costello and Paul 1975). Container-grown plants can actually require more frequent irrigation after transplanting than before removing the plant from the container (Costello and Paul 1975) because the effect of the perched water table is reduced and drainage into the surrounding soil increases (Nelms and Spomer 1983). In the experiment by Nelms and Spomer (1983), samples of peat and a sand:peat mix were embedded into sandy soil with tensiometers placed at different depths. The moisture retention of the embedded samples and the surrounding soil were compared to samples of each held within embedded containers. They found that aboveground contained peat substrates evaporated the same amount of water in a few days as compared to a few hours for the embedded substrates. After irrigation, embedded substrates dried down much more rapidly than the contained substrate and the surrounding soil.

Pinebark and peat, however, are typically difficult to rewet when they dry out due to forced air-drying during processing and added wetting agents, which enhance their hydrophobic property and may cause water availability problems for plants (Airhart et al. 1978). Since pinebark consists of small particles with a high surface area, more hygroscopic water is present than other substrates (Anisko et al. 1994). Plants are able to take up the less available water, but not as quickly as if plants were grown in other substrates (Beardsell et al. 1979). Peat, however, is the opposite with a large percentage of available water on a volumetric basis, but little in the way of less available water (buffering capacity), which causes plants to wilt faster than if in pinebark (Beardsell et al.

1979). Murray et al. (2001) found that the amount of available water in pinebark depends on the height of the container. They found that easily available water existed in the range of 0 to -0.01 MPa in a variety of substrates, including a pinebark mix. Argo (1998), however, states that container rootball substrate has a range of easily available water from tensions of 0 to -0.005 MPa, with -0.005 to -0.01 MPa representing the less available water.

Since apparently no studies have focused on the availability of water within a transplanted pinebark substrate, this experiment was undertaken to compare the volumetric water content of an embedded pinebark mix of various container sizes to the water content of surrounding soil. Focusing only on embedded substrate of various container sizes without plants should reveal the fundamental aspects of transplant establishment of container-grown landscape plants.

Materials and Methods

A ground bed consisting of groseclose silt loam soil (clayey, mixed, mesic Typic Hapludults; pH = 6.2) was roto-tilled to a depth of 20 cm in mid-August 2001, at the Virginia Tech Urban Horticulture Center in Blacksburg, VA. Fifty holes were spaced 1.2 m on center, dug to a particular container size, and filled with a mixture (volumetric 2:1) of 100% pinebark and a blend (Scott's Perennial Mix, Scott's Company, Marysville, Ohio), consisting of 65-75% pinebark, 20-25% peatmoss, and 9-15% perlite. Five container sizes were used for hole sizes: 4-L (1-gallon), 8-L (2-gallon), 20-L (5-gallon), 60-L (15-gallon), and 100-L (25-gallon). Ten replicates of each size were arranged in a completely random design. Hollow PVC pipe (7.5-cm diameter) was cut and one pipe was inserted into each embedded substrate volume and one into the surrounding soil, approximately 21 cm from the edge of the embedded substrate. Three centimeters of the top of each pipe extended above the surface of the substrate (to allow for covering with foil) and was 6 cm above the middle of the substrate-filled holes and to that same depth in the soil (to allow for the 6-cm long time domain reflectometry (TDR) metal probes to extend to the middle of the substrate or soil) (Figure 1). Middle-of-the-substrate measurement depths from substrate or soil surface to middle for the 4-, 8-, 20-, 60-, and 100-L containers were 9.2, 12.1, 13.9, 19.6, and 22.8 cm, respectively. Volumetric moisture measurements were taken with a TDR probe (Theta Meter, Type HH1, Dynamax, Inc., Houston) on the same day the experiment was installed (16 August). The TDR probe uses microwave signals to measure the average volumetric water content from the top to the end of the probes (6 cm) and the substrate surrounding the probes (Anisko et al. 1994). The TDR probe was calibrated to the pinebark substrate to accurately measure volumetric water content (see Appendix A). Five centimeters of water was then applied on 16 August to the plot via overhead sprinklers and TDR probe measurements were taken 24 hours later. TDR probe measurements were taken periodically for approximately one month afterwards. Four measurements per replicate were taken at each reading: 1) middle of container (inserting the TDR probe down the hollow PVC pipe in the container substrate), 2) top of container (6 cm from the top), 3) in soil at the depth of middle of container (inserting the TDR probe down the hollow PVC pipe in the soil), and 4) top of soil (6 cm from the top and approximately 21 cm from the edge of the embedded substrate) (Figure 1).

Soil or substrate samples were taken from the top 10-cm of soil and pinebark substrate. Unavailable water for soil and pinebark substrate was calculated with pressure plates (8 replicates) after a constant pressure of –1.5 MPa was applied for 2 weeks (Klute 1998). Unavailable volumetric water, measured with the pressure plates, was subtracted from each total volumetric water measurement made with TDR to determine the plant-available volumetric water.

Data from the TDR probe were analyzed as repeated measures analysis of variance by SAS (SAS, version 8.02, SAS Institute, Cary, NC).

Results and Discussion

For TDR measurements, repeated measures analysis of variance (Wilks-Lambda) revealed that there was an overall time effect ($P<0.0001$), a time*container size effect ($P=0.0002$), a time*depth of measurement effect ($P<0.0001$) and a time*container size*depth of measurement effect ($P=0.0013$). Data were therefore graphed to reveal patterns of change in volumetric water content over time for embedded substrate from each container size (Figures 2-6).

On a volumetric basis, 34% and 6% of the water in the pinebark mix and the soil, respectively, was unavailable (pressure plate measurement). TDR probes measure total volumetric water content but do not take into account the plant unavailable water fraction. Thus, subtracting pressure plate values of unavailable water from TDR values yielded plant-available water content (volumetric basis) (Figures 2B – 6B). The middle of the 4-L container maintained the highest volumetric water content compared to other depths of the same size container (Fig. 2A). However, when calculated on an available water basis (Fig. 2B), soil in the middle-of-the-container depth had the highest water content compared to the top of the container. Figures 3 (A and B) and 4 (A and B) show the same overall trend with 8-L and 20-L containers, respectively. The top of the soil contained the lowest water content as measured with TDR, but substrate in the top zone of the container contained the lowest available water content, with values dropping to zero by 23 August. Low plant-available water for the tops of embedded rootballs is likely due to evaporation. The low overall availability of water in pinebark has been shown in other experiments (Beardsell et al. 1979, da Silva et al. 1998). da Silva et al. (1998) reported that, even though water may be detected by the TDR probe, much is unavailable water to plants, being tightly bound to organic compounds, mineral crystals, or embedded in occluded pores. Our data confirm that available water is low despite a high TDR reading. Nelms and Spomer (1983) found that embedded samples after irrigation (100% peat and 1:1 peat and sand, by volume) had a lower water content than the surrounding soil due to increased drainage of the substrate. The embedded samples lost on average 55% of their estimated available water, and dried down rapidly, mainly from surface evaporation. The embedded samples in that study were not commonly used container substrates for landscape plant production and were only of one size (10 cm height x 10 cm width x 10 cm width). Costello and Paul (1975) measured moisture status with tensiometers of container (in the container embedded in the ground in a larger container) and the middle of the rootball of transplanted sweet gum trees (grown in sand/peat/sawdust mix). They found that transplanted rootballs were drier than the surrounding soil and contained rootballs.

Data from 60-L and 100-L containers (Figures 5A and 6A) show a similar general trend as the smaller containers. The middle of the container still contained a higher water content than the other treatments, but when adjusted (Figures 5B and 6B), middle substrate zone still provided less available water than the soil at two depths. However, compared to the smaller containers, the middle-of-the-container available water contents (60-L and 100-L) was higher. Even though removal of a container removes the perched water table created by the container (Argo 1998), a moisture gradient between the top and middle of containers was evident for all rootball sizes (Figures 2-6). This was probably mostly due to evaporation from the surface.

Our data indicate that embedded pinebark substrate retains very little plant-available water in the top and middle layers, and that larger embedded pinebark substrate volumes of 60-L and 100-L retain more water. Transpiring plants will reduce the already low available water quickly. Actual withdrawal rate will vary according to species, size and growth rate. Pro-active irrigation, directly on rootballs is imperative until roots grow into surrounding soil. Substrates that work well for container production but retain more water after transplanting are needed.

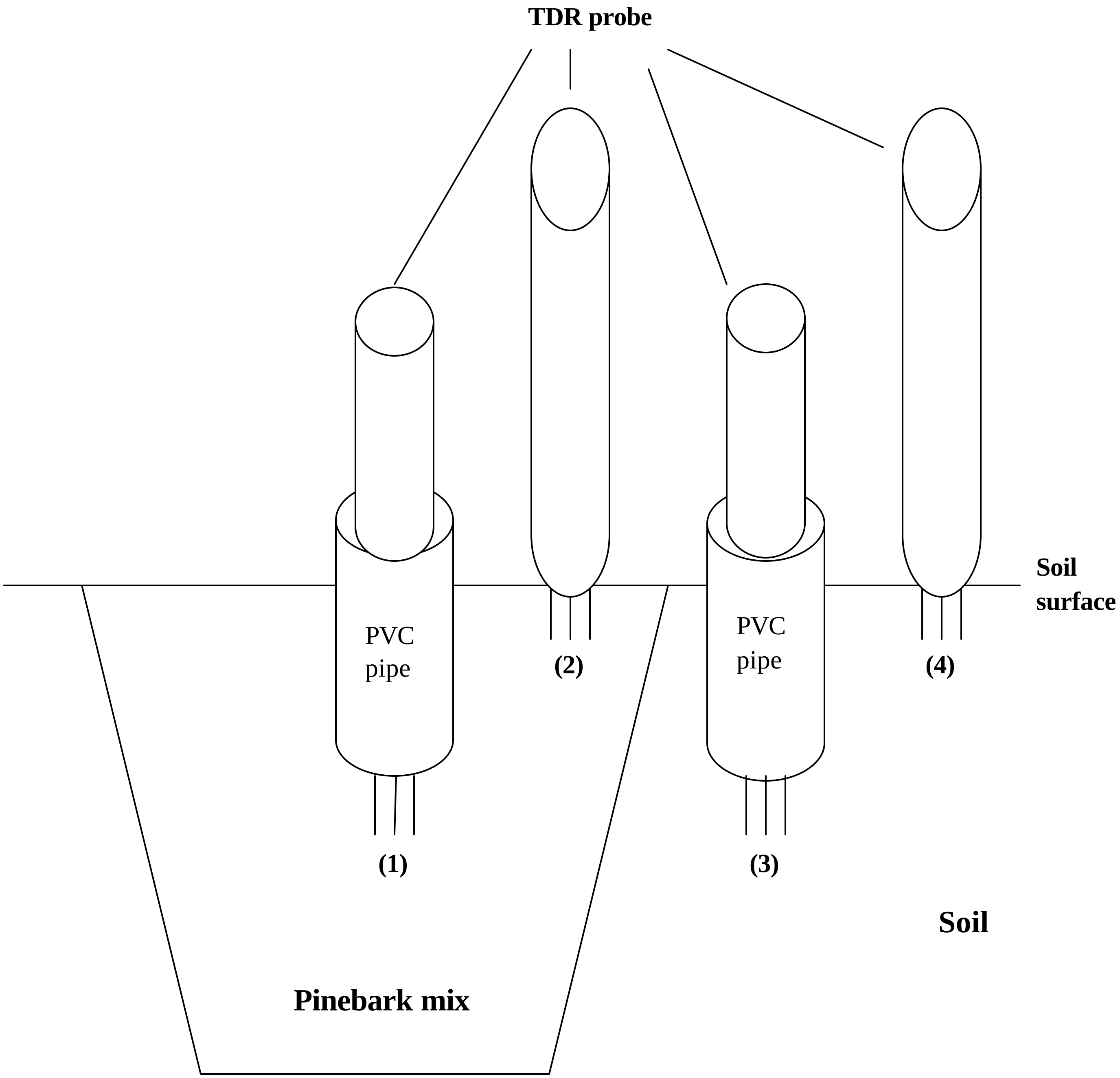

Figure 1. Diagram of general placement of time domain reflectometry (TDR) probe measurements of embedded pinebark mix and surrounding soil. (1) = middle of container (with TDR probe inserted through hollow PVC pipe); (2) = top of container; (3) = soil at the depth of middle of container (through PVC pipe); (4) = top of soil. Not drawn to scale.

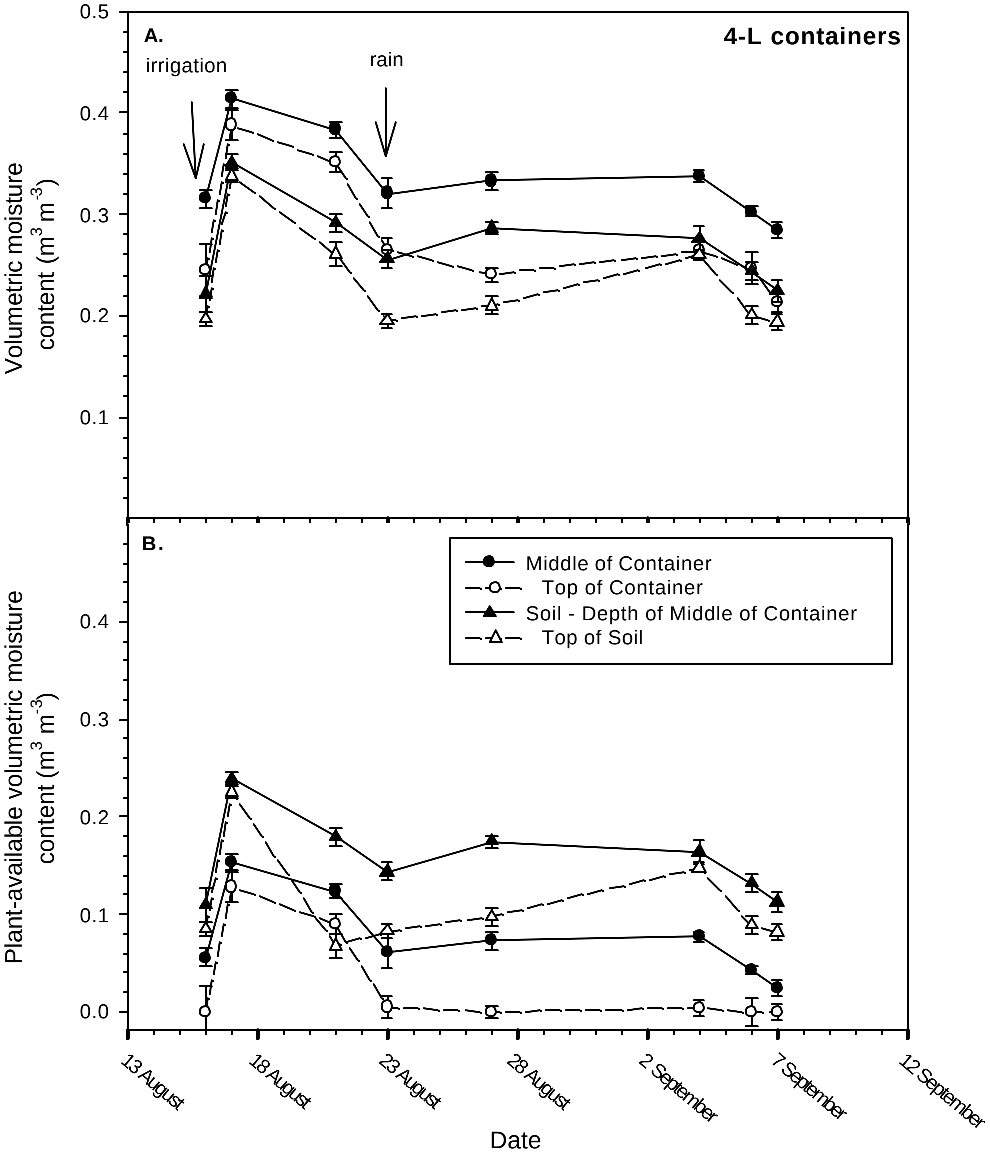

Figure 2. Volumetric water content of embedded 4-L container-sized pinebark mix vs. surrounding soil at depths of 6 cm (top) and 9.2 cm (middle). A.) TDR-measured volumetric water content, n=10. B.) Estimated plant-available volumetric water content determined by subtracting unavailable water (from pressure plate data) from data in (A), n=10.

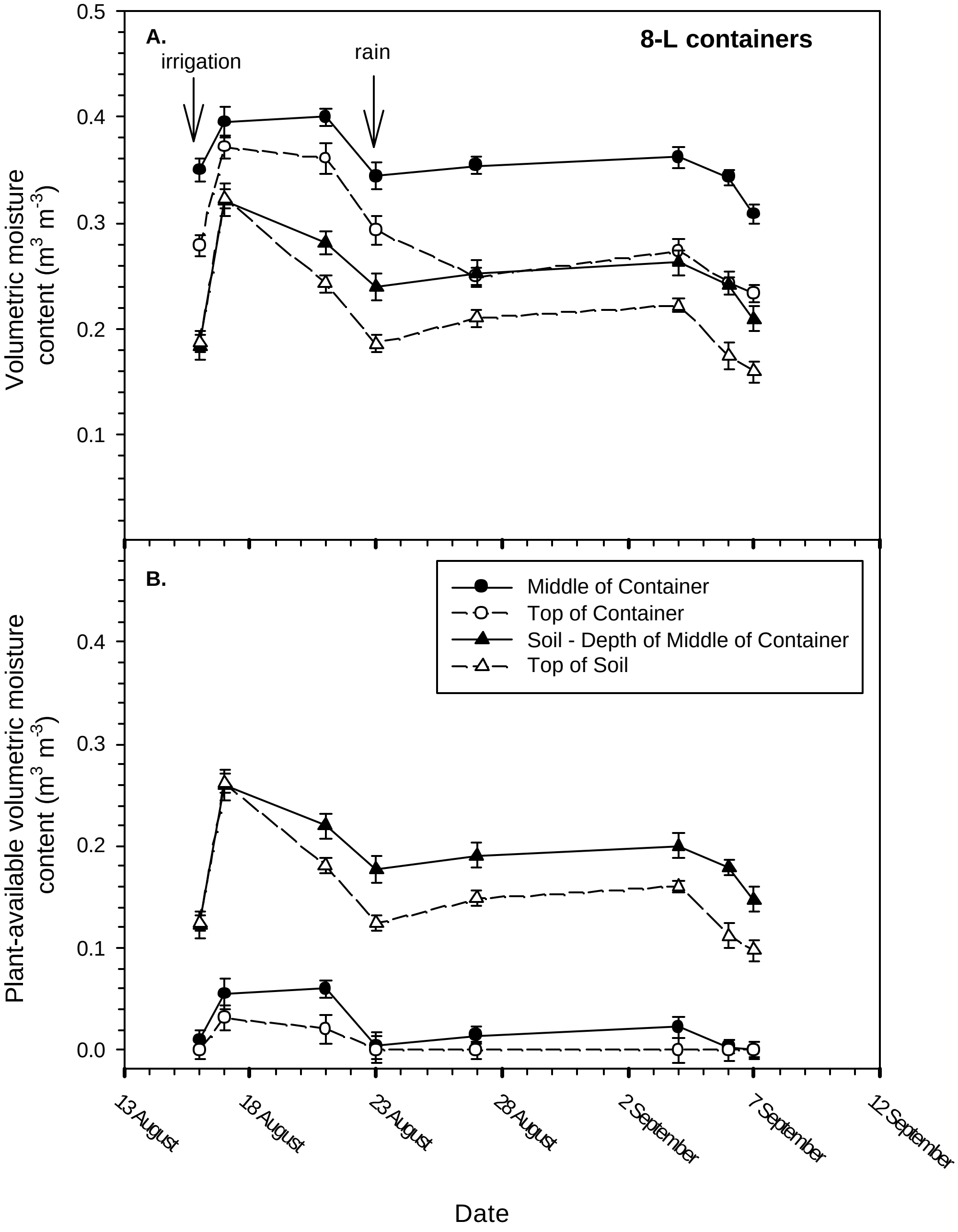

Figure 3. Volumetric water content of embedded 8-L container-sized pinebark mix vs. surrounding soil at depths of 6 cm (top) and 12.1 cm (middle). A.) TDR-measured volumetric water content, n=10. B.) Estimated plant-available volumetric water content determined by subtracting unavailable water (from pressure plate data) from data in (A), n=10.

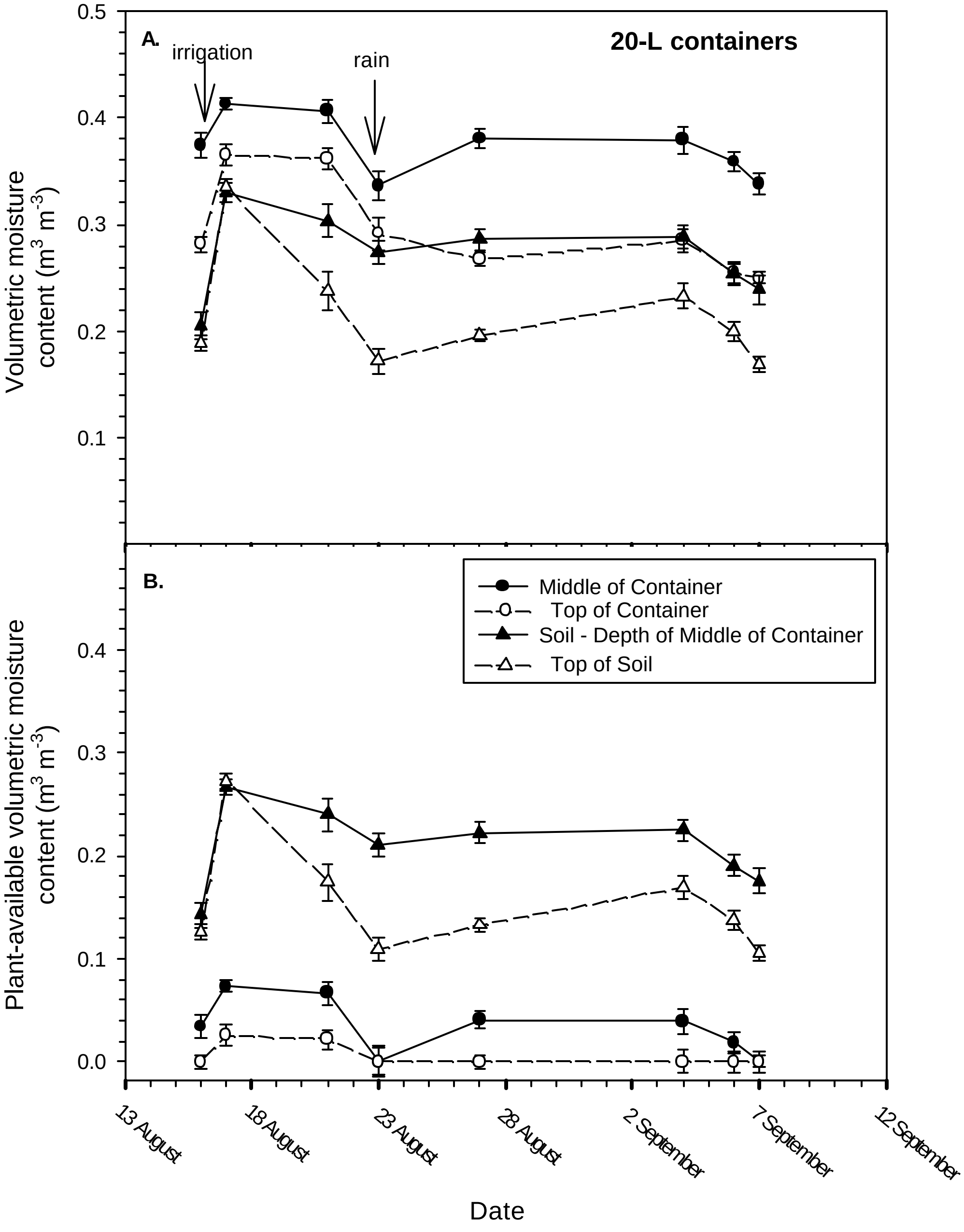

Figure 4. Volumetric water content of embedded 20-L container-sized pinebark mix vs. surrounding soil at depths of 6 cm (top) and 13.9 cm (middle). A.) TDR-measured volumetric water content, n=10. B.) Estimated plant-available volumetric water content determined by subtracting unavailable water (from pressure plate data) from data in (A), n=10.

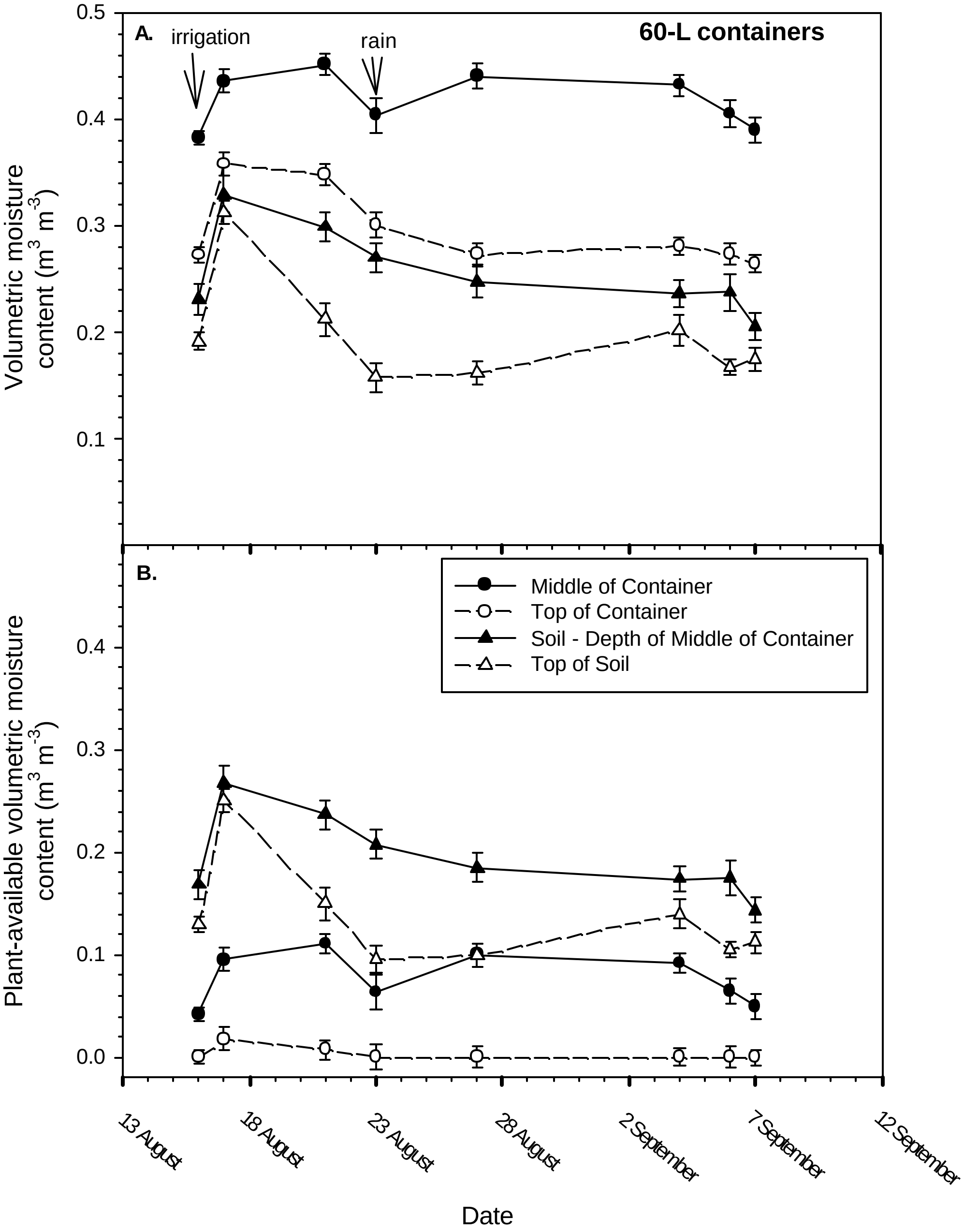

Figure 5. Volumetric water content of embedded 60-L container-sized pinebark mix vs. surrounding soil at depths of 6 cm (top) and 19.6 cm (middle). A.) TDR-measured volumetric water content, n=10. B.) Estimated plant-available volumetric water content determined by subtracting unavailable water (from pressure plate data) from data in (A), n=10.

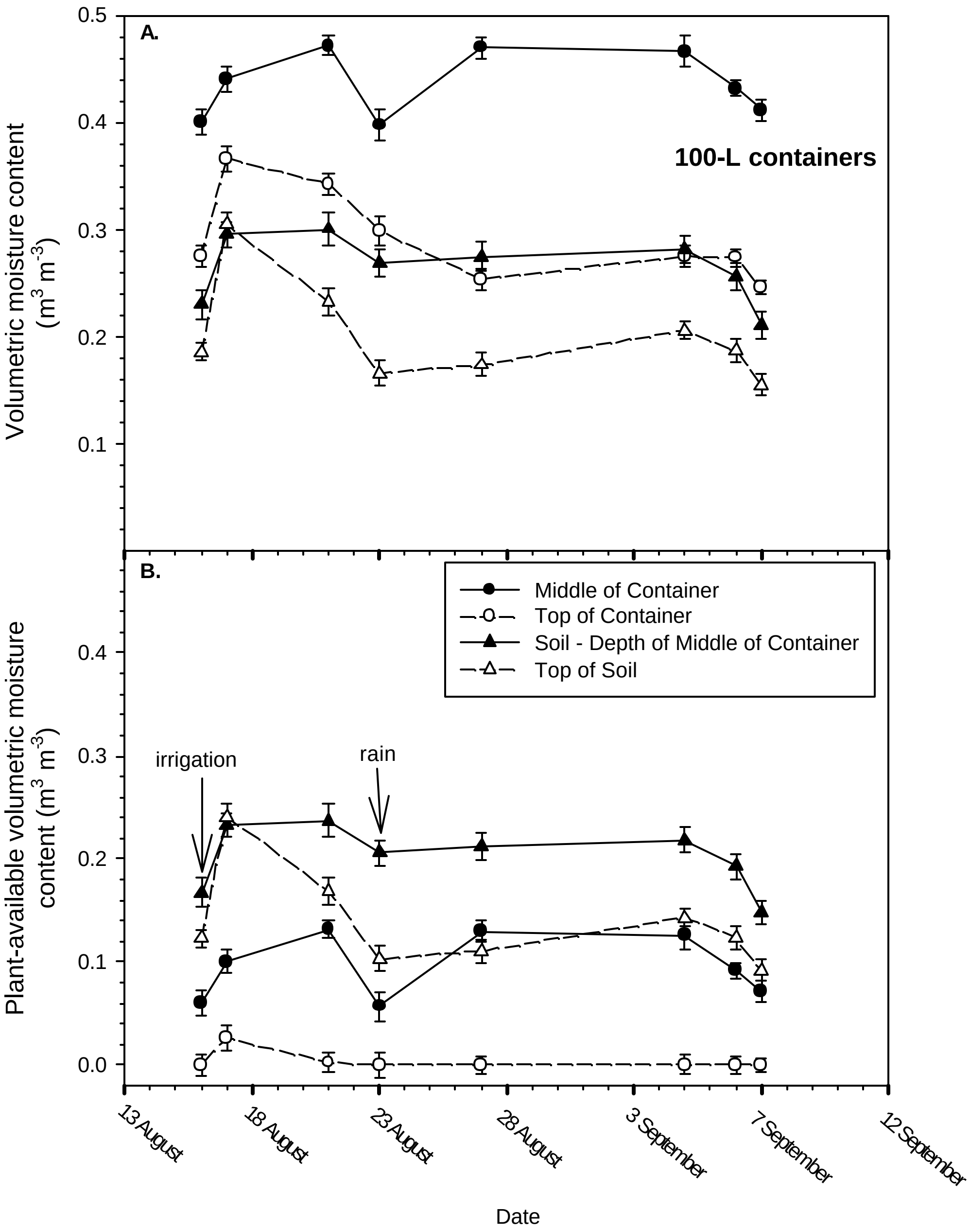

Figure 6. Volumetric water content of embedded 100-L container-sized pinebark mix vs. surrounding soil at depths of 6 cm (top) and 22.8 cm (middle). A.) TDR-measured volumetric water content, n=10. B.) Estimated plant-available volumetric water content determined by subtracting unavailable water (from pressure plate data) from data in (A), n=10.

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Chapter Four

Effects of Transplant Season and Container Size on Landscape Establishment of *Kalmia latifolia* L.

Abstract

Mountain laurel (*Kalmia latifolia* L.) is common in the eastern United States; however, this species is relatively difficult to establish in landscapes. Two experiments were conducted to test the effects of transplant season and container size on landscape establishment of *Kalmia latifolia* L. 'Olympic Wedding'. In experiment one, 7.6 and 19.0 liter container-grown plants were planted into a simulated landscape (Blacksburg, VA, USDA plant hardiness zone 6A) in the fall of 2000 or in the spring of 2001. Leaf xylem potential (Ψ), stem and leaf dry mass, canopy volume growth, leaf area, visual rating, and rootball moisture were measured. The 19-L plants had the lowest Ψ (more stressed) at the end of the growing season. Leaf dry mass was slightly higher for spring transplants than for fall transplants. Stem dry mass was similar for each size between seasons. Canopy volume increase was similar between seasons and sizes. Leaf area was higher for the spring transplants than fall transplants. The 19-L plants had a higher (better) visual rating. Experiment two was an aboveground rhizotron study, in which 19-L plants transplanted in fall 2000 or in spring 2001. Spring transplants in the rhizotrons had more canopy volume growth during the 2001-growing season. Fall transplants in the rhizotrons had longer roots than spring transplants, although very little root growth into the surrounding backfill occurred for any field-grown plant. Overall, our data suggest, that for the first post-transplant season, better visual ratings will be obtained by transplanting 19-L mountain laurel in the spring. However, fall transplanting may enhance transplant establishment.

Introduction

Mountain laurel has been touted as "the perfect shrub" for its beauty, extent of its range, and economic value to the nursery industry (Jaynes 1997). Mountain laurel is a broad-leaved evergreen shrub, sometimes reaching the stature of a small tree in the Blue Ridge Mountains in the Eastern U.S. Its native range is from Northern Florida to Maine, and can be found growing in various soil types and in a wide range of environmental conditions (Jaynes 1975). However, container-grown mountain laurel in pinebark substrate, commonly propagated by tissue culture, is relatively difficult to establish into the landscape, often resulting in death (Bir and Conner 1991).

Spring and fall are generally recognized as the two most beneficial times to transplant landscape plants, with fall being recommended for most plants (Koller 1977). Jaynes (1997) suggests that fall transplanting, approximately four weeks before the first frost, will result in better establishment for many species. For evergreen plants, fall transplanting has been recommended, because plants are potentially able to produce root growth in the fall or in the early spring, as the soil warms up (Koller 1977). Root-viewing chambers (rhizotrons) have been used (Harris and Bassuk 1994, Harris et al.

2002) to measure root periodicity. Harris et al. (2001) found that root growth of fall-transplanted Turkish hazelnut (*Corylus colurna* L.) into the backfill commenced about two weeks before budbreak in the spring, while spring transplants produced new roots shortly after being transplanted. When field-grown 4-year-old sugar maple (*Acer saccharum* Marsh. 'Green Mountain') and northern red oak (*Quercus rubra* L.) trees were transplanted into the field, fall-transplanted trees began root growth into the backfill earlier and produced more roots than the spring transplants (Harris et al. 2002). They concluded that fall transplanting is best for most deciduous trees.

Lauderdale et al. (1995) transplanted balled and burlapped 3.8-cm and 7.6-cm trunk diameter October Glory® red maples (*Acer rubrum* L.). Smaller plants had higher leaf conductance, water use efficiency, and shoot elongation, indicating less transplant stress than larger plants. They concluded that smaller plants can adjust to transplant shock quicker and are cheaper to replace. Wright et al. (2001) found that smaller (7.6-L) container-grown mountain laurel ('Olympic Wedding') had a better visual rating and a larger increase in growth compared to plants in 19-L containers. Death appeared imminent for larger plants, since second-season growth was low and visual ratings were poor. Their study focused not only on container size but exposure, with western-facing plants having a higher mortality rate. Mortality rate was also higher in the smallest plants (1-L), due to inadequate irrigation.

The objectives of this research were to 1) determine if transplanting a plant in a smaller container would improve first-season establishment compared to the traditional larger size and 2) determine if fall transplanting improved first-season establishment compared to traditional spring transplanting. Two experiments were conducted. Experiment one tested fall vs. spring transplanting with 7.6-L and 19-L container-grown mountain laurel. Experiment two was designed to measure seasonal root growth for rhizotron-grown plants.

Materials and Methods

Experiment One:

7.6 liter (#2) and 19 liter (#5) containers of *Kalmia latifolia* L. 'Olympic Wedding' (mountain laurel) were obtained from Historyland Nursery in Warsaw, VA. Twelve of each size were transplanted into Groseclose silt loam soil (clayey, mixed, mesic Typic Hapludults; pH = 6.2) on 6 October 2000, at the Virginia Tech Urban Horticulture Center in Blacksburg, VA (U.S. Dept. of Agriculture zone 6a). Twelve of each size were held in an unheated greenhouse structure covered with 0.15 mm-thick (6 mil) white polyethylene (typical for overwintering nursery stock in Virginia) until planting on 30 May 2001. The bed was tilled to a 20-cm depth prior to planting, and native soil was used as backfill. The tops of the rootballs were approximately 1 cm above the surface of the soil. Plants were transplanted into 2 rows, 1 meter between plants and rows. This was a completely random experimental design and consisted of four treatments with 12 replicates: (1) fall transplanted, 7.6-L (FS); (2) fall transplanted, 19-L (FL); (3) spring transplanted, 7.6-L (SS); (4) spring transplanted, 19-L (SL). The bed , including tops of rootballs, was mulched with a 5-cm thick layer of coarse hardwood mulch. Plants were hand-irrigated approximately every three days the first three weeks after transplanting and irrigated once a week starting in the spring with individual micro-emitters. Beginning canopy volume for each plant was calculated as the product of the height and width in two directions (in row and perpendicular) (Appendix C). One plant from each of the four treatments was randomly selected and destructively harvested on 27 October 2000. The base of the stem was severed at the rootball of each plant and stems and leaves were separated. Total leaf area was measured with a portable area meter (LI-3000, LI-COR, Lincoln, Neb.). Stems and leaves were dried to a constant weight at 70°C. The ratio of leaf area to leaf dry mass was used to calculate the leaf area of harvested plants in November 2001.

On 30 May 2001, all plants in the bed were fertilized with a slow-release fertilizer (18N-2.6P – 9.9K, Osmocote, The Scotts Co., Maryville, Ohio). FS and SS plants received 29 grams each and the FL and SL plants received 81grams each. The entire bed was mulched again with 5 cm of coarse hardwood mulch. Rootball volumetric moisture was taken periodically (30 May, 31 May, 11 June, 12 June, 2 July, and 3 July) during the growing season with a time domain reflectometry probe (TDR) (Theta Meter, Type HH1, Dynamax, Inc., Houston), inserted in the middle of the rootball. Rootball volumetric water content values have been corrected from the organic substrate setting on the TDR probe with a calibration with 100% pinebark (see Appendix B). The TDR probe uses microwave signals to measure the average volumetric water content from the top to the bottom of the metal probes (6 cm) and the substrate surrounding the probes (Anisko et al. 1994). Leaf water potential (Ψ) was measured with a Scholander pressure chamber (Soil Moisture Equipment Corporation, Santa Barbara, Calif.) for three, 12-hour periods, spaced a week apart, during the beginning of September 2001. For a 12-hour period, plants were measured at 2-hour intervals, from 700 to 1900 hours. Leaves from the southwest facing side of the plant, midway in the plant canopy height, were cut at the base of the petiole with a razor blade. Three plants from each treatment were randomly selected for each date. Two leaves from each plant were selected and the results averaged as Ψ for that replicate.

On 6 November 2001, all plants were rated with a visual rating index (VRI), consisting of leaf color, proportion of leaf spot, and fullness of canopy. For the VRI, each of the three categories consisted of a scale from 1- 5, with 1 representing a plant that is chlorotic, has a high proportion of leaf spot, and has a sparse canopy, respectively. A 5 represents a plant that has dark green leaves, a low incidence of leaf spot and a full canopy. Four observers rated each plant for the three categories. A composite VRI for each plant was calculated to be the mean of the VRI for each of the three categories and averaged over the four observations. Six plants were randomly selected from each treatment and these 24 plants were measured for canopy volume as described previously. These plants were then excavated and the water status of the root ball and adjacent soil (within 21 cm of the original rootball) were measured using a TDR probe calibrated to the 100% pinebark substrate for rootball measurements (see Appendix B). Root growth was observed in the harvested rootballs. Each plant was severed at the top of the rootball and stems and leaves were separated. The dry weights of stems and leaves, and the leaf area of a sub-sample from each treatment were measured. Leaf area measurements consisted of fifty randomly selected leaves per treatment. Total leaf area was calculated as described above.

Data were subjected to analysis of variance with the GLM procedure of SAS (SAS, version 8.02, SAS Institute, Cary, NC). Xylem potential data for 8 September was graphed to illustrate treatment differences.

Experiment Two:

On 6 October 2000, four, 19-L mountain laurel (described above) were transplanted into four aboveground rhizotrons at the Urban Horticulture Center in Blacksburg, VA. Rhizotrons were constructed from Keeper-Uppers (KU) (Lerio Corp., Kissimmee, FL), measuring 53-cm length x 54-cm width x 38-cm height), with the top opening at 43-cm diameter. Plastic bubble insulation (Reflectix Insulation, Reflectix Inc., Markleville, IN) was wrapped around the rhizotrons, maintaining a comparable temperature with the soil in the bed (data not shown). A 5-cm thick piece of plastic foam covered each of the plates, and was held in place by two stretch cords. Four additional plants were stored as described in experiment one and planted into rhizotrons on 30 May 2001. Rhizotrons were in a single row, spaced approximately 1 meter on center. This was a completely random experimental design, with four replicates of two treatments: fall transplanted (F), and spring transplanted (S). Rootballs were oriented at an angle parallel to the polycarbonate viewing plate, approximately 2-cm from the surface of the plate and 100% pinebark substrate was used as the rhizotron substrate. Coarse hardwood mulch was applied in a 5-cm layer over the rootball surface. All plants were hand-irrigated on alternate days for three weeks after transplanting. A micro-emitter irrigation system was installed in mid May 2001. Plants were irrigated twice weekly, with approximately 19 liters of water per irrigation. Canopy volume of the four plants (described in Experiment One) was measured at the time of transplanting.

On 30 May 2001, the remaining four plants (overwintered and irrigated in a polyhouse at the Urban Horticulture Center) were transplanted into the last four rhizotrons. All eight plants were fertilized with 81 grams of slow-release fertilizer (18N-2.6P-9.9K, Osmocote, The Scotts Co., Maryville, Ohio). Newly transplanted plants were hand-irrigated for a week and then put on the same irrigation system as stated above. Canopy volume of fall and spring transplants was taken at this time. Each rhizotron was checked periodically for the presence of new root growth.

On 6 November 2001, rhizotrons were removed and the pinebark was gently removed from each rootball. Since the pinebark was coarse, roots extremely fine, and rootball intact, new root growth was easily recognizable. Roots from the plate side of the rootball were gently stretched and the longest roots were grouped together and the length measured. Four measurements were taken per plant. The longest measurement was excluded and the remaining three were averaged together to be the maximum root extension for that plant.

Data were subjected to analysis of variance with the GLM procedure of SAS and mean separations was by Fisher's protected LSD (P=0.05).

Results and Discussion

Experiment One

Growing Season Rootball Moisture:
On 30 May, rootballs of 7.6-L plants contained more water than rootballs of 19-L plants (Table 1A). There were no moisture content differences with seasons and no interactions. On 31 May, 7.6-L rootballs contained a higher volumetric water content overall compared to 19-L rootballs. However, there was an interaction with season and size, with 7.6-L rootballs decreasing in water content from fall to spring and 19-L rootballs increasing in water content from fall to spring. The remaining dates of 11 June, 12 June, 2 July, and 3 July (Table 1B and C), showed 7.6-L rootballs contained more water than 19-L plants. The rootballs of 7.6-L plants contained more water during the beginning of the growing season. A higher rootball volumetric moisture content indicates less severe transplant shock (Watson 1985).

Leaf Xylem Potential:
There were no differences in mean leaf xylem potential between seasons or sizes measured on 25 August and 2 September (Table 2). On 8 September, 19-L plants had a lower potential (more negative), indicating more tissue stress (Table 2, Figure 1). Over the 12-hour measurement period (Figure 1), differences in tissue stress became apparent, with 19-L plants having a lower Ψ than 7.6-L plants, indicating more tissue stress for the 19-L plants. Our results are similar to results reported by Lauderdale et al. (1995) where smaller *Acer rubrum* L. were able to overcome transplant shock sooner than larger trees. Beeson (1994) studied the internal water stress of *Quercus virginiana* Mill. branches and found that newly transplanted trees had larger dusk to pre-dawn Ψ differences than field-grown and transplanted but established trees, due to little root growth beyond the rootball. The Ψ values stabilized as establishment of root growth progressed. Internal water stress will occur if transpiration is greater than absorption (Kozlowski and Davies 1975) due to an unbalanced root/shoot ratio.

The rootball surface area to rootball volume ratio of our mountain laurel in November 2000 was determined to be 0.23 and 0.18 for 7.6-L and 19-L plants, respectively (Appendix C). This higher rootball:soil interface area per unit rootball volume for 7.6-L plants should favor root growth into backfill soil and a higher leaf xylem potential (less negative) for the 7.6-L mountain laurel. A relatively higher ratio represents an efficient use of water by the root system, which increases establishment and survival of the plant (Kozlowski and Davies 1975). Leaf area index (LAI) (total leaf area divided by the product of two perpendicular canopy widths) values for 7.6-L plants and 19-L plants were 1.31 and 3.18, respectively (Appendix C). 7.6-L plants had lower individual values for total leaf area (1863.03 cm^2) and canopy leaf shadow (1418.63 cm^2) than 19-L plants (7543.59 cm^2 and 2375.83 cm^2, respectively). Larger plants had a much greater difference (5168 cm^2) between leaf area and leaf shadow, compared to smaller plants (445 cm^2). This indicates a denser canopy with larger leaves for the larger plants. The rootball volume to leaf surface area ratio was 4.76 and 2.27 for 7.6-L and 19-L plants, respectively (Appendix C). The potential for better establishment exists for the smaller plants due to a relatively larger rootball volume to canopy volume ratio. Even though the 7.6-L plants had a smaller canopy with smaller leaves than 19-L plants, potential exists for these plants to reach the same size as a 19-L plant transplanted at the same time within a few years (Watson 1985). However, others have found that larger trees had higher mortality, but of those that survived, establishment was faster than smaller trees (Struve et al. 2000).

Canopy Growth:

There were no differences in canopy growth from May 2001 to November 2001 between sizes or seasons (Table 3). Given that this experiment spanned only one growing season and mountain laurel is a slow-growing plant, second season data would be helpful in determining treatment differences. In an exposure study on mountain laurel, smaller plants had more shoot growth than 19-L plants for a two-year period (Wright et al. 2001). Hummel et al. (1990) did not see any improvement in root or shoot growth in response to soil amendments for three mountain laurel cultivars. For trees, Lauderdale et al. (1995) found that smaller *Acer rubrum L.* produced four times the shoot elongation and established faster than larger specimens. Also, Watson (1985) hypothesized that smaller trees had the ability to surpass larger trees in size when planted at the same time, although Struve et al. (2000) did not find this to always be true (see discussion above). If the canopy and rootball size are unbalanced, transplant shock is more severe. In terms of seasonal transplanting, fall-transplanted *Chionanthus viginicus* L. produced larger canopies than trees planted in winter and early spring (Harris et al. 1996).

Visual Rating Index:

At the end of the first growing season, 19-L plants had the highest visual rating index, with a fuller canopy, darker leaves, and less occurrence of leaf spot than 7.6-L plants (Table 4). No differences were detected between seasons. Visual rating of container-grown mountain laurel in Raleigh, NC (USDA plant hardiness zone 7), compared to Blacksburg, VA (USDA plant hardiness zone 6A), however, showed that 7.6-L plants looked better than 19-L plants after two growing seasons (Wright et al. 2001). Jaynes (1988) found that mountain laurel grown in pinebark-amended backfill produced better leaf color, while others did not have these results (Hummel et al. 1990). Since our study only focused on one growing season and our data confirm that mountain laurel is slow to establish, data from a second and third year after transplanting would be necessary to fully evaluate the effect of transplant size on visual ratings.

Harvested Rootball vs. Surrounding Soil Volumetric Moisture:

There were no rootball volumetric water content differences between seasons or container sizes on 6 November 2001 (Table 5). However, the soil surrounding the fall-transplanted plants had a higher water content than the soil around spring-transplanted plants, possibly due to soil settling around the fall transplants, decreasing macropores and increasing water retention. The rootballs were clearly drier than the surrounding soil (visual observation), which is understandable since we did not find any roots extending into the backfill, indicating that plants were only withdrawing water from rootballs. Water is only available to the plant within the rootball, unless roots start to extend past the rootball (Harris et al. 1996). Irrigation directly on the rootballs during the first growing season will be necessary for mountain laurel establishment.

Root Growth:

No root growth for the harvested plants was observed beyond the original rootball into the surrounding soil, but new root tips were found within the rootball center itself (visual observation). The abundance of roots within the rootball and not into the backfill indicates that roots were not able to access water within the backfill. Gouin (1983) found that "butterflying" the rootball, spreading the rootball open and making cuts on the surface of the rootball, could prevent girdling of the roots. Blessing and Dana (1987), however, concluded that disrupting the rootball of container-grown plants before transplanting had no effect on new root dry weight of *Juniperus chinensis* L. in the first season. In our study, we used native silt loam soil as the backfill, with a top layer of hardwood mulch. No soil amendments were added to the backfill, which could explain the lack of root growth beyond the rootball-backfill interface. Soil amendments can play an integral role in root growth. Ingram and van de Werken (1978) found that *Ilex crenata* Thunb. 'Green Luster' roots grew just along the rootball-soil interface in unamended field soil. In the amended backfills, including combinations of peat, perlite, sand, pinebark, and native soil, they found root growth beyond the rootball, into the backfill. Corley (1984), however, found that amending the backfill around four woody nursery crops did not affect top and root growth. Similar results were found with *Liquidambar styraciflua* L. transplanted into combinations of soil amendments (Hummel and Johnson 1985). *Kalmia latifolia* L. 'Ostbo Red' showed variable, but not different, growth when transplanted into combinations of pinebark and peat amendments (Bir and Ranney 1991).

Leaf and Stem Dry Mass, Leaf Area:

Leaf dry mass of spring transplants was greater than fall transplants ($P = 0.0582$) in November 2001 (Table 6). Stem dry mass was similar between fall and spring transplant dates ($P = 0.4468$), but were different between sizes, with 19-L plants having a higher leaf and stem dry mass than 7.6-L plants ($P < 0.0001$). For leaf area, an interaction between season and size was present, with the effect of season more pronounced for 19-L plants. Harris et al. (1996) found that November-transplanted *Chionanthus virginicus* L. had higher leaf area than for those trees planted in December and March.

Experiment Two

Root Growth and Canopy Volume Growth:

Root extension for fall-transplanted mountain laurel was first observed in mid-April in the rhizotrons, approximately six weeks before spring transplants were planted. Root extension for spring transplants was first noticed 3 weeks after transplanting. Others have also found that fall-transplanted plants do not begin root extension into backfill until early the following spring (Harris et al. 2001, 2002). Harris and Bassuk (1994) working with four species of in-ground rhizotron trees, concluded that root growth into the backfill immediately before bare-root transplanting does not necessarily result in improved establishment.

Fall transplants had longer roots beyond the original rootball than spring transplants as measured in November 2001, while spring transplants produced more canopy volume growth over the 2001-growing season (Table 7). Canopy volume growth for spring transplants was approximately five times greater than that for fall transplants. The combination of a smaller canopy and more root growth should favor establishment, especially when irrigation is inadequate.

Conclusions

In the field experiment, both sizes had similar canopy growth. In the rhizotron study with only the large size, spring transplants had the largest canopy growth after one growing season. In the field experiment, very few roots of any treatment extended into the backfill. However, in the rhizotron experiment, fall transplants had longer root extension into the backfill than spring transplants, suggesting that fall-transplanted mountain laurel in field soil has the potential for faster first-season establishment. Backfill composition possibly played a role, since pinebark was used both as a container substrate and for backfill in the rhizotron experiment but native soil was used for backfill in the field experiment. However, in terms of customer appeal, spring-transplanted mountain laurel had increased growth, more profuse flowering, less leaf spot, and absence of winter burn.

The 7.6-L plants had a larger rootball surface area/ rootball volume ratio relative to 19-L plants, suggesting that more roots of the 7.6-L plants had close contact with the backfill and therefore a greater potential for extension beyond the rootball. Smaller plants also had double the rootball volume to leaf surface area ratio, suggesting that a given volume of rootball water (the supply) had to support a smaller demand. For the 19-L plants, more leaves per unit rootball volume should equal more stress. Compared to 7.6-L rootballs, 19-L rootballs in fact contained lower volumetric water content during the growing season and had more internal leaf stress (lower Ψ) at the end of the season; yet, related visual stress symptoms were not apparent. In contrast, Wright et al. (2001) found that 19-L containers of transplanted mountain laurel exhibited greater visual symptoms of stress than 7.6-L plants, possibly due to the effect of a warmer climate and a more stressful exposure. In Raleigh, North Carolina, where the USDA plant hardiness zone is 7, the increased stress was probably enough to produce visual stress for the larger plants.

Second growing season data will prove useful in clearly determining when mountain laurel should be transplanted and what size establishes better in this area. Climate-specific recommendations might be necessary for mountain laurel cultivars.

Table 1. Effects of transplant season and container size on volumetric moisture content of mountain laurel rootballs measured by TDR probe during the 2001-growing season.

A.

Container size (L)	**Season**	**Volumetric moisture content (m^3 m^{-3})**	
		May 30	**May 31**
7.6	Fall	0.371 (0.008)[z]	0.353 (0.008)
7.6	Spring	0.395 (0.006)	0.339 (0.007)
19	Fall	0.350 (0.008)	0.285 (0.009)
19	Spring	0.354 (0.008)	0.308 (0.007)
		P > F	
Season		0.072	0.62
Size		0.0001	<0.0001
Season*Size		0.199	0.021

B.

Container size (L)	**Season**	**Volumetric moisture content (m^3 m^{-3})**	
		June 11	**June 12**
7.6	Fall	0.341 (0.012)	0.315 (0.011)
7.6	Spring	0.340 (0.011)	0.299 (0.014)
19	Fall	0.290 (0.011)	0.246 (0.009)
19	Spring	0.295 (0.012)	0.245 (0.012)
		P > F	
Season		0.86	0.46
Size		0.0002	<0.0001
Season*Size		0.82	0.53

C.

Container size (L)	**Season**	**Volumetric moisture content (m^3 m^{-3})**	
		July 2	**July 3**
7.6	Fall	0.322 (0.013)	0.293 (0.015)
7.6	Spring	0.311 (0.016)	0.290 (0.014)
19	Fall	0.290 (0.017)	0.249 (0.014)
19	Spring	0.253 (0.013)	0.220 (0.010)
		P > F	
Season		0.11	0.25
Size		0.0039	0.0002
Season*Size		0.36	0.38

[z] Numbers in parentheses represent the standard error of the mean. n=11.

Table 2. Effects of transplant season and container size on daily mean leaf xylem potential of mountain laurel.

Container size (L)	**Season**	**Leaf xylem potential (MPa)**		
		25 Aug.	**2 Sept.**	**8 Sept.**
7.6	Fall	-0.68 (0.06)	-0.60 (0.05)	-0.86 (0.07)
7.6	Spring	-0.76 (0.06)	-0.73 (0.19)	-0.79 (0.06)
19	Fall	-0.77 (0.05)	-0.58 (0.05)	-1.01 (0.07)
19	Spring	-0.76 (0.06)	-0.63 (0.05)	-1.05 (0.07)
			P > F	
Season		0.5419	0.3811	0.8532
Size		0.4645	0.5680	0.0027
Season*Size		0.4544	0.7071	0.4306

Numbers in parentheses represent the standard error of the mean. n=42.

Table 3. Effects of transplant season and container size on canopy growth of mountain laurel during the 2001-growing season.

Container size (L)	**Season**	**Canopy growth (cm^3)**
7.6	Fall	27037 (10284)
7.6	Spring	38381 (10890)
19	Fall	49071 (20045)
19	Spring	42749 (19165)
		P > F
Season		0.8742
Size		0.4072
Season*Size		0.5783

Numbers in parentheses represent the standard error of the mean. n=12.

Table 4. Effects of transplant season and container size on the Visual Index Rating at harvest (Fall 2001) of mountain laurel.

Container size (L)	**Season**	**Visual index rating**^{z}
7.6	Fall	2.95 (0.170)
7.6	Spring	3.21 (0.149)
19	Fall	3.92 (0.092)
19	Spring	3.76 (0.170)
		P > F
Season		0.7183
Size		<0.0001
Season*Size		0.1617

^{z} The visual rating index (VRI) consisted of a scale from 1- 5, with 1 representing a plant that is chlorotic, has a high proportion of leaf spot, and has a sparse canopy, respectively. A 5 represents a plant that has dark green leaves, a low incidence of leaf spot and a full canopy. Four observers rated each plant for the three categories. A composite VRI for each plant was calculated to be the mean of the VRI for each of the three categories and averaged over the four observations.

Numbers in parentheses represent the standard error of the mean. n=11.

Table 5. Harvest (November 2001) volumetric moisture content of mountain laurel rootballs vs. the surrounding soil measured with a TDR probe.

Size (L)	**Season**	**Volumetric Rootball Moisture ($m^3\ m^{-3}$)[z]**	**Volumetric Soil Moisture ($m^3\ m^{-3}$)**
7.6	Fall	0.227 (0.0063)	0.306 (0.0441)a[y]
7.6	Spring	0.226 (0.0021)	0.169 (0.0236)b
19	Fall	0.232 (0.0046)	0.265 (0.0290)a
19	Spring	0.229 (0.0044)	0.167 (0.0320)b
		P > F	
Season		0.7476	0.0020
Size		0.3572	0.5241
Season*Size		0.8580	0.5599

[z] Individual measurements corrected with an instrument calibration = .1748 + .5269*(measurement).

[y] Means followed by the same letter within columns are not significantly different by Fisher’s LSD ($P \leq 0.05$), n=12.

Numbers in parentheses represent the standard error of the mean.

Table 6. Effects of transplant season and container size on leaf and stem dry mass and leaf area of mountain laurel measured in November 2001.

Container size (L)	Season	Leaf dry mass (g)	Stem dry mass (g)	Leaf area (cm^2)[z]
7.6	Fall	60.78 (4.25)	87.53 (5.82)	2867.14 (200.6) a
7.6	Spring	76.40 (7.14)	84.47 (6.29)	3278.97 (306.31) a
19	Fall	162.65 (10.89)	260.65 (12.78)	6328.79 (423.55) b
19	Spring	185.98 (13.72)	280.88 (15.90)	8772.80 (647.06) a
			P > F	
Season		0.0582	0.4468	0.0033
Size		<.0001	<.0001	<.0001
Season*Size		0.6948	0.3048	0.0277

Means tested with Fisher's LSD. $P \leq 0.05$, $n = 6$, unless otherwise noted.

Numbers in parentheses represent the standard error of the mean.

[z] Letters denote effect of season within size. P=0.5039 for 7.6-L plants and 0.006 for 19-L plants.

Table 7. Effects of transplant season on average root length and canopy growth for the 2001-growing season for mountain laurel in rhizotrons.

Season	**Average root length (cm)**[z]	**Canopy growth (cm^3)**
Fall	13.8 (0.84) a[y]	15276 (8970) b
Spring	9.2 (1.02) b	77151 (21296) a
	P > F	
Season	0.0019	0.0367

[z] Measured on 6 November 2001.

[y] Means followed by the same letter within columns are not significantly different by Fisher's LSD ($P \leq 0.05$), n=12.

Numbers in parentheses represent the standard error of the mean.

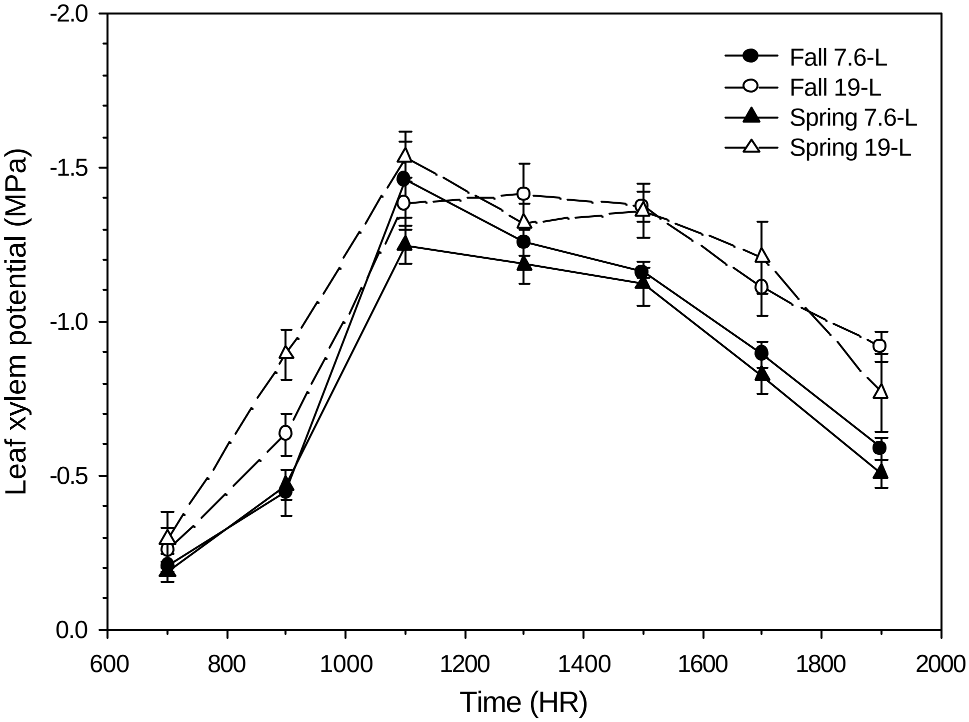

Figure 1. The leaf xylem potential (Ψ) on 8 September of mountain laurel. Each point represents a mean of six values (three randomly selected mountain laurel plants per treatment, and 2 subsamples per plant), with standard error bars present for each point.

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Chapter Five

Summary

Mountain laurel has proved difficult to establish in the landscape. Our research suggests that this is probably due to a lack of root growth into the backfill soil during the first post-transplant season. The fact that roots of mountain laurel transplanted into pinebark (Chapter 4, experiment two) grew into the backfill, whereas those that were planted into field soil (Chapter 4, experiment one) did not, suggests that organic backfill amendments may be beneficial. However, studies are inconclusive concerning whether or not to amend the soil. Plants that have shown increased growth and vigor from backfill soil amendments include: *Ilex crenata* (Ingram and van de Werken 1978); *Viburnum plicatum* var. *tomentosum* 'Mariesii' (Wood et al. 1994). Soil amendments had no effect on *Lonicera korolkowi zabeli* and *Syringa chinensis* (Pellet 1971); *Ilex crenata* 'Helleri,' *Cornus florida*, *Rhododendron obtusum* 'Hinodegiri,' *Juniperus conferta* (Corley 1984), and most importantly, *Kalmia latifolia* L. 'Ostbo Red' (Birr and Ranney 1991).

In our first experiment (Chapter 3), the pinebark mix (similar to a common nursery container substrate) provided little available water when embedded into field soil in most cases compared to the silt loam field soil, especially for smaller container sizes. The 20-L volume of embedded pinebark substrate had more plant-available water in the middle depth than the 8-L volume at the same depth. However, during the growing season, the smaller mountain laurel rootballs (Chapter 4, experiment one) contained a higher volumetric water content than the larger mountain laurel, due to the inbalance of the rootball volume to leaf area ratio for the larger plants. For a transplanted shrub, root growth would eventually occur outside of the rootball, where more available water is present. However, we found no root growth into the surrounding backfill soil (Chapter 4, experiment one) after one growing season, so very little water was available to these plants. Roots must grow beyond the rootball if plants are to be relieved of moisture stress. Costello and Paul (1975) concluded that the rootballs of transplanted plants must rely on the soil to move water to the rootball, since they found transplanted sweet gum trees did not produce roots into the loam backfill. However, unsaturated, lateral water flow from the finer textured soil would be minimal (Hillel 1982). Research with backfill amendments may indicate more favorable conditions for establishment, allowing mountain laurel transplanted to landscapes in the fall to have more root growth compared to spring-transplanted plants, as shown in the rhizotron experiment (Chapter 4, experiment two).

The effect of plant (container) size is probably dependent upon climate. Rootballs and plants themselves were drier for the larger plants, although the stresses were apparently not great enough to result in lower visual ratings. Hotter climates such as in Tidewater Virginia or Piedmont North Carolina may actually favor the smaller sizes, as was apparent in the study by Wright et al. (2001). Of course, different results may occur if soil amendments prove to be the key to root growth into the backfill. Finally, our plants were transplanted into full sun. Winter burn was prominent on fall transplants, as observed during the 2000-2001-winter season (visual observation – no data). Some winter protection is probably warranted to increase customer satisfaction for fall transplants.

My original hypothesis was that smaller plants, planted in the fall would transplant most successfully. Since neither size grew roots into the backfill soil in the field experiment in Chapter 4, I am unable to say which size transplants most successfully. However, the 19-L plants had higher visual ratings. As roots grow into the backfill these ratings may change. Although spring-transplanted plants in the field experiment in Chapter 4 had more favorable visual ratings and denser canopies, the combination of less canopy growth and longer root extension of fall transplants in the rhizotrons indicates that fall transplanting will be preferable for establishment if methods can be discovered to promote first-season root growth of mountain laurel planted into field soil.

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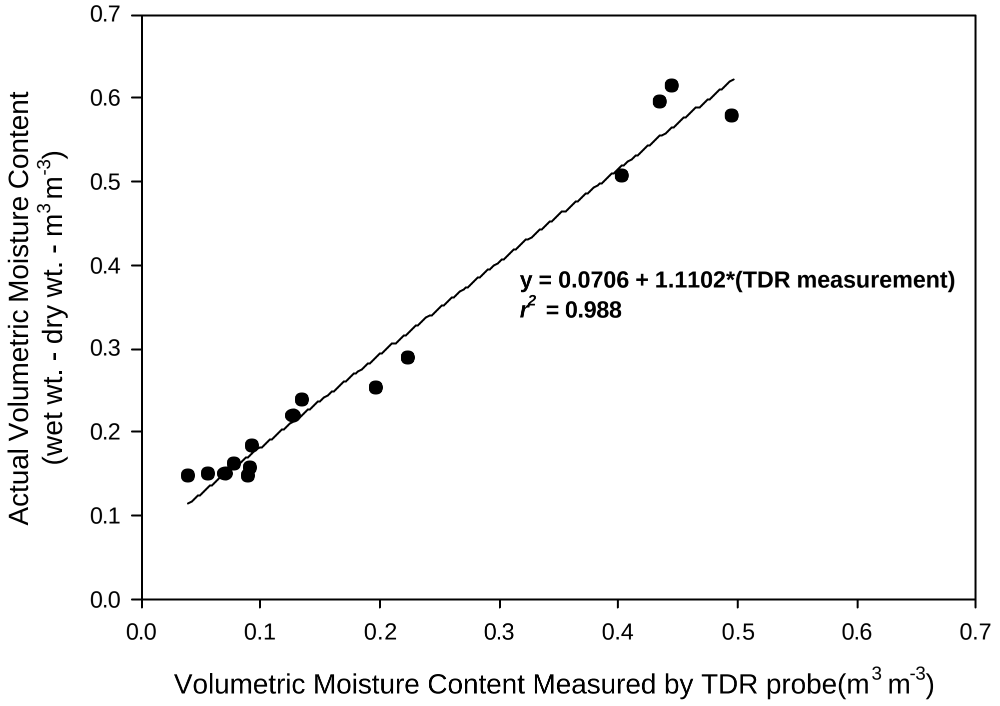
Appendix A

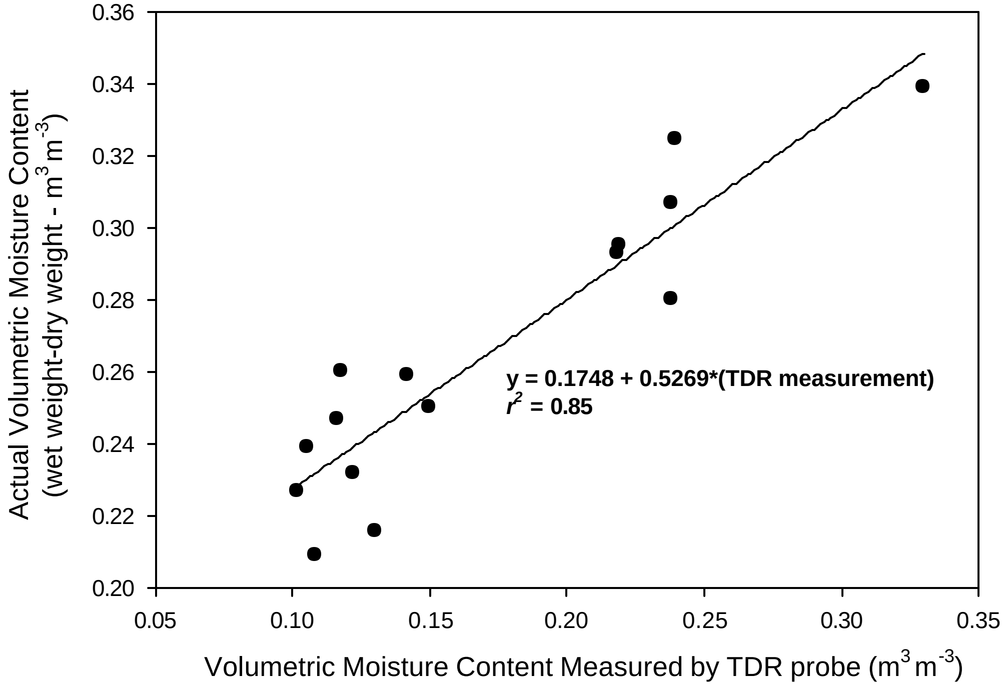
TDR probe Calibration with Pinebark Mix



Hollow PVC pipe (10 cm long, 5 cm diameter) was covered on one end with four layers of heavy cheesecloth, attached with rubber bands, and filled with media. Pipes were placed in a mesh tray to allow for drainage.

Appendix B

TDR probe Calibration with 100% Pinebark



See Appendix A for materials and methods.

Appendix C

Area and volume calculations of rootballs and leaves of 7.6-L and 19-L containers of mountain laurel

Rootball surface area = $2p(r)(h) + p(r)^2$

7.6-L: $2\pi(10.88)(23.5) + \pi(10.88)^2 = 1978.36\ cm^2$
19-L: $2\pi(14.0)(28.0) + \pi(14.0)^2 = 3078.75\ cm^2$

Rootball volume = $p\,r^2h$

7.6-L: $\pi(10.88)^2(23.5) = 8739.28\ cm^3$
19-L: $\pi(14.0)^2(28.0) = 17241.06\ cm^3$

Rootball surface area/ rootball volume:

7.6-L = 1978.36/ 8739.28 = 0.23
19-L = 3078.75/ 17241.06 = 0.18

Leaf area (measured with Licor leaf area meter):

7.6-L = 1863.03 cm^2
19-L = 7543.59 cm^2

Average canopy diameter = [(width one) + (width two)]/ 2

7.6-L = [(42.0) + (43.0)]/ 2 = 42.5 cm
19-L = [(60.0) + (50.0)]/ 2 = 55.0 cm

Canopy radius = (average canopy diameter)/ 2

7.6-L = 42.5/ 2 = 21.15 cm
19-L = 55.0/ 2 = 27.5 cm

Leaf shadow = $p\,r^2$

7.6-L = $\pi(21.25)^2 = 1418.63\ cm^2$
19-L = $\pi(27.5)^2 = 2375.83\ cm^2$

Leaf Area Index (LAI) = leaf area/ leaf shadow:

7.6-L = 1863.03/ 1418.63 = 1.31
19-L = 7543.59/ 2375.83 = 3.18

Rootball volume/ leaf area:

7.6-L = 8739.28/ 1863.03 = 4.76
19-L = 17241.06/ 7543.59 = 2.27

Vita

Anne-Marie Hanson

Anne-Marie Hanson was born on August 17, 1976 in Lynchburg, VA. She went to E.C. Glass High School and graduated in the top 10% of her class in 1994. She went on to James Madison University for her undergraduate degree in Biology, with a concentration in Botany. She worked in the Edith J. Carrier Arboretum on the campus of JMU, where she gained an appreciation for public gardens. After graduating Cum Laude in 1998, she moved to the rolling hills of Orange County, VA, where she interned in the gardens at Montpelier, the home of President James Madison. After a summer of caring for an historic garden, she moved to Northern Virginia for a change of pace. She started a garden maintenance internship in D.C. at the Smithsonian Institute in the fall of 1998. She rotated between the gardens surrounding the museums and learned what public gardening within a big city entails. She also had an opportunity to teach a children's horticulture class, which sparked an interest for teaching. To expand her base of horticultural knowledge, Anne-Marie interned at a small mail-order nursery in Pennsylvania for the summer of 1999. After three months of backbreaking work, she had experienced all the nursery had to offer and decided to move on and save up some money for graduate school. She began her Master's in Horticulture at Virginia Tech in the fall of 2000 and will finish in May 2002. She will start an education internship at the Holden Arboretum in Kirtland, Ohio at the end of May 2002. Her career goals are to pursue education within a public garden.