POST-TRANSPLANT IRRIGATION SCHEDULING OF

NATIVE DECIDUOUS SHRUB TAXA

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POST-TRANSPLANT IRRIGATION SCHEDULING OF NATIVE DECIDUOUS SHRUB TAXA

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POST-TRANSPLANT IRRIGATION SCHEDULING OF

NATIVE DECIDUOUS SHRUBTAXA

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Date of Graduation

VITA

Abby Lee Bailey, daughter of Frank and Vicky Bailey, was born March 2, 1985 in Gadsden, Alabama. She has one sister, Anna Claire. She graduated from Gadsden High School in May, 2003. In August she began her education at Auburn University where she graduated with a Bachelors of Science in horticulture and a minor in business in August, 2007. After graduation she entered graduate school at Auburn University to pursue a Master of Science degree in horticulture under the direction and guidance of the one and only Dr. Amy Noelle Wright. She received her Master of Science degree in horticulture on December 18, 2009.

THESIS ABSTRACT

POST-TRANSPLANT IRRIGATION FREQUENCY OF

NATIVE DECIDUOUS SHRUB TAXA

Abby Lee Bailey

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The effect of irrigation scheduling treatments on root and shoot growth and photosynthesis of *Hydrangea quercifolia* Bart. ‘Alice’ (‘Alice’ oakleaf hydrangea), *Rhododendron austrinum* Rehd. (florida flame azalea), and *Itea virginica* L. ‘Henry’s Garnet’ (‘Henry’s Garnet’ sweetspire) was evaluated using Horhizotrons in a greenhouse in Auburn, Ala. Irrigation frequency treatments included: backfill and root ball maintained at or above 20% moisture (well watered, WW); backfill and root ball re-watered when root ball moisture reached 10% (10RB); backfill and root ball re-watered when quadrant soil moisture reached 15% (15S). For all three species horizontal root length (HRL) increased linearly over time for all treatments. Overall, 10RB plants exhibited the longest

HRL followed by plants in WW and 15S treatments. Shoot growth index (GI) and photosynthetic rates (Ps) were similar among treatments for *H. quecifolia* 'Alice' and *R. austrinum.* GI for *I. virginica* 'Henry's Garnet' in general was highest in WW and 10RB followed by 15S. Dry weight of roots in soil was similar among all three treatments for *H. quecifolia* 'Alice', and was higher in WW and 10RB than 15S for *I. virginica* 'Henry's Garnet'. SDW of *R. austrinum* and *I. virginica* 'Henry's Garnet' in general was highest in WW and 10RB followed by 15S. To further evaluate the effect of irrigation scheduling treatments on shoot growth and Ps, plants of *I. virginica* 'Henry's Garnet' and *R. austrinum* were planted under shade structures in field plots in Auburn, Ala. Irrigation scheduling treatments included: root ball and surrounding soil maintained at or above 25 cb (centibar) (well-watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); or root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S). For *I. virginica* 'Henry's Garnet' final GI was highest in WW and 25S treatments, followed by 50S, 50RB, and 75RB while there were no differences among treatments for *R. austrinum*. Both taxa had the largest increase in GI during the first growing season and the lowest in winter months. For *R. austrinum* Ps was higher in WW, 25S, and 50RB than in 75RB and 50S. Stem water potential (SWP) was similar among treatments. For *I. virginica* 'Henry's Garnet' Ps was higher in 50S, 50RB, and 25S than in WW, followed by 75RB. SWP was higher in 50S and 75RB than in 50RB, WW, and 25S. For both experiments results indicate that until and even after roots grow into the backfill soil, monitoring both backfill soil and root ball moisture is important for scheduling and reducing post-transplant irrigation.

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CHAPTER I

LITERATURE REVIEW

Introduction

Irrigation requirements for landscape plants are rapidly becoming a concern due to changing climate, rising water costs, and increased water restrictions (Chaves et al., 2003; CNN.com, 2007; Haley et al., 2007; St. Hilaire et al., 2008). Of a home's annual water consumption, 40% to 70% is used for landscape water use (Fergnson, 1987; St. Hilaire et al., 2008). Since water conservation is a growing area of concern in horticulture, research has been conducted on improved methods of irrigation in the landscape. The use of native plants in the landscape has also come to the forefront in an effort to produce more environmentally sustainable landscapes (Helfand et al., 2006). Using native plants in the landscape is a practice that is assumed to help lower inputs in the landscape since plants are adapted to the region (Stewart et al., 2007). The proposed research will expand on previous work to evaluate methods for irrigation scheduling for selected native shrubs. This will provide information that may support more sustainable landscape irrigation scheduling.

Irrigation application efficiency

Irrigation application efficiency in horticulture has become a deeply researched area aimed at optimizing irrigation efficiency and scheduling (Dodd et al., 2006). Due to increasing water restrictions and costs associated with irrigation (Haley et al., 2007), increased research has been done to indentify specific water needs of landscape plants. Water is considered the most limiting aspect in newly transplanted container plants (Costello and Paul, 1975; Scheiber et al., 2007), and the most common cause of death of recently transplanted container-grown plants is water stress (Costello and Paul, 1975; Nelms and Spomer, 1983). This could be attributed to the fact that there is greater water loss from the original root ball due to movement of available water into the backfilled soil, which is a greater volume for water movement than the container alone (Costello and Paul, 1975; Nelms and Spomer, 1983).

Research on irrigation application efficiency found irrigation outside the original root ball did not aid in the fast establishment of transplanted trees (Gilman et al., 1998). Instead, irrigation frequency is more important than larger quantities of water applied infrequently to transplanted trees after transplanting 1.2 L of water/cm (1.2 gal/in) of trunk diameter was required to support high-quality growth. There also appeared to be a maximum volume of irrigation water needed for plant functions, above which no added benefit is gained by the plant. This implies that once that volume of water is applied, adding more can be wasteful.

A different approach involves partial rootzone drying or deficit irrigation (Dodd et al., 2006; Glenn, 2000; Schackel et al., 2000). When using the method of partial rootzone drying, the plant is irrigated on one side only and the other side of the rootzone is allowed to dry (Dodd et al., 2006). The plant responds to the drying soil by signaling for stomatal closing to decrease water loss in the plant, which improves water use efficiency (Dodd et al., 2006). Tests suggest however that extended periods of drying on one side of the plant diminishes the desired result of signaled stomatal closing (Dodd et al., 2006; Stoll et al., 2000). To maintain the desired result of partial rootzone drying it is essential to frequently change the irrigated and non-irrigated sides of the plant's rootzone (Dodd et al., 2006; Stoll et al., 2000).

Monitoring soil moisture

Scheduling irrigation in the landscape based primarily on daytime air temperature and the number of days of precipitation is not well correlated with plant water needs (Qualls et al., 2001). Instead evapotranspiration and precipitation should be used to schedule irrigation. Soil moisture monitoring is a technological approach that can more accurately quantify water use. This should aid in the conservation of water usage in relation to horticultural needs.

Soil water is expressed as soil water content or soil water potential. While soil water content indicates the amount of water present in the soil on a volume or weight basis, soil water potential is correlated to the energy necessary for a plant to take up water (Irmak, 2006). Soil water potential is often referred to as matric potential since total soil water potential is the sum of gravitational, matric, and osmotic potentials, and gravitational and osmotic potential are generally not a factor in most landscape soils (Irmak, 2006).

Since it has been shown that precision irrigation based on soil moisture lowers direct water usage and can yield the same plant responses, many methods of measuring soil water content have been developed. The thermogravimetric method of measuring soil moisture has been recognized as the standard method of determining soil water content (Topp, 2003). Using this method a soil sample is collected and dried to determine soil water content based on weight. Since the thermogravimetric method is considered destructive to the site and without logging capability for it, this method has become more of a reference tool for calibrations and computations.

Agricultural research studies have long used soil moisture sensors (U.S.D.I.B.R., 2006). In the past, soil moisture sensor technology was impractical in landscape irrigation control due to the combination of its limited technology, sensor maintenance requirements, and installation cost. In recent years there have been significant advancements in soil moisture sensor technology that have led to precise and maintenance-free systems available for landscape use at affordable prices. These sensors have been used to efficiently schedule and control irrigation thereby reducing water usage and lowering direct costs associated with irrigation (Dukes et al., 2005; Qualls et al., 2001). Compared to speculative requirements, sensors decreased irrigation applications by approximately 73% on a seasonal average, which resulted in a savings of almost 30 inches of water seasonally (Qualls et al., 2001). Moreover, soil moisture monitoring aids in quantifying plant water use, by providing an indication of drying rates within the rhizosphere.

Today many different types of soil moisture sensors are available. Time-domain reflectometry (TDR) is one that allows for non-destructive monitoring of soil water content (Inoue et al., 2008; Topp, 2003). This sensor type measures soil water content by initiating an electrical pulse through the sensor to its end, while in the soil, and then measuring the time taken for the pulse to travel back to the instrument (Topp, 2003; U.S.D.I.B.R., 2006). The travel time taken for the pulse to return to the instrument is directly related to the water content of the soil (Topp, 2003; U.S.D.I.B.R., 2006). These sensors have historically been reliable and given accurate readings, but they were expensive and difficult to operate which led the development of time domain transmissometry (TDT) sensors (U.S.D.I.B.R., 2006). TDT sensors work in basically the same way as TDR sensors but are more economical and suited for use in landscape irrigation scheduling (U.S.D.I.B.R., 2006).

Another soil moisture sensor is an electrical resistance type sensor. This sensor type consists of two fixed electrodes imbedded in a matrix material which is surrounded by a corrosion resistant, permeable case (Irmak et al., 2006; U.S.D.I.B.R., 2006). The matrix material can consist of gypsum, plaster of paris, ceramic, or nylon cloth (Irmak et al., 2006). Today many electrical resistance sensors use gypsum as their matrix material, but tend to resist decay associated with older gypsum block sensors (U.S.D.I.B.R., 2006). The highly permeable case of the sensors allows them to absorb and release water as the surrounding soil moisture conditions change (Irmak et al., 2006; U.S.D.I.B.R., 2006). As moisture conditions change it is reflected by the electrical resistance between the electrodes; as soil moisture increases conductivity increases (Irmak et al., 2006; U.S.D.I.B.R., 2006). Electrical resistance sensors can be used for up to 7 years and are inexpensive, however reaction time is slow (U.S.D.I.B.R., 2006).

Watermark® sensors (model 900M) (Irrometer Company, Inc.) are classified as an electrical resistant type sensor. Watermark sensors measure the soil water potential of a soil or substrate in centibars (cb). Sensors have a diameter of 2.2 cm (0.8 in) and a length of 8.5 cm (3.3 in) and are enclosed in a protective stainless steel mesh. The installation of this sensor is somewhat more invasive and time consuming to install than others that are smaller and may have pointed (rather than blunt) insertion points. This sensor is durable and will not dissolve over time if left in soil or substrate. Evaluations of this sensor found that it was a suitable means of irrigation scheduling and could be used to improve irrigation schedules (Irmak et al., 2006; Leib et al., 2003).

ECH2O soil moisture sensors (Decagon Devices Inc., Pullman, Wash.) determine the volumetric percent moisture of the soil or substrate. The EC-5 determines volumetric water content by measuring the dielectric constant of the soil or substrate. This type of sensor can be a valuable tool for real-time, immediate, and long-term measurements (Inoue et al., 2008). It has been evaluated for use in monitoring and controlling irrigation and was found to be an acceptable means of irrigation scheduling (Nemali et al., 2007). The EC-5 is a thin two pronged sensor; its dimensions are 8.9 x 1.8 x 0.7 cm (3.5 x 0.7 x 0.2 in). The slender nature of the sensor allow it to be easily installed into soil or root ball with little disruption to existing roots. The sensor can last in field conditions for three years and have proved an accurate, reliable, and long lasting means of scheduling irrigation.

Measuring photosynthesis and plant water

Correlating soil moisture to physiological plant measurements can be helpful in understanding the effects of plant stressors such as drought (Griffin et al., 2004). Determining photosynthesis and plant water potential at given levels of soil moisture can help us better understand plant physiological functions during times when the plant is well-watered and during times of water stress.

While older leaves are usually shed in water stress situations, younger leaves sometimes become more resistant (Chaves et al., 2003). Surviving leaves frequently exhibit higher photosynthetic rates due to the water stress once rewatered, when compared to leaves of like age in well-watered plants (Chaves et al., 2003; Ludlow and Ng, 1974). Growth of a species often declines before photosynthetic rates of that species when under stress (Herms and Mattson, 1992). It is also true that leaves grown in water stressed conditions may also reach maturity at a smaller size (Chaves et.al. 2003).

Plant available water plays an important role in photosynthesis. As soil dries, root dehydration signals shoots through the production and accumulation of abscisic acid, which impacts stomatal function reducing stomatal aperture (Chaves et al., 2003; Davies and Zhang, 1991; Schachtman and Goodger, 2008; Sharp and LeNoble, 2001; Xiong et al., 2006). During periods of drought, decreased photosynthesis following a reduction of stomatal aperture is generally one of the first responses to minimize plant water loss (Bargali and Tewari, 2004; Chaves et al., 2003; Griffin et al., 2004; Schachtman and Goodger, 2008). Photosynthetic rates of a plant can be measured using the LI-6400 (LI-COR Biosciences, Inc., Lincoln, Nebr.). The open system of the LI-6400 is often used to measure the gas exchange of a single leaf (Bugbee, 1992). To operate, a leaf is positioned inside the cuvette and clamped into place. Once in place the atmosphere inside the cuvette can be controlled and monitored. Steady-state conditions are created inside the cuvette by pumping carbon dioxide through the cuvette (Bugbee, 1992), as well as into a separate reference chamber. This allows the amount of carbon dioxide in the reference chamber to be compared to the amount in the cuvette with the leaf sample (Mitchell, 1992). Consequently, the rate of gas exchange of the leaf in the cuvette will result in a different concentration of carbon dioxide from that of the reference carbon dioxide. The difference between the two concentrations of carbon dioxide corresponds to net photosynthesis of the sample leaf (Mitchell, 1992). The LI-6400 is also equipped with an adjustable lamp light source that allows the researcher to utilize a constant ambient light inside the cuvette (Mitchell, 1992). This allows the researcher to operate the LI-6400 with a varied external environment since the cuvette environment remains constant all samples are exposed to the same conditions.

Measuring plant water potential is a good way to characterize a plant's water requirements (Martin-Vertedor et al., 2008) and a plant's water status during periods between irrigation events. Stem water potential can be determined using a pressure chamber. A terminal shoot section is removed from the plant and placed with the cut side protruding from a sealed pressure chamber (Hopkins and Hüner, 2004). Once cut, the xylem's water column that was under tension retracts from the stems cut surface into the stem (Hopkins and Hüner, 2004). The sealed chamber is then filled with compressed gas to pressurize the chamber, forcing the xylem water column back to the stems cut surface (Hopkins and Hüner, 2004). Once visible the known pressure needed to force the water back to the cut surface equals the tension that was present in the original plant that the sample was taken from (Hopkins and Hüner, 2004; Spomer, 1985). This method can be useful in determining and better understanding plant water stress, since plant water potential decreases with increasing dehydration.

Shoot and root growth

Plants subjected to water stress frequently experience decreased shoot growth (Sharp and LeNoble, 2001) and lower visual quality than well-watered plants (Kjelgren et al., 2000; Stewart et al., 2007). Leaf drop of older leaves on plants under water stress contributes to the lower visual quality associated with plants experiencing water stress (Bargali and Tewari, 2004; Chaves et al., 2003). Furthermore, when subjected to water deficits, shoot dry weight can be reduced by almost half when compared to well-water plants (Niu et al., 2008).

The reduction in vigorous shoot growth caused by water stress results in a smaller more compact plant (Cameron et al., 2008). Water stress generally impacts shoot growth, and especially leaf growth, more severely than root growth (Chaves at al. 2003; Hopkins and Hüner, 2004). Furthermore, exposure to water stress leads to an increase in root:shoot ratio which can be favorable for a plant's ability to survive such conditions (Hopkins and Hüner, 2004; Sharp and Davies, 1979). The increasing root:shoot ratio allows the root system to continue growing and therefore is able to attain more available water (Hopkins and Hüner, 2004).

One significant factor affecting the establishment of post-transplanted plant material is root growth (Watson and Himelick, 1997), and the development of an extensive root system is critical for a plants survival (Taiz and Zeiger, 2006). Roots are responsible for absorption of water and nutrients from the soil, respiration, and anchorage and support of the plant (Kozlowski and Pallardy, 1997; Preece and Read, 2005; Taiz and Zeiger, 2006). Because of the impact soil moisture has on root growth (Qualls et al., 2001), proper irrigation scheduling can directly impact the post-transplant root growth critical for plant establishment and survival (Taiz and Zeiger, 2006).

Root growth occurs at root tips in the apical meristem by cell division and by cell expansion at the root apex (Clark et al., 2003; Hopkins and Hüner, 2004). Since maintaining turgor pressure is needed for cell elongation (Davies and Bacon, 2003), water is a limiting factor for plant growth and development (Costello and Paul, 1975; Scheiber et al., 2007). Mechanical impedance, water stress, and oxygen deficiency are all soil physical stresses impacted by moisture content, which often inhibit root growth (Bengough et al., 2006). As the water content of the soil decreases the soil strength or mechanical impedance increases and therefore negatively impacts root growth and plant establishment (Clark et al., 2003).

Until newly transplanted container grown plants become established, the plant must attain all water requirements from its original container root ball (Costello and Paul, 1975; Nelms and Spomer, 1983). Percent moisture in the root ball can be very different from the surrounding soil, and in fact, the root ball may experience drought conditions even when the surrounding soil is well-watered (Costello and Paul, 1975; Nelms and Spomer, 1983). Available water and nutrients in the soil affects root distribution (Bengough et al., 2006; Schachtman and Goodger, 2008). When water is plentiful roots may grow only a small amount, in contrast to times when water is limited, such as during periods of drought, when longer main roots may be required to access water deeper in the soil (Bengough et al., 2006).

Root growth may also be affected by seasonal changes or time of year in which the plant is transplanted. Many tree and shrub species benefit from fall transplanting due to the fact that moisture requirements for plants are lower since shoot growth is decreased and thereby reducing water needs (Harris and Bassuk, 1994). Moreover, fall transplanting may also be most beneficial to plant establishment since during the fall root growth rates are at their highest (Kozlowski and Davies, 1975).

Observing and measuring root growth over time is often expensive and instruments can be difficult to create (Wright and Wright, 2004). One method of observing shoot and subsurface plant growth and development uses rhizotrons. Rhizotrons are facilities built with transparent materials for the purpose of repeated and nondestructive measurements and observations of subsurface plant parts (Klepper and Kasper, 1994). Installation of a transparent wall either against a native soil, or divided and separated to allow observation with different substrates. These facilities are permanent, very large, and expensive to create which makes them very limited in availability. Since rhizotrons are such a large investment, minirhizotrons can similarly be used for root growth monitoring. Minirhizotrons also allow continual observation of subsurface plant development, mainly root growth, by placing translucent tubing in the soil and inserting fiber-optic borescopes or video cameras. Moreover, they can be strategically placed in the soil at any time and in desired locations relative to plants (Box et al., 1989; Keppler and Kasper, 1994). Though minirhizotrons do allow simultaneous root and shoot growth observation of plants they are also limiting since they are designed to be used in field research, are expensive, and offer only a limited view of the soil profile and rhizosphere (Keppler and Kasper, 1994).

The Horhizotron™ is a simple and non-destructive tool that allows for the measurement of horizontal root growth over time and within varying growing environments (Wright and Wright, 2004). The Horhizotron is a modified container-type rhizotron that can be used to gain further understanding of successful landscape plant establishment requirements. It utilizes four glass quadrants that extend away from the root ball through which root growth can be monitored. The versatility of the Horhizotron for use indoors or outdoors and the ability to control in growing environment are contributing factors to its success as an effective tool for measuring root growth. The combination of the Horhizotron and soil moisture sensors should lead to a better understanding of irrigation requirements for transplanted landscape plants.

Native deciduous plants

In recent years the use of native plants in the landscape has become increasingly popular in landscape design (Alder and Ostler, 1989). A naturalized landscape is created from plant material that is native to or expressly adapted to the environment in which it is to be planted. The use of plant material that will require little or no additional inputs such as irrigation, fertilizer, herbicides, and support biological diversity, after plant establishment in the landscape is the goal of a native landscape (Alder and Ostler, 1989; Dieckelmann and Schuster, 2002).

Furthermore, native plants in the landscape can be just as attractive in the landscape as non-native species (Helfand et al., 2006). The promotion of native plant use in the landscape has led to an increase in the availability of these plants (personal observation).

Shrubs such as *Hydrangea quercifolia* Bart. (oakleaf hydrangea), *Itea virginica* L. (virginia sweetspire), and *Rhododendron austrinum* Michx. (florida flame azalea) are native to the southeastern United States, flower in late spring to early summer and are classified as deciduous to semi-evergreen woody ornamental shrubs (Dirr, 1998). These plants differ from each other with respect to light requirements, water needs, and growth rate (Dirr, 1998). The use of these native species for this research was based on their varied tolerance for water stress, their similar form (multistemmed, deciduous shrub), and their popularity in the landscape and horticulture industry.

Hydrangea quercifolia is a broad-leaved deciduous to semi-evergreen shrub that is native to the southeastern United States and is found in North Carolina west to Tennessee and south to Florida and Louisiana where it can grow up to 3 meters (10 feet) tall (Dirr, 1998). *H. quercifolia* prefers shade to full sun. Its most attractive features are its 10 to 30 centimeter long erect panicles form late May to early July and red fall color (Dirr, 1998). *H. quercifolia* has a slow to medium growth rate and shown little drought tolerance (Dirr, 1998).

Itea virginca is a broad-leaved deciduous or semi-evergreen shrub that has a height of 1 to 1.5 meters (3.2 to 4.9 ft.) (Dirr, 1998). *I. virginica* is found in swamps or wet woodlands from New Jersey south to Florida and as far west as Texas and Missouri (Dirr, 1998). Landscape attributes include showy white racemes in May that are lightly fragrant (Dirr, 1998) and red fall color. *I. virginica* has a medium to fast growth rate and has shown some drought tolerance when planted outside its native wet habitats (Dirr, 1998).

Rhododendron austrinum is a broad leaved deciduous shrub that can reach heights of 2.4-3 meters (8-10 feet) but usually not seen that tall in the cultivated landscape (Dirr, 1998). *R. austrinum* native range is from northern and western Florida into southern Alabama and west to southern Mississippi (Dirr, 1998). Its primary landscape quality is fragrant yellow to orange flowers in April to May (Dirr, 1998).

Conclusion

Landscapers and homeowners need to be aware of more specific irrigation requirements and methods that can reduce water use in the landscape. The research will determine what soil moisture contents are required to sustain root growth, plant visual quality, and adequate photosynthetic rates for selected native shrubs. The Horhizotron™ will be used to monitor the effect of different irrigation scheduling strategies effects on root and shoot growth and physiology of the plant (Wright and Wright, 2004). The results from these investigations will be used to schedule post transplant irrigation and to promote water use efficiency in horticultural fields. The goal of this investigation is to determine more precise irrigation requirements to help consumers become environmentally conscious of water use allocation in the landscape. More precise requirements will help lower inputs in the landscape with the same plant output.

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Chapter II

Landscape Irrigation Scheduling for Native Deciduous Shrub Taxa

Index Words: Horhizotron™, establishment, *Hydrangea quercifolia* ‘Alice’, *Rhododendron austrinum*, *Itea virginica* ‘Henry’s Garnet’, root growth

Abstract: The effect of three irrigation scheduling treatments on root and shoot growth and photosynthesis of *Hydrangea quercifolia* Bart. ‘Alice’ (‘Alice’ oakleaf hydrangea), *Rhododendron austrinum* Rehd. (florida flame azalea), and *Itea virginica* L. ‘Henry’s Garnet’ (‘Henry’s Garnet’ sweetspire) were studied using Horhizotrons™ in a greenhouse in Auburn, AL. Fifteen plants of each taxa were removed from 11.4 L (3 gal) containers, and each plant was placed in the center of one Horhizotron™. *H. quecifolia* ‘Alice’, *R. austrinum*, and *I. virginica* ‘Henry’s Garnet’ were planted 14 February 2008, 9 June 2008, and 18 February 2009 respectively; the experiment was repeated for each species on 28 May 2008, 8 October 2008, and 1 April 2009, respectively. Horhizotron quadrants (representing soil backfill) were filled with sandy loam soil level with the root ball. Percent moisture (by volume) was measured 7.6 cm (3 in) from the stem in the root ball and 20.3 cm (8 in) from the stem in the backfill. Irrigation frequency treatments included: (1) backfill and root ball maintained at or above 20% moisture (well watered, WW); (2) backfill and root ball re-watered when root ball

moisture reached 10% (10RB); (3) backfill and root ball re-watered when quadrant soil moisture reached 15% (15S). The experimental design was a randomized complete block design with plants assigned to five blocks. Horizontal root length (HRL) was measured once every two weeks. Net photosynthesis was measured for all three species. Dry weight of roots in each quadrant was determined at experiment termination. For all three species HRL increased linearly over time in all three irrigation treatments, and overall plants that were re-watered when the root ball dried to 10% moisture exhibited the longest HRL followed by plants in WW and 15S treatments. Shoot growth and net photosynthesis was similar among treatments for *H. quecifolia* 'Alice' and *R. austrinum*. Shoot growth for *I. virginica* 'Henry's Garnet' in general was highest in WW and 10RB followed by 15S. Dry weight of roots in soil-filled quadrants was similar among all three irrigation treatments for *H. quecifolia* 'Alice', and was higher in WW and 10RB than 15S for *I. virginica* 'Henry's Garnet'. SDW of *R. austrinum* and *I. virginica* 'Henry's Garnet' in general were highest in WW and 10RB followed by 15S. Results indicate that until and even after roots grow into the backfill soil, monitoring both backfill soil and root ball moisture is important for scheduling and reducing post-transplant irrigation applications. Regardless of treatment, all plants displayed good visual quality and maintained root and shoot growth, indicating that irrigation may be reduced without compromising plant survival.

Introduction

Irrigation application efficiency in horticulture has become a deeply researched area aimed at optimizing irrigation efficiency and scheduling (Dodd et al., 2006). Due to increasing water restrictions and costs associated with irrigation (Haley et al., 2007), increased research has been done to identify specific water needs of landscape plants. Water is considered the most limiting aspect in newly transplanted container plants (Costello and Paul, 1975; Scheiber et al., 2007), and the most common cause of death of recently transplanted container-grown plants is water stress (Costello and Paul, 1975; Nelms and Spomer, 1983). This could be attributed to the fact that there is greater water loss from the original root ball due to movement of available water into the backfilled soil, which is a greater volume for water movement than in container (Costello and Paul, 1975; Nelms and Spomer, 1983).

Research on irrigation application efficiency found irrigation outside the original root ball did not aid in the fast establishment of transplanted trees (Gilman et al., 1998). Instead, irrigation frequency is more important than larger quantities of water applied infrequently to transplanted trees after transplanting, and 1.2 L of water/cm (1.2 gal/in) of trunk diameter was required to support high-quality growth. There also appeared to be a maximum volume of irrigation water needed for plant functions, above which no added benefit is gained by the plant. This implies that once that volume of water is applied, adding more can be wasteful.

Scheduling irrigation in the landscape based primarily on daytime air temperature and the number of days of precipitation is not well correlated with plant water needs (Qualls et al., 2001). Instead, evapotranspiration and precipitation volume should be used to schedule irrigation. Soil moisture monitoring is a technological approach that can even more accurately quantify water use. This should aid in the conservation of water usage in relation to horticultural needs.

Agricultural research studies have long used soil moisture sensors (U.S.D.I.B.R., 2006). In the past, soil moisture sensor technology was impractical in landscape irrigation control due to the combination of its limited technology, sensor maintenance requirements, and installation cost. In recent years there have been significant advancements in soil moisture sensor technology that have led to precise and maintenance-free systems available for landscape use at affordable prices . These sensors have been used to efficiently schedule and control irrigation thereby reducing water usage and lowering direct costs associated with irrigation (Dukes et al., 2005; Qualls et al., 2001). Compared to speculative requirements, sensors decreased irrigation applications by approximately 73% on a seasonal average, which resulted in a savings of almost 30 inches of water seasonally (Qualls et al., 2001). Moreover, soil moisture monitoring aids in quantifying plant water use by providing and indication of drying rates within the rhizosphere.

Until newly transplanted container grown plants become established, the plant must attain all water requirements from its original container root ball (Costello and Paul, 1975; Nelms and Spomer, 1983). Percent moisture in the root ball can be very different from the surrounding soil, and in fact, the root ball may experience drought conditions even when the surrounding soil is well-watered (Costello and Paul, 1975; Nelms and Spomer, 1983). Available water and nutrients in the soil affects root distribution (Bengough et al., 2006; Schachtman and Goodger, 2008). When water is plentiful roots may grow only a small amount, in contrast to times when water is limited, such as during periods of drought, when longer main roots may be required to access water deeper in the soil (Bengough et al., 2006).

These plants differ from each other with respect to light requirements, water needs, and growth rate (Dirr, 1998). The use of these native species for this research was based on their varied tolerance for water stress, their similar form (multi-stemmed, deciduous shrub), and their popularity in the landscape and horticulture industry.

Landscapers and homeowners need specific irrigation recommendations that can reduce water use in the landscape without compromising plant quality and survival. The object of this research was to use soil moisture contents to determine more precise irrigation requirements needed to sustain root and shoot growth, plant visual quality, and adequate photosynthetic rates for three native shrubs. The results from these investigations will be used to schedule post-transplant irrigation and to promote water use efficiency in the landscape.

Materials and Methods

Plant species used in this experiment included 11.4 L (3 gal) *Hydrangea quercifolia* Bartr. 'Alice' ('Alice' oakleaf hydrangea), *Rhododendron austrinum* Rehd. (Florida flame azalea), and *Itea virginica* L. 'Henry's Garnet' ('Henry's Garnet' sweetspire). *H. quercifolia* 'Alice' was obtained from Greene Hill Nursery, Inc. (Lee County, Waverly, Ala.) on 11 February 2008. The plants were propagated in the spring of 2006 from cuttings from existing nursery stock and were grown in a 9:1 pine bark:sand by volume medium. *R. austrinum* was obtained from Moore & Davis Nursery LLC (Macon County, Shorter, Ala.) on 21 February 2008. These plants were propagated in the summer of 2006 from cuttings from existing nursery stock and grown in 9:1 pine bark:sand by volume medium. *I. virginica* 'Henry's Garnet' was obtained from Greene Hill Nursery, Inc. (Lee County, Waverly, Ala.) on 4 February 2009. *I. virginica* 'Henry's Garnet' was propagated from cuttings of existing nursery stock in 2008 and grown in 9:1 pine bark:sand by volume medium. All plants were held on an outdoor full sun holding pad at the Patterson Greenhouse complex on the Auburn University campus in Auburn, Ala. until experiments began.

Experiments using *H. quercifolia* 'Alice' began on 14 February 2008 (hereafter referred to as February planting) and repeated on 28 May 2008 (hereafter referred to as May planting); *R. austrinum* began on 9 June 2008 (hereafter referred to as June planting) and repeated on 8 September 2008 (hereafter referred to as September planting); and *I. virginica* ‘Henry’s Garnet’ began on 18 February 2009 (hereafter referred to as February planting) and repeated on 1 April 2009 (hereafter referred to as April planting).

Marvyn loamy sand soil was collected from field research plots on the Auburn University campus in Auburn, Ala. The full taxonomic classification of this soil is fine-loamy, kaolinitic, thermic Typic Kanhapludults (U.S.D.A.N.R.C.S., 2009). This soil type is made of deep, well drained, moderately permeable soils that formed in loamy marine sediments on Coastal Plain uplands (U.S.D.A.N.R.C.S., 2009). Rocks, weeds, and other debris were removed, and soil was mixed using shovels and rakes to ensure homogeneous texture and composition. Five soil samples were collected once from the area for chemical and particle size analysis.

Horhizotrons™ used in these experiments were placed on greenhouse benches at the Paterson greenhouse complex at Auburn University in Auburn, Ala. [average day/night temperatures set at 26/21˚C (79/70˚F). In each experiment 15 plants of one species were removed from containers, and each plant was placed in the center of one of 15 Horhizotrons. Each Horhizotron contained four wedge-shaped quadrants made of glass extending outward from the root ball. Quadrants corners were sealed with silicon caulking and allowed to dry before beginning the experiment. Horhizotron quadrants were filled with the collected soil to a height even with the top of the root ball.

Percent moisture (by volume) was measured using ECH_2O EC-5 soil moisture sensors, (Decagon Devices, Inc., Pullman, Wash.) installed in two Horhizotrons per treatment per species. ECH_2O EC-5 soil moisture sensors (Decagon Devices Inc., Pullman, WA) determine volumetric water content by measuring the dielectric constant of the soil or substrate. Each of the two Horhizotrons had one sensor installed 7.6 cm (3 in) from the stem in the root ball 9.5 cm (3.7 in) deep and one installed 20.3 cm (8 in) from the stem in a quadrant 9.5 cm (3.7 in) deep. One of the two Horhizotrons has one additional sensor installed in one of the quadrants. A data logger (Em5b, Decagon Devices, Inc., Pullman, Wash.) was used to record soil water content every 6 hours, which was used to schedule irrigation frequency for the treatments. The experimental design was a randomized complete block design with five blocks (Horhizotrons) per treatment per species. At planting each plant was randomly assigned one of three irrigation treatments. Treatments were selected based on previous work which found that post-transplant root growth of three native shrub species was able to continue even under decreased irrigation frequency in which the surrounding soil was allowed to dry to 15% moisture by volume (Wilkin, 2007). Treatments were initiated once new root growth became visible in quadrants and included: (1) quadrants and root ball maintained at or above 20% moisture (well watered, WW); (2) quadrants and root ball re-watered when *root ball moisture* reached 10% (10RB); and (3) quadrants and root ball re-watered when *quadrant soil moisture* reached 15% (15S). When irrigated, 600 mL of tap water was applied to the root ball and 400 mL of tap water was applied to each quadrant in all five Horhizotrons of a treatment. When applying irrigation effort was made to both evenly distribute water across the root ball or the quadrant and to minimize runoff by slowing the rate at which the irrigation was applied.

Net photosynthesis of each plant were measured using a LI-COR 6400 (LI-COR Biosciences, Inc., Lincoln, Nebr.) between 10:00 AM and 2:00 PM on one day during one run of each species. Photosynthetically active radiation (PAR) within the cuvette of the LI-COR was set at 1800 $\mu mol \bullet m^{-2} \bullet s^{-1}$. Reference carbon dioxide was set as 400 ppm, stomatal ratio was 0, flow rate set to 500 mol/sec, and temperature and humidity were ambient.

Growth index (GI) [(widest width + width perpendicular + height)/3] was determined for each plant at experiment initiation (initial GI, IGI) and termination (final GI, FGI), and relative growth index (RGI) [(FGI – IGI)/IGI] for each plant was calculated. Horizontal root length (HRL) was measured once every two weeks using a Scale Master® II digital plan measuring system (Calculated Industries®, Carson City, Nev.) for the five longest roots on each side of a quadrant. HRL is measured parallel to the ground and represents the advancement of the root growth front into the surrounding soil from the original container root ball. An experiment was terminated once roots within one of the treatments approached the end of a quadrant. At experiment termination roots growing into each quadrant were cut from the original root ball, rinsed to remove soil, dried at 66°C (150°F) for 48 hours, and weighed. Root dry weight (RDW) was not determined for *R. austrinum* since the fine, hair-like roots were too difficult to separate from the quadrant soil. Shoot dry weight (SDW) was determined for *R. austrinum* and *I.* virginica 'Henry's Garnet' at experiment termination by removing all above ground shoot growth, drying for 72 hours at 66°C (150°F), and weighing. Data were analyzed using General Linear Models with means separation using Protected Least Significant Differences at each date to identify differences (P<0.05) (SAS Institute, Inc., 2004).

Initially 25 *H. quercifolia* 'Alice' were used in the experiment and five irrigation scheduling treatments were utilized. These treatments included the three afore mentioned treatments with the addition of a) quadrants and root ball re-watered when root ball moisture reached 15% (15RB) and b) quadrants and root ball re-watered when quadrant soil moisture reached 20% (20S). These two additional treatments were not utilized in subsequent experiments since statistical data showed the greatest differences between WW, 10RB, and 15S treatments. Following the initial experiment with 25 plants and 5 treatments, all subsequent experiments had 15 plants and three treatments.

Results

***Hydrangea quercifolia* 'Alice'**

In both runs of this experiment all plants survived in all treatments. Horizontal root length (HRL) in the February planting increased linearly over time in all irrigation treatments (Table 1, Fig. 1A). At 33 days after planting (DAP), HRL was longest in 10RB followed by 15RB, WW, 20S, and 15S (P=0.0001).

This trend continued, and by 60 DAP all treatments were different from one another (P=0.0001). However, differences among treatments became smaller for final HRL measurements at 75 DAP with the longest HRL in 10RB and 15RB followed by WW, 20S, and 15S (Table 1). HRL in the May planting increased linearly over time in all irrigation treatments (Table 1, Fig. 1B). At 21 DAP HRL was higher in 10RB than 15S followed by WW (P=0.0001). HRL at 36 DAP remained longest in 10RB, while HRL in WW treatment was higher than in 15S (P=0.0001). Final HRL (57 DAP) shifted yet again and was longer in 10RB and 15S than WW (Table 1). Final GI and RGI for both the February and May plantings were similar among treatments (Table 2). RDW was also similar among treatments for both the February and May plantings (Table 3). Photosynthetic rates of *H. quercifolia* 'Alice' were not different among treatments (Table 4).

Rhododendron austrinum

In both runs of this experiment all plants survived in all treatments. HRL in the June planting increased linearly over time in all irrigation treatments (Table 5, Fig. 2A). At 57 DAP HRL was longest in WW followed by 15S and 10RB (P=0.0022). All subsequent HRL measurements were higher in WW than 10RB followed by 15S (Fig. 2A). HRL in the September planting increased linearly over time in all irrigation treatments (Table 5, Fig. 2B). At 64 DAP HRL was highest in 10RB and 15S followed by WW (P=0.0001). However, as the experiment progressed HRL was longest in 10RB followed by 15S and WW (78 DAP)

(P=0.0001). All remaining measurements exhibited the same trend (Fig 2B, Table 5). Final GI within each planting date was similar among treatments, however RGI in the June planting was highest in WW and 10RB followed by 15S (Table 2), with RGI in all treatments in September planting being similar (Table 2). Plants in the June planting had the highest SDW in 10RB and WW followed by 15S (Table 3), while SDW was similar among treatments in September planting (Table 3). Photosynthetic rates of *R. austrinum* were not different among treatments (Table 4).

***Itea virginica* 'Henry's Garnet'**

In both runs of this experiment all plants survived in all treatments. HRL in the February planting increased linearly over time in all irrigation treatments (Table 6, Fig. 3A). At 72 DAP, HRL was greatest in WW followed by 10RB and 15S (P=0.0001). This trend continued until experiment termination, with differences among treatments widening, and final HRL being higher in WW than in 10RB followed by 15S (Table 6, Fig. 3A). HRL of plants in the April planting increased linearly over time in all irrigation treatments (Table 6, Fig. 3B). At 56 DAP HRL was longer in 10RB than WW followed by 15S (Fig 3B). This trend continued until 83 DAP at which time HRL was longest in 10RB and WW followed by 15S (Table 6, Fig. 3B). GI and RGI within both planting dates showed differences among treatments and were highest in WW followed by 10RB and 15S (Table 2). RDW in the February planting was similar among treatments, while RDW in the April planting was highest in 10RB and WW followed by 15S (Table 2). SDW in the February planting was higher in WW than 10RB followed by 15S (Table 3). SDW in the April planting was highest in WW and 10RB followed by 15S (Table 3).

Discussion

The rate of root growth was affected by irrigation frequency treatments, and although not compared statistically, root growth appeared to differ among taxa (Table 1, 5, and 6; Fig. 1, 2, and 3). *H. quercifolia* 'Alice' roots grew the fastest (0.36 – 0.44 cm/day) among the taxa followed by *I. virginica* 'Henry's Garnet' (0.20 – 0.35 cm/day) and *R. austrinum* (0.08 – 0.22 cm/day) (Table 1, 5, and 6; Fig. 1, 2, and 3). Rate of root growth following transplanting is a critical factor for transplant establishment and survival (Watson and Himelick, 1997). The slower rates of root growth for *R. austrinum* were typical of plants with fibrous, hair-like root systems (Wright et al., 2004; Wright et al., 2007; Price et al., 2009). Additionally, root growth of *R. austrinum* was particularly affected by irrigation frequency treatments in the June 2008 planting compared to the September 2008 planting (Fig. 2). This is likely due to the fact that shoots were actively growing during the summer months and competing with roots for photoassimilates, increasing the impact of irrigation frequency. Furthermore, the September planting would have occured during the time of year when root growth is often highest, making irrigation frequency less critical for root growth (Wright et al., 2004). This makes this time of year ideal for transplanting most species (Kozlowski and Davies, 1975). In spite of these seasonal differences for

R. austrinum, overall results for all taxa followed generally the same trend. In general, plants that were WW or allowed to dry until the root ball reached 10% moisture exhibited the highest HRL in all three taxa, and the lowest HRL was in 15S (Table 1, 5, and 6). In fact, withholding irrigation until the root ball dried to 10% moisture resulted in longer HRL in at least one run in all three taxa compared to WW (Table 1, 5, and 6). Results from this study are consistent with others which found that root diameter is affected by soil moisture and that often, roots exposed to mild drought will become longer and thinner (Davies and Bacon, 2003). This may be why RDW was often not different among treatments and thus was not a good indicator of affects of irrigation frequency treatments on root growth.

For *H. quercifolia* ‘Alice’ and *R. austrinum* shoot growth was not as affected by irrigation frequency treatments as root growth (Table 2). In contrast, shoot growth of *I. virginica* ‘Henry’s Garnet’ was significantly affected by irrigation frequency treatments (Table 2). *I. virginica* ‘Henry’s Garnet’ GI was highest in either WW or 10RB treatments while 15S was consistently lower (Table 2). This is likely due to the faster rates of shoot growth (high RGI) for this taxa than the other two. Despite differences in shoot growth, plants in 15S treatment were still visually acceptable in *I. virginica* ‘Henry’s Garnet’ as well as in the other *taxa*.

Photosynthetic rates were not different among taxa or treatments (Table 4). Growth of a species often declines before photosynthetic rates of that species when under stress (Herms and Mattson, 1992). Similar photosynthetic rates of *H. quercifolia* 'Alice', *R. austrinum,* and *I. virginica* 'Henry's Garnet' are consistent with this, since photosynthetic rates were similar and growth continued for all taxa (Herms and Mattson, 1992).

Results indicate that irrigation frequency can be reduced if soil or root ball moisture is monitored. The ECH_2O soil moisture sensor, model EC-5, was a reliable means of monitoring both soil and root ball moisture, which was consistent with others findings (Inoue et al., 2008; Nemali et al., 2007). This sensor proved not only reliable but also easy to install since installation of the sensors was neither invasive nor destructive of existing roots. As would be expected, irrigation frequency increased over time. For example, days between irrigation decreased in 15S from once every 6 days to once every 4 days (Fig. 4) for *H.* quercifolia 'Alice' and decreased from once every 8 days to once every 6 days in *I.* virginica 'Henry's Garnet' (Fig. 5). For *I.* virginica 'Henry's Garnet' receiving 10RB treatments, days between irrigation decreased from once every 7 days to once every 5 days (Fig. 5). In general, plants that were WW received water once per day throughout the experiment (Fig. 4, 5, 6). The increase in irrigation frequency is likely due to the increase of roots in the soil as well as the root ball. Consistently, the biggest difference between root ball and soil moisture occurs when irrigation scheduling is based on soil moisture rather than root ball moisture. This illustrates how fast the root ball can dry, which is much faster than the soil (Nelms and Spomer, 1983; Costello and Paul, 1975). Regardless of the presence of plant roots in the soil, the root ball still dried at a faster rate than the soil, however as roots grew into the soil, differences between root ball and soil moisture decreased, particularly in 15S. When scheduling irrigation based on soil moisture the volume of water applied may need to be increased, since root ball moisture tends to be lower than soil moisture and root ball moisture never recovered to as high a percent moisture as soil did (Fig. 4, 5, 6). Results suggest that monitoring root ball moisture is more effective for irrigation scheduling than monitoring the surrounding soil moisture with respect to increased root length and exploration of surrounding soil. This is in agreement with other research which found that irrigation outside the original root ball did not aid in quick establishment of transplanted trees (Gilman et al., 1998), and initially following transplanting root ball moisture can be significantly lower than backfill soil (Nelms and Spomer, 1983; Costello and Paul, 1975). However once roots grow into the backfill soil, monitoring both backfill soil and root ball moisture is important for scheduling post-transplant irrigation.

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Table 1. Effect of irrigation frequency treatment on final horizontal root length (HRL[z]) of *Hydrangea quercifolia* 'Alice' grown in Horhizotrons in a greenhouse in Auburn, Ala.; 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. *Hydrangea quercifolia* 'Alice' were grown from 14 Feb. 2008 - 5 May 2008 and 28 May 2008 – 31 July 2008.

Feb. 2008 - May 2008

Treatment[y]	Final HRL (cm)	Equation[x]	R^2	P-value
WW	24.6b[w]	y = 0.40x - 50.29	0.70	< 0.0001
15% RB	24.7ab	y = 0.38x - 31.02	0.69	< 0.0001
10% RB	25.3a	y = 0.35x - 4.43	0.77	< 0.0001
20% S	23.1c	y = 0.38x - 59.84	0.72	< 0.0001
15% S	21.9d	y = 0.35x - 55.95	0.70	< 0.0001

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

May 2008 - July 2008

Treatment	Final HRL (cm)	Equation	R^2	P-value
WW	20b	y = 0.38x - 13.30	0.52	< 0.0001
10% RB	22.7a	y = 0.38x - 55.56	0.52	< 0.0001
15% S	23.1a	y = 0.44x - 24.84	0.71	< 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]Irrigation frequency treatments were quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 15% (15RB); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S) and quadrants and root ball re-watered when quadrant soil moisture reached 20% (20S).
[x]y= HRL, x = [v]Days after planting.

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

Table 2. Effect of irrigation frequency on initial and final shoot growth index (GI) and relative growth index (RGI) of *Hydrangea quercifolia* 'Alice', *Rhododendron austrinum,* and *Itea virginica* 'Henry's Garnet' grown in a greenhouse in Auburn, Ala. *Hydrangea* quercifolia 'Alice' grown 14 Feb. 2008 - 5 May 2008 and 28 May 2008 – 31 July 2008. *Rhododendron austrinum* was grown from 9 June 2008 – 3 November 2008 and 8 Sept. 2008 – 28 December 2008. *Itea virginica* 'Henry's Garnet' was grown from 18 Feb. 2009 – 16 June 2009 and 1 Apr. 2009 – 23 June 2009.

H. quercifolia 'Alice

	Feb-08		May-08	
Treatment[z]	Final GI (cm)	RGI[y]	Final GI[x] (cm)	RGI
WW	56.2	0.31	74.4	0.08
15RB	62.3	0.46	-	-
10RB	59.7	0.39	75.4	0.09
20 S	57.9	0.28	-	-
15 S	56.5	0.33	75.6	0.01

R. austrinum

	Jun-08		Sep-08	
Treatment	Final GI (cm)	RGI	Final GI (cm)	RGI
WW	85.2	0.04a[w]	80.1	0.03
10RB	93.4	0.02ab	77.5	0.03
15S	84.2	0.01b	77.8	0.01

I. virginica 'Henry's Garnet'

	Feb-08		Apr-08	
Treatment	Final GI (cm)	RGI	Final GI (cm)	RGI
WW	95.6a	1.17a	104.2a	1.34a
10RB	72.8b	0.77b	100.6a	1.33a
15S	73.0b	0.62b	77.06b	0.78b

[z]Irrigation frequency treatments were quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 15% (15RB); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S) and quadrants and root ball re-watered when quadrant soil moisture reached 20% (20S).

[y]RGI = (Final GI – Initial GI)/Initial GI
[x]GI = (height + widest width + width perpendicular to widest width)/3
[w]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at $P<0.05$ (SAS Institute, Inc., 2004). If no differences then letters are omitted.

Table 3. Effect of irrigation frequency treatment on root dry weight (RDW) and shoot dry weight (SDW) of *Hydrangea quercifolia* ‘Alice’, *Rhododendron austrinum,* and *Itea virginica* ‘Henry’s Garnet’ grown in a greenhouse in Auburn, Ala. *Hydrangea quercifolia* ‘Alice’ was grown 14 Feb. 2008 - 5 May 2008 and 28 May 2008 – 31 July 2008. *Rhododendron austrinum* was grown from 9 June 2008 – 3 November 2008 and 8 Sept. 2008 – 28 December 2008. *Itea virginica* ‘Henry’s Garnet’ was grown from 18 Feb. 2009 – 16 June 2009 and 1 Apr. 2009 – 23 June 2009.

H. quercifola 'Alice'

	Feb. 2008	May 2008
Treatment[z]	RDW (g)	RDW (g)
WW	16.96	25.36
15RB	24.6	-
10RB	15.4	29.45
20 S	20.46	-
15 S	15.4	21.12

R. austrinum

	June 2008	Sept. 2008
Treatment	SDW (g)	SDW (g)
WW	339a[y]	246
10RB	408a	251
15S	254b	259

I. virginica 'Henry's Garnet'

	Feb. 2009		April 2009	
Treatment	RDW (g)	SDW (g)	RDW (g)	SDW (g)
WW	14.69a	139a	12.25ab	145a
10RB	14.57a	112b	14.86a	150a
15S	10.09a	83c	9.26b	116b

[z]Irrigation frequency treatments were quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 15% (15RB); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S) and

quadrants and root ball re-watered when quadrant soil moisture reached 20% (20S).
[y]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at P<0.05 (SAS Institute, Inc., 2004). If no differences then letters are omitted.

Table 4. Effect of irrigation frequency treatment on net photosynthesis (Ps) (μmol/$m^{2/}$sec) of *Hydrangea quercifolia* 'Alice', *Rhododendron austrinum,* and *Itea virginica* 'Henry's Garnet' grown in a greenhouse in Auburn, Ala. *Hydrangea quercifolia* 'Alice' was grown 14 Feb. 2008 - 5 May 2008 and 28 May 2008 – 31 July 2008. *Rhododendron austrinum* was grown from 9 June 2008 – 3 November 2008 and 8 Sept. 2008 – 28 December 2008. *Itea virginica* 'Henry's Garnet' was grown from 18 Feb. 2009 – 16 June 2009 and 1 Apr. 2009 – 23 June 2009.

H. quercifolia 'Alice' May 2008		*R. austrinum* Sept. 2008	*I. virginica* 'Henry's Garnet' April 2009
Treatment	Ps	Ps	Ps
WW	9.8	10.0b	10.5
10RB	8.6	13.6a	9.7
15S	7.4	13.4a	11.6

[z]Irrigation frequency treatments were quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).
[y]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at P<0.05 (SAS Institute, Inc., 2004). If no differences then letters are omitted.

Table 5. Effect of irrigation frequency treatments on final horizontal root length (HRL[z]) of *Rhododendron austrinum* grown in Horhizotrons in a greenhouse in Auburn, Ala.; 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. *Rhododendron austrinum* were grown from 9 June 2008 – 3 Nov. 2008 and 8 Sept. 2008 – 28 Dec. 2008.

June 2008 - Nov. 2008				
Treatment[y]	Final HRL (cm)	Equation[x]	R^2	P-value
WW	19.9a[y]	y = 0.19x - 71.52	0.71	< 0.0001
10% RB	15.4b	y = 0.14x - 53.47	0.45	< 0.0001
15% S	9.1c	y = 0.07x - 24.40	0.25	< 0.0001

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

Sept. 2008 - Dec. 2008				
Treatment	Final HRL (cm)	Equation	R^2	P-value
WW	11.8b	y = 0.19x - 77.13	0.23	< 0.0001
10% RB	14.6a	y = 0.22x - 82.20	0.28	< 0.0001
15% S	10.8b	y = 0.11x - 16.61	0.15	< 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]Irrigation frequency treatments were quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); and quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).
[x]y= HRL, x = [v]Days after planting.
[y]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at P<0.05 (SAS Institute, Inc., 2004).

Table 6. Effect of irrigation frequency treatments on final horizontal root length (HRL[z]) of *Itea virginica* 'Henry's Garnet' grown in Horhizotrons in a greenhouse in Auburn, Ala; 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. *Itea virginica* 'Henry's Garnet' were grown from 18 Feb. 2009 – 16 June 2009 and 1 Apr. 2009 – 23 June 2009.

Feb. 2009 - June 2009

Treatment[y]	Final HRL (cm)	Equation[y]	R^2	P-value
WW	16.2a[x]	y = 0.29x - 161.30	0.5	< 0.0001
10% RB	14.5b	y = 0.27x - 160.48	0.47	< 0.0001
15% S	11.5c	y = 0.20x - 109.42	0.52	< 0.0001

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

April 2009 - June 2009

Treatment	Final HRL (cm)	Equation	R^2	P-value
WW	18.6a	y = 0.34x - 105.27	0.57	< 0.0001
10% RB	19.0a	y = 0.35x - 102.29	0.79	< 0.0001
15% S	15.0b	y = 0.27x - 80.22	0.8	< 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]Irrigation frequency treatments were quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); and quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).
[w]y= HRL, x = [v]Days after planting.
[x]Lowercase letters denote mean separation (n=50) among treatments within species by PDIFF at P<0.05 (SAS Institute, Inc., 2004).

Figure 1. Effect of irrigation frequency on horizontal root length (measured parallel to the ground, HRL) of *Hydrangea quercifolia* 'Alice' grown in Horhizotrons in a greenhouse in Auburn, Ala. from (A) 14 Feb. 2008 - 5 May 2008 and (B) 28 May 2008 – 31 July 2008. Treatments began once roots were visible in quadrants (31 and 18 days after planting, DAP, respectively). Treatments include: quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 15% (15RB); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S) and quadrants and root ball re-watered when quadrant soil moisture reached 20% (20S).

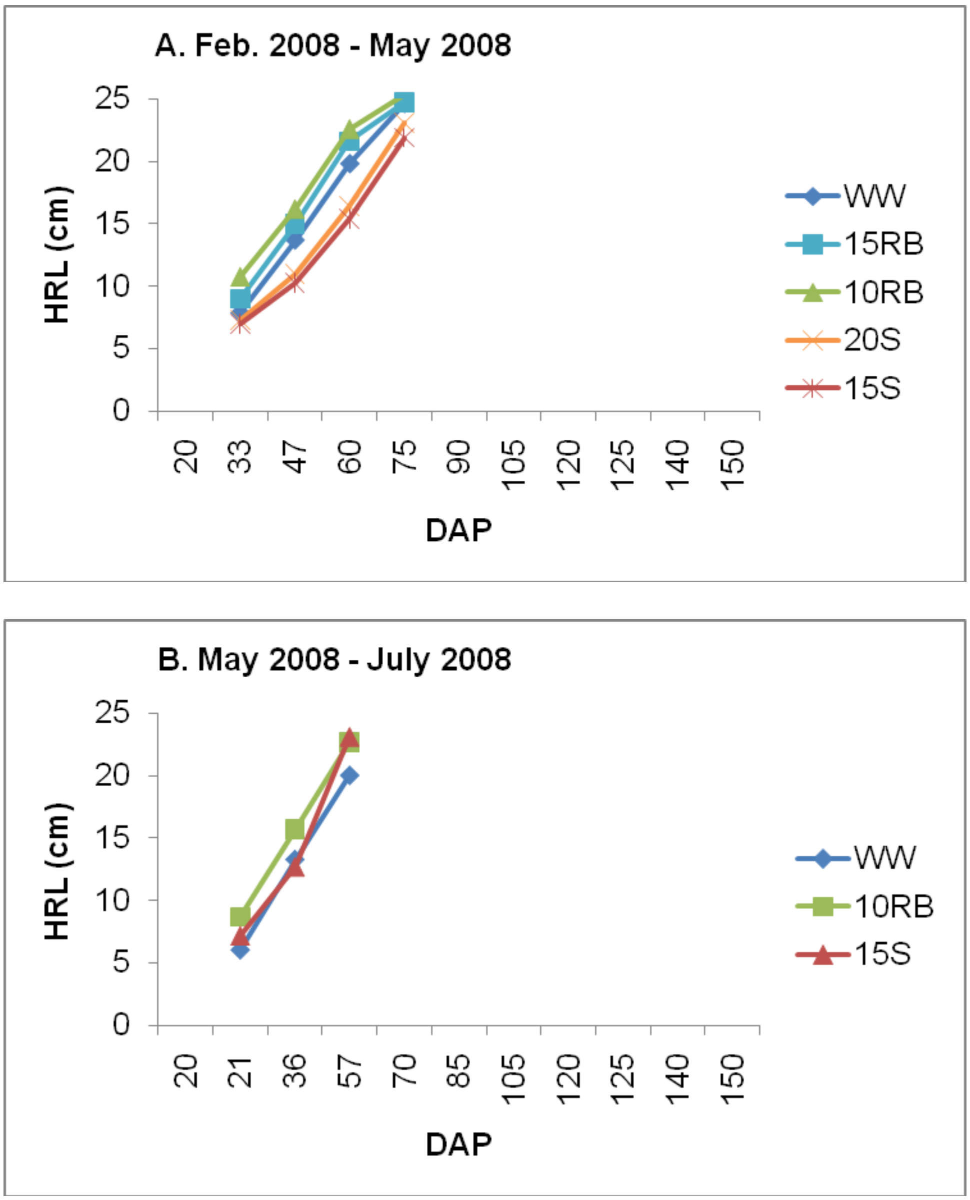


Figure 2. Effect of irrigation frequency on horizontal root length (measured parallel to the ground, HRL) of *Rhododendron austrinum* grown in Horhizotrons in a greenhouse in Auburn, Ala. from (A) 9 June 2008 – 3 Nov. 2008 and (B) 8 Sept. 2008 – 28 Dec. 2008. Treatments began once roots were visible in quadrants (52 and 58 days after planting, DAP, respectively). Treatments include: quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).

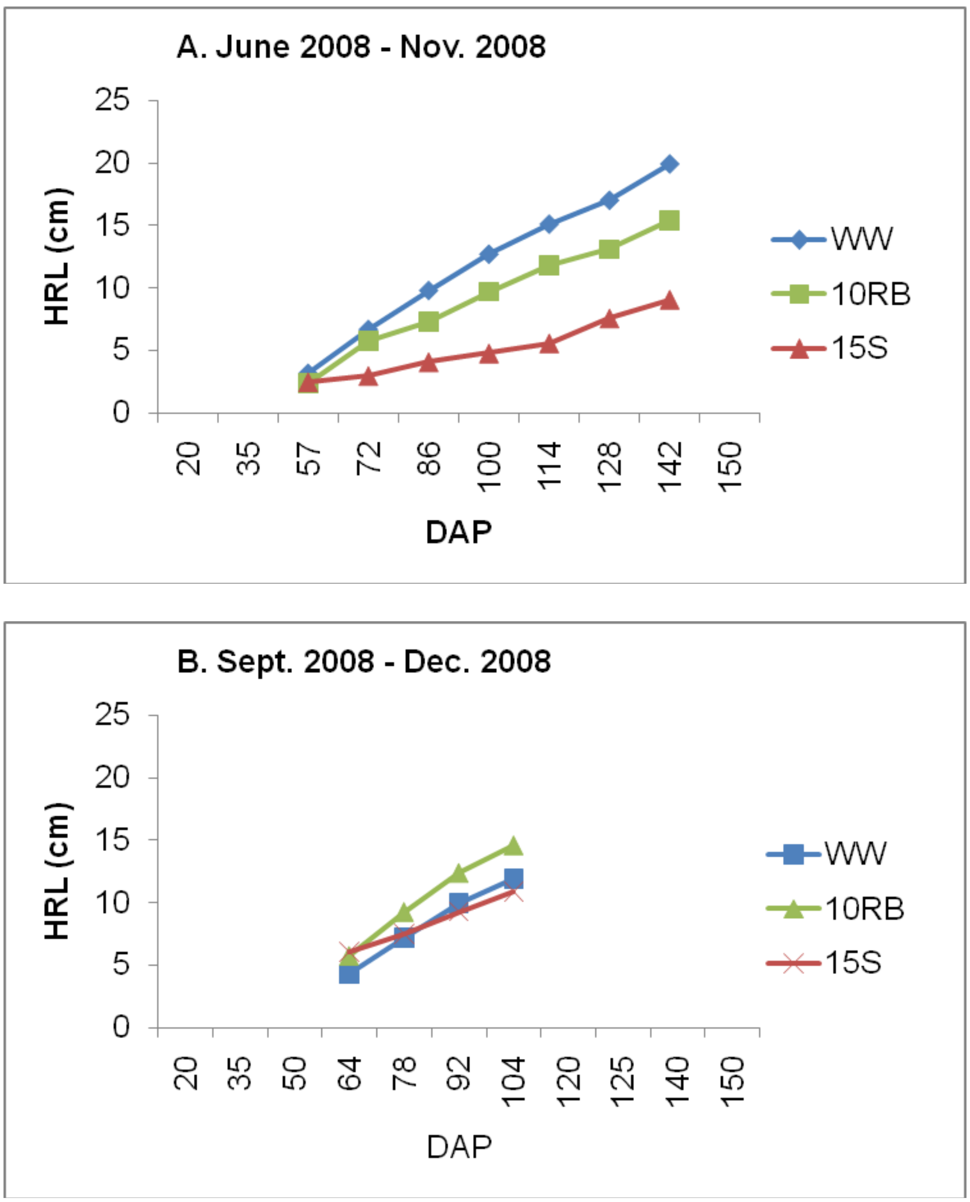


Figure 3. Effect of irrigation scheduling on horizontal root length (measured parallel to the ground, HRL) of *Itea virginica* 'Henry's Garnet' grown in Horhizotrons in a greenhouse in Auburn, Ala. from (A) 18 Feb. 2009 – 16 June 2009 and (B) 1 Apr. 2009 – June 2009. Treatments began once roots were visible in quadrants (and days after planting, DAP, respectively). Treatments include: quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).

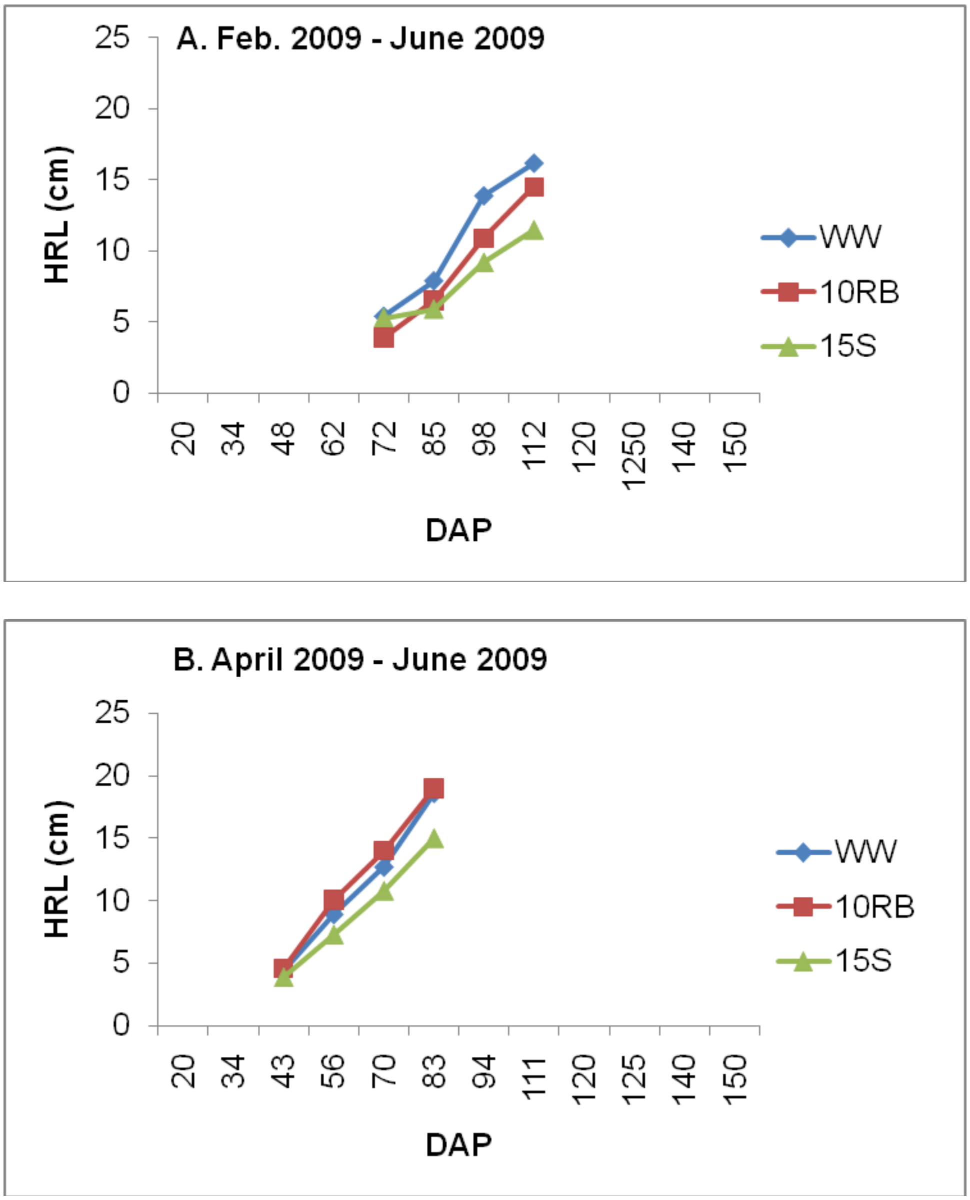
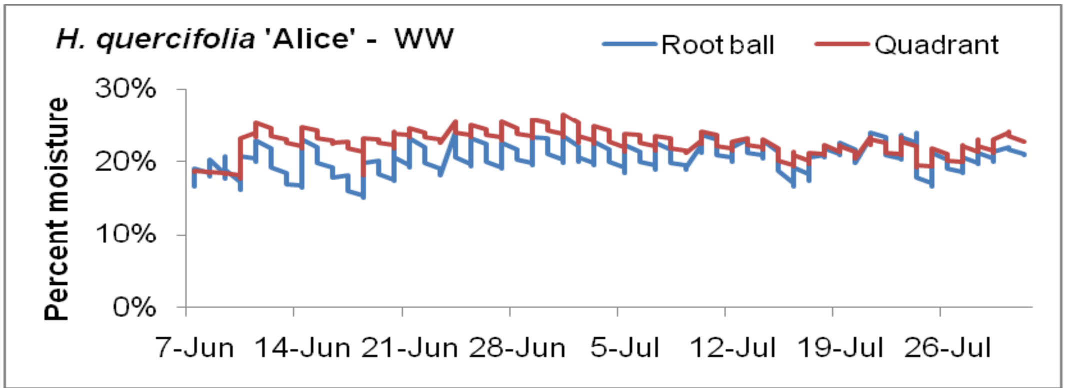
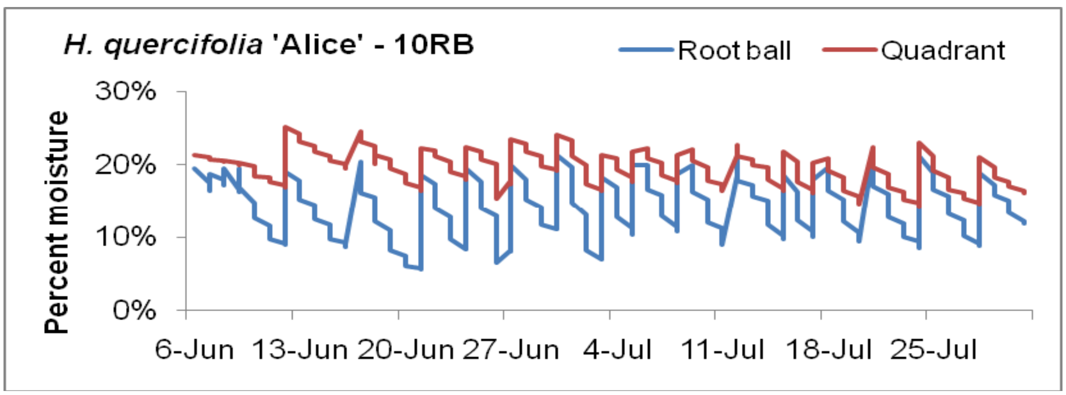


Figure 4. Effect of irrigation frequency on root ball and soil moisture of *Hydrangea quercifolia* 'Alice' grown in Horhizotrons in a greenhouse in Auburn, Ala. from 28 May 2008 – 31 July 2008. Treatments include: quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 15% (15RB); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S) and quadrants and root ball re-watered when quadrant soil moisture reached 20% (20S).





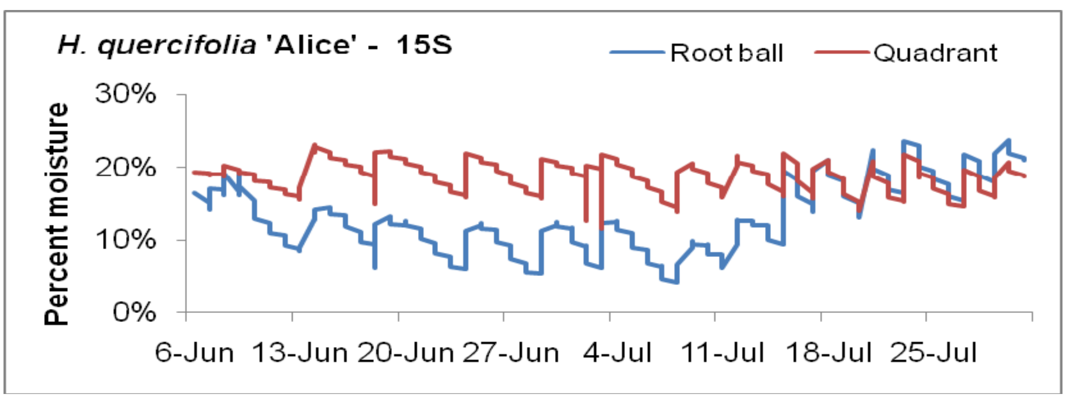


Figure 5. Effect of irrigation scheduling on root ball and soil moisture of *Itea virginica* ‘Henry’s Garnet’ grown in Horhizotrons in a greenhouse in Auburn, Ala. from (A) 18 Feb. 2009 – 16 June 2009. Treatments include: quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).

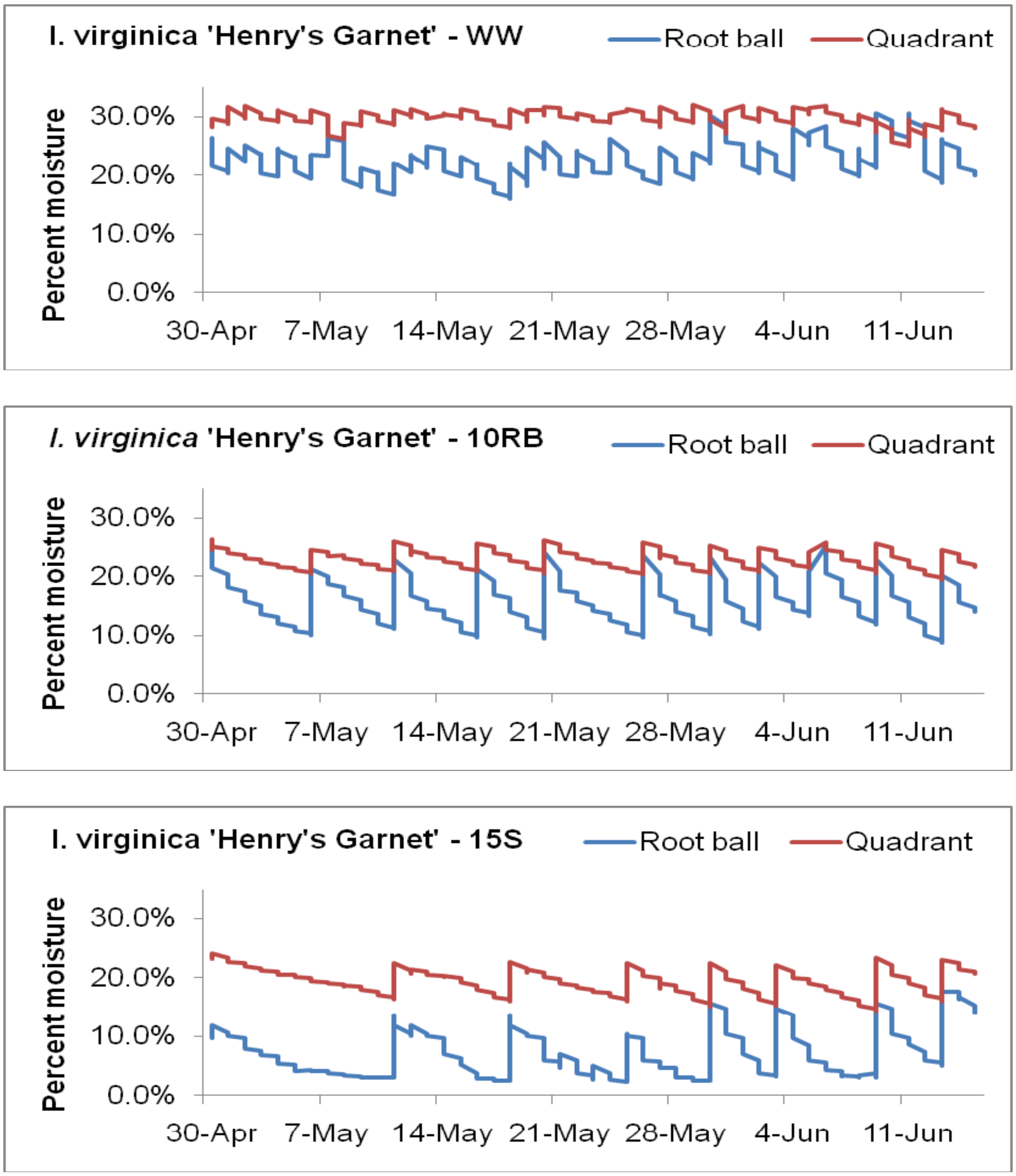
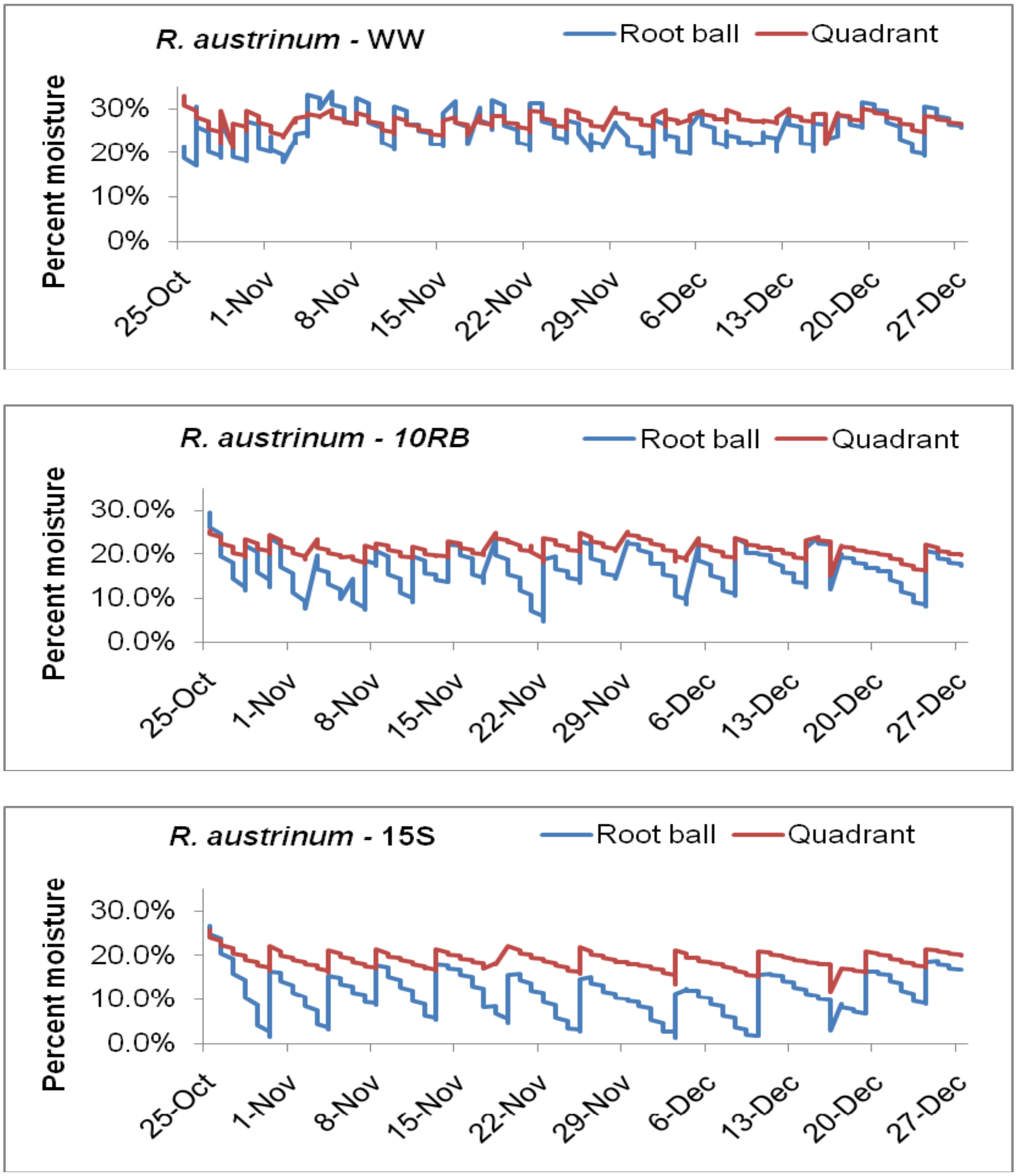


Figure 6. Effect of irrigation frequency on root ball and soil moisture (measured parallel to the ground, HRL) of *Rhododendron austrinum* grown in Horhizotrons in a greenhouse from (B) 8 Sept. 2008 – 28 Dec. 2008.Treatments include: quadrants and root ball maintained at or above 20% moisture (well-watered, WW); quadrants and root ball re-watered when root ball moisture reached 10% (10RB); quadrants and root ball re-watered when quadrant soil moisture reached 15% (15S).



Chapter III

Post-transplant Irrigation Scheduling for Two Native Deciduous Shrub Taxa

Index Words: Establishment, landscape, *Itea virginica* 'Henry's Garnet', *Rhododendron austrinum*

Abstract

Establishing newly transplanted plants in the landscape generally requires the application of irrigation. The effect of five irrigation scheduling treatments on shoot growth and net photosynthesis of *Itea virginica* L. 'Henry's Garnet' ('Henry's Garnet' sweet spire) and *Rhododendron austrinum* Rehd. (florida flame azalea) were studied. All plants were planted on 13 March 2008 at grade level in holes dug twice the width of the root ball, and soil was used to create a berm around the plant beginning at outer edge of root ball. All plants were planted 1.2 m (4 ft) on center under shade structures in field plots of sandy loam soil on the Auburn University campus in Auburn, Ala. Irrigation scheduling treatments included: root ball and surrounding soil maintained at or above 25 cb (centibar) (well-watered, WW); root ball and surrounding soil re-watered when *root ball moisture* reached 50 cb (50RB) or 75 cb (75RB); or root ball and surrounding soil re-watered when *surrounding soil moisture* reached 25 cb (25S) or 50 cb (50S).

Soil moisture was measured 7.6 cm (3 in) from the stem in the root ball and 20.3 cm (8 in) from the stem in the backfill for three plants per treatment per species. Growth index (GI) was measured for each plant at the beginning of the experiment, at the end of the first growing season (7 October 2008), the following spring (17 February 2009), and at experiment termination (30 June 2009). Photosynthetic rates of each plant were measured in 2008 and during Summer 2009. In both taxa shoot growth index (GI) increased linearly over time in all five irrigation treatments. For *I. virginica* 'Henry's Garnet' final GI (474 DAP) was highest in WW and 25S treatments, followed by 50S, 50RB, and 75RB while there were no visible differences among treatments at any measurement date for *R. austrinum*. Both *I. virginica* 'Henry's Garnet' and *R. austrinum* had the largest increase in GI during the first growing season and the lowest in winter months. For *R. austrinum* net photosynthesis (Ps) was different among treatments with WW, 25S, and 50RB higher than 75RB and 50S, and stem water potential (SWP) was not different among treatments. For *I. virginica* 'Henry's Garnet', Ps was different among treatments with treatments of 50S, 50RB, and 25S being higher than in WW, followed by 75RB and SWP was different among treatments with 50S and 75RB higher than 50RB, WW, and 25S. Results indicate that until and even after roots grow into the backfill soil, monitoring both backfill soil and root ball moisture is important for scheduling and reducing post-transplant irrigation applications. Additionally, irrigation frequency for the plants tested can be reduced without compromising plant visual quality or survival.

Introduction

Often the amount irrigated could be considered excessive or beyond plant water needs. Since water restrictions and costs are increasing it is important to know more specific plant water requirements and how best to schedule and monitor these needs in order to conserve water. Irrigation application efficiency in horticulture has become a deeply researched area aimed at optimizing irrigation efficiency and scheduling (Dodd et al., 2006). Due to increasing water restrictions and costs associated with irrigation (Haley et al., 2007), increased research has been done to identify specific water needs of landscape plants. Water is considered the most limiting aspect in newly transplanted container plants (Costello and Paul, 1975; Scheiber et al., 2007), and the most common cause of death of recently transplanted container-grown plants is water stress (Costello and Paul, 1975; Nelms and Spomer, 1983). This could be attributed to the fact that there is greater water loss from the original root ball due to movement of available water into the backfilled soil, which is a greater area for water movement than in container (Costello and Paul, 1975; Nelms and Spomer, 1983).

Research on irrigation application efficiency found irrigation outside the original root ball did not aid in the fast establishment of transplanted trees (Gilman et al., 1998). Instead, irrigation frequency is more important than larger quantities of water applied infrequently to transplanted trees after transplanting 1.2 L of water/cm (1.2 gal/in) of trunk diameter was required to support high-quality growth. There also appeared to be a maximum volume of irrigation water needed for plant functions, above which no added benefit is gained by the plant . This implies that once that volume of water is applied, adding more can be wasteful.

Scheduling irrigation in the landscape based primarily on daytime air temperature and the number of days of precipitation is not well correlated with plant water needs (Qualls et al., 2001). Instead evapotranspiration and precipitation should be used to schedule irrigation. Soil moisture monitoring is a technological approach that can more accurately quantify water use. This should aid in the conservation of water usage in relation to horticultural needs.

Since it has been shown that precision irrigation based on soil moisture lowers direct water usage and can yield the same plant responses, many methods of measuring soil water content have been developed. In the past, soil moisture sensor technology was impractical in landscape irrigation control due to the combination of its limited technology, sensor maintenance requirements, and installation cost (U.S.D.I.B.R., 2006). In recent years there have been significant advancements in soil moisture sensor technology that have led to precise and maintenance-free systems available for landscape use at affordable prices . These sensors have been used to efficiently schedule and control irrigation thereby reducing water usage and lowering direct costs associated with irrigation (Dukes et al., 2005; Qualls et al., 2001).

Correlating soil moisture to physiological plant measurements can be helpful in understanding the effects of plant stressors such as drought (Griffin et al., 2004). Determining photosynthesis and plant water potential at given levels of soil moisture can help us better understand plant physiological functions during times when the plant is well-watered and during times of water stress.

Until newly transplanted container grown plants become established, the plant must attain all water requirements from its original container root ball (Costello and Paul, 1975; Nelms and Spomer, 1983). Percent moisture in the root ball can be very different from the surrounding soil, and in fact, the root ball may experience drought conditions even when soil is well-watered (Costello and Paul, 1975; Nelms and Spomer, 1983). Available water and nutrients in the soil affects root distribution (Bengough et al., 2006; Schachtman and Goodger, 2008). When water is plentiful roots may grow only a small amount, in contrast to times when water is limited, such as during periods of drought, when longer main roots may be required to access water deeper in the soil (Bengough et al., 2006).

More specific irrigation requirements and methods are needed that can reduce water use in the landscape without compromising plant quality. The results from these investigations will be used to schedule post transplant irrigation and to promote water use efficiency in the landscape.

Materials and Methods

Itea virginica L. ‘Henry’s Garnet’ (‘Henry’s Garnet’ sweetspire) and *Rhododendron austrinum* Rehd. (Florida flame azalea) were used in this experiment and all plants were in 11.4 L (3 gal) containers. *I. virginica* ‘Henry’s Garnet’ were obtained from Greene Hill Nursery, Inc. (Lee County, Waverly, Ala.) on 11 March 2008. These plants were propagated from cuttings from existing nursery stock in 2007 and grown in 9:1 pine bark:sand by volume medium. *R. austrinum* were obtained from Moore & Davis Nursery LLC in (Macon County, Shorter, Ala.) on 21 February 2008. These plants were propagated in the summer of 2006 from cuttings from existing nursery stock and grown in 9:1 pine bark:sand by volume medium. All plants were held in an unheated retractable roof greenhouse at the Paterson Greenhouse complex on the Auburn University campus in Auburn, Ala. until installed.

On 13 March 2008 all plants were planted 1.2 m (4 ft) on center in field plots that consist of a Marvyn loamy sand in Auburn, Ala on the Auburn University campus. The full taxonomic classification of this soil is fine-loamy, kaolinitic, thermic Typic Kanhapludults (U.S.D.A.N.R.C.S., 2009). This soil type is made of deep, well drained, moderately permeable soils that formed in loamy marine sediments on Coastal Plain uplands (U.S.D.A.N.R.C.S., 2009). Plants were planted at soil grade level in holes dug twice the width of the root ball, with soil used to create a berm around the plant beginning at outer edge of root ball. *I. virginica* ‘Henry’s Garnet’ were planted under 30% shade and *R. austrinum* were planted under 47% shade. Both shade structures consisted of a metal frame with shade cloth across the top of the pad and extending to the ground on all sides. Initial soil tests did not indicate the need for any addition of fertilizer to plots. A 7.6 cm (3 in) layer of pine straw (*Pinus taeda* L., loblolly pine) was applied to ground between plants and rows. A fresh layer of pine straw 7.6 cm (3 in) was added again in September 2008 and April 2009.

Two field plots were used with one species planted per plot. Within each species (plot) treatments were arranged in a randomized complete block design. There were five blocks with five randomly assigned irrigation scheduling treatments per block. Plants were irrigated with overhead irrigation (#4 Nozzle mini-Wobbler®, Senninger Irrigation, Inc., Clermont, Fla.) three times per week with 2.5 cm (1 in) water until treatments began 1 April 2008. Two rain gauges were installed in each plot area under the shade structure, and dates and amounts of precipitation events throughout the experiment were recorded. Watermark® soil moisture sensors (model 900M) (Irrometer Company, Inc., Riverside, Calif.) were installed 20 March 2008 to measure soil and root ball water potential for use in scheduling irrigation in each of the five treatments. Sensors were installed 7.6 cm (3 in) from the stem in the root ball 10 cm (4 in) deep and 20.3 cm (8 in) from the stem in the surrounding soil 10 cm (4 in) deep on three plants per treatment within each species. The five treatments included: (1) root ball and surrounding soil maintained at or above - 25 cb (centibar) (well-watered, WW); (2) root ball and surrounding soil re-watered when *root ball moisture* reached - 50 cb (50RB); (3) root ball and surrounding soil re-watered when *root ball moisture* reached - 75 cb (75RB); (4) root ball and surrounding soil re-watered when *surrounding soil moisture* reached - 25 cb (25S); (5) root ball and surrounding soil re-watered when *surrounding soil moisture* reached - 50 cb (50S). Treatments were selected based on recommendations from the manufacturer of sensors (Irrometer Company, Fla.) and personal communication with others (Haris, 2008). When re-watered, plants were hand watered with 2.5 cm (1 in) of water applied in a 30.5 cm (12 in) radius around the plant [7.4 L (1.9 gal) water per plant]. By applying water in concentric circles that became gradually smaller effort was made to evenly distribute water on the root ball and surrounding soil. Growth index (GI) [(widest width + width perpendicular + height)/3] was measured for each plant at the beginning of the experiment (initial GI), before the start of the first growing season (7 Oct. 2008, Fall 08), at the end of the second growing season (17 Feb. 2009, Spring 09), and at experiment termination (30 June 2009, final GI, Summer 09). Cumulative relative growth index (RGI) was calculated for all plants each measurement date [(GI_x – initial GI)/initial GI] where GI_x = GI at that particular measurement date. Seasonal RGI was also calculated to reflect change in GI since the last measurement [(GI_x – GI_{x-1})/GI_{x-1}] where GI_x = GI at that particular measurement date and GI_{x-1} = GI at the previous measurement date. Cumulative GI [cumulative GI/DAP (days after planting)] was calculated to reflect cumulative change in shoot growth per day over the course of the experiment [(GI_x – initial GI)/DAP] where GI_x and DAP_x are GI and DAP at that particular measurement date. Seasonal GI (seasonal

GI/DAP) was also calculated to reflect change in shoot GI per day since the last measurement [(GI_x – GI_{x-1})/DAP_x - DAP_{x-1}] where GI_x and DAP_x are GI and DAP at that particular measurement date, and where GI_{x-1} and DAP_{x-1} are GI and DAP at the previous measurement date.

Net photosynthesis of each plant were measured using the LI-COR 6400 (Model 1000, LI-COR Biosciences, Inc., Lincoln, Nebr.) immediately before and after re-watering in the Spring and Summer of 2009. All measurements were taken beginning at 10:00 AM and generally concluded by 11:30 AM. Immediately following net photosynthesis measurements plants in corresponding treatments were irrigated and the following morning "after" irrigation photosynthesis was measured. Photosynthetically active radiation (PAR) within the cuvette of the LI-COR was set at 1800 $\mu mol \bullet m^{-2} \bullet s^{-1}$. Reference carbon dioxide was set as 400 ppm, stomatal ratio was set to 0, flow rate was set to 500 mol/sec, and temperature and humidity were set as ambient. Stem water potential was measured using a pressure chamber (PMS Instruments, Corvallis, Ore.) on the same days as net photosynthesis measurements. When measuring stem water potential a 10 cm (4 in) terminal stem section was removed from each plant at 10:00 AM placed in a plastic bag, put on ice in a cooler, and immediately returned to the lab (approximate 5 minute transport). Stem sections were then recut to 7.6 cm (3 in), foliage was removed from the basal end 2.5 cm (1 in) of the stem, and stem water potential was measured using the pressure chamber.

Data were analyzed using GLM procedures and regression analysis, and means separation using Least Significant Difference ($P<0.05$) (SAS Institute Inc., 2003).

Results

I. virginica 'Henry's Garnet'

All plants in all treatments survived for *I. virginica* 'Henry's Garnet'. Shoot growth index (GI) increased linearly over time in all five irrigation treatments (Table 1, Fig. 1). At 208 days after planting (DAP) GI was highest in WW followed by 50S, 25S, 50RB, and 75RB ($P = 0.002$). At 341 DAP GI was highest in WW and 50S treatments, followed by 25S, 50RB and 75RB (Fig. 1). Final GI (474 DAP) was highest in WW and 25S treatments, followed by 50S, 50RB, and 75RB (Table 2, Fig. 1). Cumulative relative growth index (RGI) and seasonal RGI were different among treatments (Table 3). Cumulative RGI at all three measurement dates was highest in WW and 25S treatments, followed by 50S and 75RB, and was lowest in 50RB (Table 3). Seasonal RGI had the greatest increase in growth in Fall 2008 (Table 3). Seasonal RGI in Fall 2008 was greatest in WW and 25S treatments, followed by 50S and 75RB, and was lowest in 50RB (Table 3). Spring 2009 seasonal RGI was highest in 50RB, 75RB, and 50S treatments, followed by WW and 25S (Table 3). Seasonal RGI shifted again in Summer 2009 with the highest RGI in 50RB, 75RB, and 25S, followed by WW and 50S (Table 3). Both cumulative GI by day (cumulative GI/DAP) and seasonal GI by day (seasonal GI/DAP) were different among treatments (Table

2). Overall, the largest increase in growth occurred between Spring 2008 and Fall 2008 (Table 2). The largest increase in growth was in WW which grew 0.26 cm/day, followed by 25S (0.20 cm/day) and 50S (0.19 cm/day), and was lowest in 50RB (0.13 cm/day) and 75RB (0.13 cm/day) (Table 2). Between Fall 2008 and Spring 2009 growth in all treatments slowed and plants grew on average only 0.03 cm/day (Table 2). Shoot growth began to increase again between Spring 2009 and Summer 2009 where the largest increase in GI was in WW, 50RB, 75RB, and 25S; which grew an average of 0.10 cm/day, while 50S grew 0.07 cm/day (Table 2).

Net photosynthesis (Ps) was different among treatments with that of 50S, 50RB, and 25S being higher than in WW, followed by 75RB (Table 4). Comparing Ps within a treatment for before and after irrigation, Ps was only different in 75RB where after Ps was great than before Ps measurements (Fig. 2).

Stem water potential (SWP) was different among treatments with 50S and 75RB higher than 50RB, WW, and 25S (Table 4). SWP taken before and after irrigation did have some differences among irrigation frequency treatments (Fig. 3). In 75RB before, SWP was higher than WW followed by 75RB after, while 50S after was higher than 50S before and WW (Fig. 3).

R. austrinum

All plants in all treatments survived for *R. austrinum.* Shoot growth index (GI) increased linearly overtime in all five irrigation treatments (Table 1, Fig. 1).

There were no visible differences among treatments at any measurement date (Fig. 1), however, cumulative and seasonal RGI were different among treatments (Table 3). Cumulative RGI in Fall 2008 was highest in WW, 50RB, and 75RB treatments, followed by 25S and 50S (Table 3). Spring and Summer 2009 cumulative RGI both followed the same trend with seasonal RGI being highest in WW, 50RB, 75RB, and 25S treatments, followed by 50S (Table 3). Seasonal RGI in Fall 08 was highest in WW, 50RB, and 75RB treatments, followed by 25S and 50S (Table 3). Spring 2009 seasonal RGI was highest in WW, 50RB, 25S, and 50S treatments and was lowest in 75RB (Table 3). Summer 2009 seasonal RGI had no differences among treatments (Table 3). Both cumulative GI by day (cumulative GI/DAP) and seasonal GI by day (seasonal GI/DAP) also had differences among treatments (Table 2). Overall, the largest increase in growth occurred between Spring 2008 and Fall 2008 (Table 2). The largest increase in growth was in WW, 50RB, and 75RB which grew an average of 0.13 cm/day, followed by 50S (0.11 cm/day) and 25S (0.11 cm/day) (Table 2). Between Fall 2008 and Spring 2009 growth in all treatments slowed and plants grew an average of 0.03 cm/day (Table 2). Shoot growth had a large increase between Spring 2009 and Summer 2009 where WW, 50RB, 75RB, and 25S plants grew an average of 0.10 cm/day, while 50S grew 0.07 cm/day (Table 2).

Net photosynthesis (Ps) was different among treatments with WW, 25S, and 50RB higher than 75RB and 50S (Table 4). Comparing Ps within a treatment before and after irrigation, Ps measurements were different; WW and

50RB after were higher than 50RB before, WW was higher than 75RB after followed by 75RB before, and WW and 50S after were higher than 50S before (Fig. 2).

Stem water potential (SWP) was not different among treatments, while SWP within a treatment taken before and after irrigation was different for 75RB before which was higher than WW and 75RB after (Table 4, Fig. 3).

Discussion

Both *I. virginica* ‘Henry’s Garnet’ and *R. austrinum* had the largest increase in GI during the first growing season (Table 2, 3). During the first growing season, with the exception of plants in WW treatments, RGI was approximately two times higher in *I. virginica* ‘Henry’s Garnet’ than *R. austrinum* in soil treatments; in WW treatments, RGI was approximately three times higher in *I. virginica* ‘Henry’s Garnet’ than *R. austrinum* (Table 3). Cumulative RGI continued to be two times higher in *I. virginica* ‘Henry’s Garnet’ soil treatments than in *R. austrinum* (soil treatments) at the following two measurement dates (Table 3). For seasonal RGI after the first growing season when *I. virginica* ‘Henry’s Garnet’ was two times higher than *R. austrinum*, at the following two measurement dates seasonal RGI was similar between taxa (Table 3). After Fall 2008, treatment differences became smaller and could be attributed to increased precipitation (Fig. 4), which decreased soil drying and resulted in fewer scheduled irrigation applications. Initial GI of *I. virginica* ‘Henry’s Garnet’ and *R. austrinum* were 45 cm (18 in) and 58 cm (23 in), respectively. Initially *I.* virginica

‘Henry’s Garnet’ was smaller than *R. austrinum*, which may explain why *I.* virginica ‘Henry’s Garnet’ RGI was much higher than *R. austrinum* (Table 3). Furthermore, the similar cm/day growth rate reflected *I. virginica* ‘Henry’s Garnet’ growing more relative to its size than *R. austrinum,* which grew less (Table 2). Shoot GI did increase in all treatments and both species. Overall, irrigation frequency affected shoot growth more in *I. virginica* ‘Henry’s Garnet’ than *R. austrinum* (Table 3, Fig. 1). The apparent difference in shoot growth may be attributed to the fast growth rate of *I. virginica* ‘Henry’s Garnet’. Since *R. austrinum* has a slower growth rate, shoot growth was not as affected by fewer irrigation events. The number of inflorescences per plant was also affected by irrigation scheduling treatments for *I. virginica* ‘Henry’s Garnet’. *I. virginica* ‘Henry’s Garnet’ WW had more inflorescences per plant (161) than all other treatments (78).

Net photosynthesis (Ps) fluctuated more within an irrigation treatment for *R. austrinum* than *I. virginica* ‘Henry’s Garnet’. In *R. austrinum*, Ps was generally higher in WW or after irrigation than in a treatment before irrigation (Fig. 2). With the exception of 50S, all plants were able to maintain or “recover” Ps rates after irrigation in both taxa (Table 4, Fig. 3). *R. austrinum* 50S was the driest treatment and had the lowest Ps rates, which is consistent with others who found that generally one of the first responses to minimize plant water loss during periods of drought is the closing of stomata with decreased photosynthesis as a result (Chaves et al., 2003; Bargali and Tewari, 2004; Griffin et al., 2004;

Schachtman and Goodger, 2008). Though *R. austrinum* plants in 50S treatments continued to grow over the course of the experiment, growth rates and Ps rate were lower than other more frequently irrigated treatments. These results are in agreement with Herms and Mattson (1992) who found that growth of a species often declines before photosynthetic rates of that species when under stress, but in this case the plants were under such stress that both growth and Ps had begun declining.

Within a treatment, SWP fluctuated more in *I. virginica* 'Henry's Garnet' than *R. austrinum* and was lower before irrigation than after or in WW treatments (Fig. 3). Fluctuations in *I. virginica* 'Henry's Garnet' may be a result of the succulent new shoot growth, which was used in sampling (terminal stem sections), while *R. austrinum* stem samples were more woody. *I. virginica* 'Henry's Garnet' treatments irrigated more frequently had similar SWP, while those least irrigated (75RB and 50S) had more fluctuations in SWP (Fig. 3). In 50S, the driest treatment, it is not clear why after irrigation plants had a lower SWP than before irrigation (Fig. 3). In 25S, the one most frequently irrigated after WW, SWP was not different between before and after irrigation or from WW (Fig. 3).

With the exception of WW, irrigation frequency increased over time in all other treatments. For example, days between irrigation decreased in 25S from once every 8 days to once every 4 days (Fig. 5) for *I. virginica* 'Henry's Garnet' and decreased from once every 9 days to once every 5 days in R. austrinum

(Fig. 6). Plants receiving 50S treatments, days between irrigation decreased from once every 9 days to once every 6 days (Fig. 5) for *I. virginica* 'Henry's Garnet'. Plants receiving 50RB treatments, days between irrigation decreased from once every 6 days to once every 4 days (Fig. 5) for *I. virginica* 'Henry's Garnet' and decreased from once every 6 days to once every 5 days for *R. austrinum* (Fig. 6). Plants receiving 75RB treatments, days between irrigation decreased from once every 14 days to once every 8 days (Fig. 5) for *I. virginica* 'Henry's Garnet' and decreased from once every 12 days to once every 6 days for *R. austrinum* (Fig. 6). In general, plants in both taxa that were WW received water once every 4 or 5 days throughout the experiment (Fig. 5, 6). During winter months neither taxa needed additional irrigation and root ball and soil moisture remained high (Fig. 5, 6). Approximate volume of irrigation applied over the course of a growing season was determined [(total days in growing season/ average number of days between irrigation events within a treatment) x 7.1 L]. During the first growing season *I. virginica* 'Henry's Garnet' WW received 341 L (90 gal) of water, 50RB received 227 L (60 gal) of water, 75RB received 97 L (25 gal) of water, 25S received 170 L (45 gal) of water, and 50S received 151 L (40 gal) of water. Beginning April 2009 to experiment termination (30 June 2009) *I. virginica* 'Henry's Garnet' WW received 136 L (36 gal) of water, 50RB received 136 L (36 gal) of water, 75 RB received 68 L (18 gal) of water, 25S received 136 L (36 gal) of water, and 50S received 90 L (24 gal) of water. During the first growing season *R. austrinum* WW received 341 L (90 gal) of water, 50RB received 227 L (60 gal) of water, 75RB received 113 L (30 gal) of water, 25S received 151 L (40 gal) of water, and 50S received 45 L (12 gal). Beginning April 2009 to experiment termination (30 June 2009) *R. austrinum* WW received 136 L (36 gal)

of water, 50RB received 105 L (28 gal) of water, 75RB received 90 L (24 gal) of water, 25S received 105 L (28 gal) of water, and 50S received 21 L (5.7 gal) of water.

I. virginica 'Henry's Garnet' plants in the WW treatment and the treatments based on soil moisture had the most growth and received the most irrigation due to the fact that roots were growing into the surrounding soil, likely at a faster rate than roots of *R. austrinum*. In greenhouse studies *I. virginica* 'Henry's Garnet' had faster rates of root growth than *R. austrinum* (unpublished data). At planting *I. virginica* 'Henry's Garnet' had fewer roots in the original root ball than *R. austrinum* in which the root ball was completely filled with roots. This may explain why *I. virginica* 'Henry's Garnet' in treatments based on root ball moisture were irrigated less frequently than *R. austrinum* in treatments based on root ball moisture. Rate of root growth following transplanting is a critical factor for transplant establishment and survival (Watson and Himelick, 1997). The slower rates of root growth for *R. austrinum* were typical of plants with fibrous, hair-like root systems (Wright et al., 2004; Wright et al., 2007; Price et al., 2009).

Consistently, the biggest difference between root ball and soil moisture occured when irrigation scheduling was based on soil moisture rather than root ball moisture. This illustrates how fast the root ball can dry, which is much faster than the soil (Nelms and Spomer, 1983; Costello and Paul, 1975). Regardless of the presence of plant roots in the soil, the root ball still dried at a faster rate than the soil, however as roots grew into the soil, differences between root ball and soil moisture decreased. When scheduling irrigation based on soil moisture the volume of water applied may need to be increased, since root ball moisture tends to be lower than soil (Fig. 5, 6).

Results suggest that monitoring root ball moisture is more effective for irrigation scheduling than monitoring the surrounding soil moisture with respect to increased shoot growth and initial establishment of a plant. Results indicate that irrigation frequency can be reduced if soil or root ball moisture is monitored. This is in agreement with other research which found that irrigation outside the original root ball did not aid in quick establishment of transplanted trees (Gilman et al., 1998), and initially following transplanting root ball moisture can be significantly lower than backfill soil (Nelms and Spomer, 1983; Costello and Paul, 1975). In all cases it appears that until and once roots grow into the backfill soil, monitoring both backfill soil and root ball moisture is important for scheduling post-transplant irrigation.

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Table 1. Effect of irrigation frequency on shoot growth of *Itea virginica* 'Henry's Garnet' and *Rhododendron austrinum* grown in field plots. Shoot growth index (GI[z]) was taken for each plant at planting and GI was measured at the end of each growing season [208 DAP (Fa 08), 341 DAP (Sp 09), and 474 DAP (Su 09)].

I. virginica 'Henry's Garnet'

Treatment[z]	Equation[y]	R^2	P-value
WW	y = 0.14x + 52.67	0.79	< 0.0001
50RB	y = 0.09x + 51.08	0.75	< 0.0001
75RB	y = 0.09x + 42.51	0.84	< 0.0001
25S	y = 0.12x + 49.28	0.87	< 0.0001
50S	y = 0.11x + 52.47	0.86	< 0.0001

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

R. austrinum

Treatment	Equation	R^2	P-value
WW	y = 0.09x + 60.93	0.88	< 0.0001
50RB	y = 0.10x + 59.43	0.82	< 0.0001
75RB	y = 0.09x + 59.85	0.77	< 0.0001
25S	y = 0.08x + 57.76	0.85	< 0.0001
50S	y = 0.08x + 61.31	0.76	< 0.0001

Significance	P-value
Treatment	< 0.0001
DAP	< 0.0001
Treatment x DAP	0.06

[z]Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50 RB) or 75 cb (75 RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25 S) or 50 cb (50 S).
[y]y = GI, x = Days after planting

Table 2. Effect of irrigation frequency on shoot growth of *I. virginica* 'Henry's Garnet' and *R. austrinum* grown in field plots. Initial growth index (GI) was taken for each plant at planting and GI was measured at the end of each growing season [208 DAP (Fa 08), 341 DAP (Sp 09), and 474 DAP (Su 09)].

I. virginica 'Henry's Garnet'							
		GI/DAP - Cumulative[z]			GI/DAP - Seasonal[y]		
Treatment[x]	Final GI (cm)	Fa 08	Sp 09	Su 09	Fa 08	Sp 09	Su 09
WW	115.4a[w]	0.26a	0.17a	0.15a	0.26a	0.03	0.08ab
50RB	94.6cb	0.13c	0.09c	0.09c	0.13c	0.04	0.10ab
75RB	89.7c	0.13c	0.09c	0.10bc	0.13c	0.03	0.12a
25S	104.9ab	0.20b	0.14b	0.12ab	0.20b	0.03	0.10ab
50S	102.6b	0.19b	0.13b	0.12bc	0.19b	0.03	0.07b
R. austrinum							
		GI/DAP - Cumulative			GI/DAP - Seasonal		
Treatment	Final GI (cm)	Fa 08	Sp 09	Su 09	Fa 08	Sp 09	Su 09
WW	107.2	0.13abc	0.09abc	0.10ab	0.13abc	0.04	0.11
50RB	111.2	0.13ab	0.10a	0.11a	0.13ab	0.04	0.14
75RB	103.6	0.15a	0.10ab	0.10ab	0.15a	0.02	0.09
25S	99.8	0.11c	0.08bc	0.09ab	0.11c	0.03	0.11
50S	100.3	0.11bc	0.08c	0.08b	0.11bc	0.03	0.10

[z]Cumulative GI/DAP = [(GI$_x$ – initial GI)/DAP] where GI$_x$ = GI at that particular measurement date.

[y]Seasonal GI/DAP = $[(GI_x - GI_{x-1})/DAP_x - DAP_{x-1}]$ where GI_x and DAP_x = GI and DAP at that particular measurement date and with GI_{x-1} and DAP_{x-1} = GI and DAP at the previous measurement date.

[x]Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S).

[w]Letters represent means separation among treatments within species using LSD ($P<0.05$). If no differences then letters are omitted.

Table 3. Effect of irrigation frequency on shoot growth of *Itea virginica* 'Henry's Garnet' and *Rhododendron austrinum* grown in field plots. Initial growth index (GI) was taken for each plant at planting and GI was measured at the end of each growing season [208 DAP (Fa 08), 341 DAP (Sp 09), and 474 DAP (Su 09)] and relative growth index was calculated (RGI). Treatments began 1 May 2008 (51 days after planting, DAP).

I. virginica 'Henry's Garnet'

	RGI - Cumulative[z]			RGI – Seasonal[y]		
Treatment[x]	Fa 08	Sp 09	Su 09	Fa 08	Sp 09	Su 09
WW	1.26a[w]	1.37a	1.64a	1.26a	0.05b	0.11b
50RB	0.57d	0.68c	0.96c	0.57d	0.07a	0.16ab
75RB	0.68cd	0.80bc	1.21bc	0.68cd	0.07a	0.22a
25S	0.99ab	1.10ab	1.43ab	0.99ab	0.05b	0.15ab
50S	0.90bc	1.01b	1.23bc	0.90bc	0.05ab	0.10b

R. austrinum

	RGI - Cumulative			RGI - Seasonal		
Treatment	Fa 08	Sp 09	Su 09	Fa 08	Sp 09	Su 09
WW	0.46ab	0.57ab	0.83ab	0.46ab	0.07a	0.16
50RB	0.51ab	0.59ab	0.93a	0.51ab	0.05ab	0.21
75RB	0.57a	0.62a	0.86ab	0.57a	0.04b	0.14
25S	0.41b	0.48ab	0.76ab	0.41b	0.05ab	0.18
50S	0.40b	0.47b	0.69b	0.40b	0.04ab	0.15

[z]Cumulative RGI = (GI_x – initial GI)/initial GI, where GI_x = GI at that particular measurement date.
[y]Seasonal RGI = (GI_x – GI_{x-1})/GI_{x-1} where GI_x = GI at that particular measurement date and GI_{x-1} = GI at the previous measurement date.
[x]Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50 RB) or 75 cb (75 RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25 S) or 50 cb (50 S).
[w]Letters represent means separation among treatments within species using LSD ($P<0.05$). If no differences then letters are omitted.

Table 4. Effect of irrigation frequency on net photosynthesis (Ps) (μmol/m$^{2/}$sec) and stem water potential (SWP) (-MPa) of *I. virginica* 'Henry's Garnet' and *R. austrinum* grown in field plots in Auburn, Ala. Ps and SWP measurements were taken before and after irrigation 13 April 2009 – 25 June 2009.

I. virginica 'Henry's Garnet'			*R. austrinum*	
Treatment	Ps	SWP	Ps	SWP
WW	14.5b	0.87c	12.6a	1.13
50RB	16.8a	0.94bc	11.3ab	0.68
75RB	11.5c	1.04a	8.8b	0.89
25S	14.5ab	0.66c	14.1a	1.12
50S	18.5a	1.16a	3.8c	0.75

[z]Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S).
[y]Letters represent means separation among treatments within species using LSD (P<0.05). If no differences then letters are omitted.

Figure 1. Effect of irrigation frequency on shoot growth of (A) *Itea virginica* 'Henry's Garnet' and (B) *Rhododendron austrinum* grown in field plots. Shoot growth indeces (GI) were measured for each plant on 13 march 2008, 7 Oct. 2008 (208 DAP), 17 Feb. 2009 (341 DAP), and 30 June 2009 (474 DAP). Treatments began 1 May 2008 (51 days after planting, DAP). Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S).

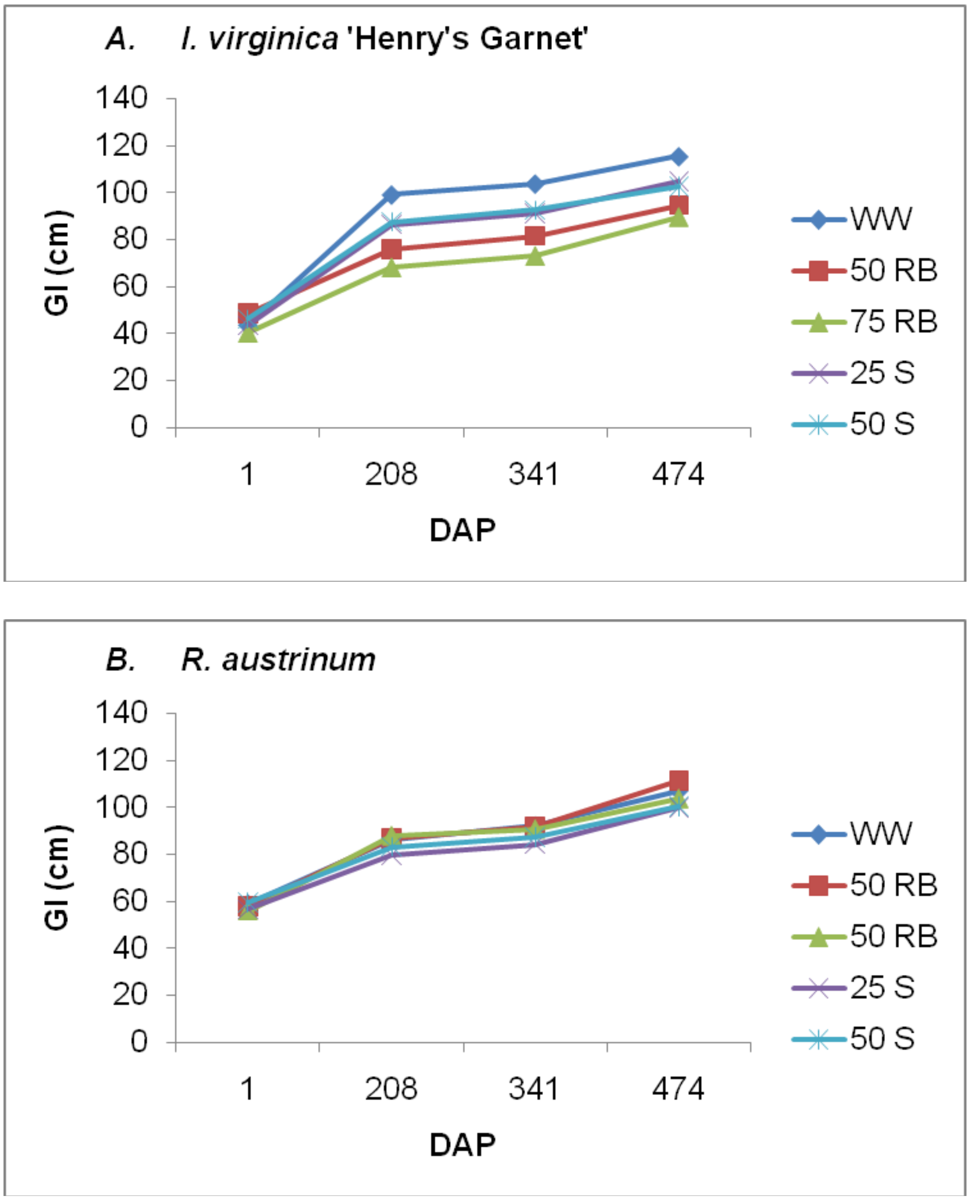
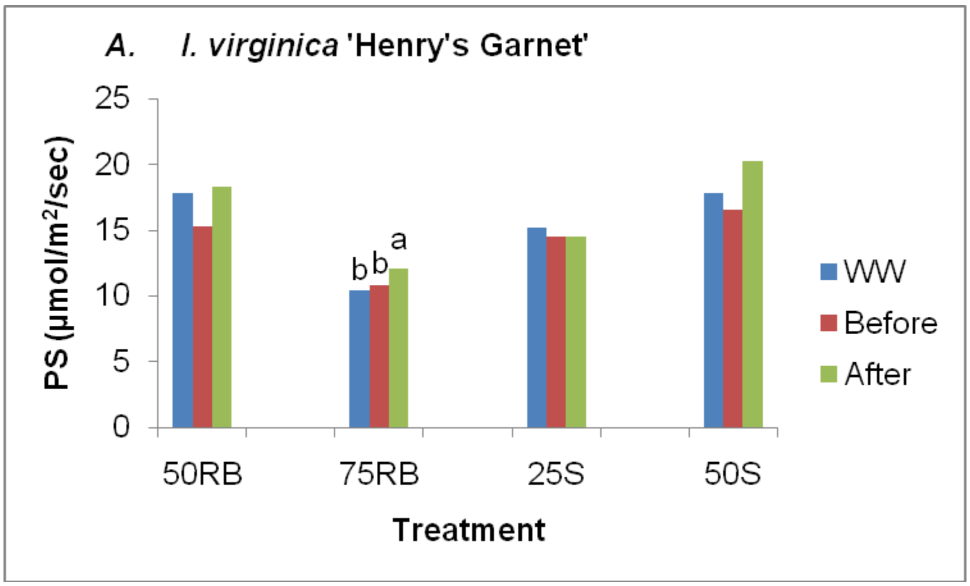


Figure 2. Effect of irrigation frequency on net photosynthesis (Ps) of (A) *Itea virginica* 'Henry's Garnet' grown in a field plot under 30% shade and (B) *Rhododendron austrinum* grown in a field plot under 47% shade from 13 Mar. 2008 – 25 June 2009. Irrigation frequency treatments included: root ball and surrounding soil maintained at or above 25 cb (centibar) (well-watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S). Photosynthesis measurements were taken before and after irrigation 13 April 2009 – 25 June 2009. Letters represent means separation among treatments within species using LSD ($P<0.05$). If no differences then letters are omitted.



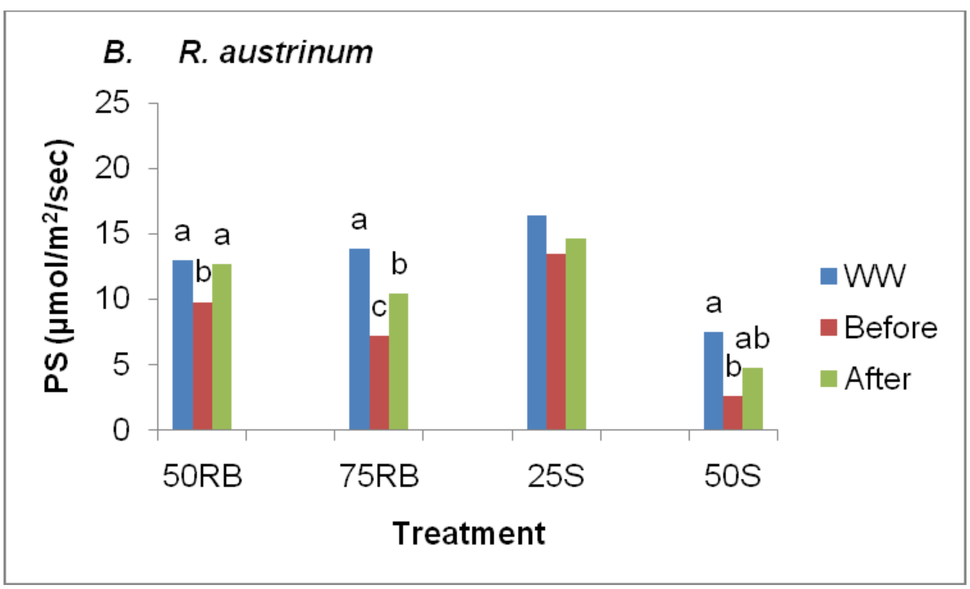
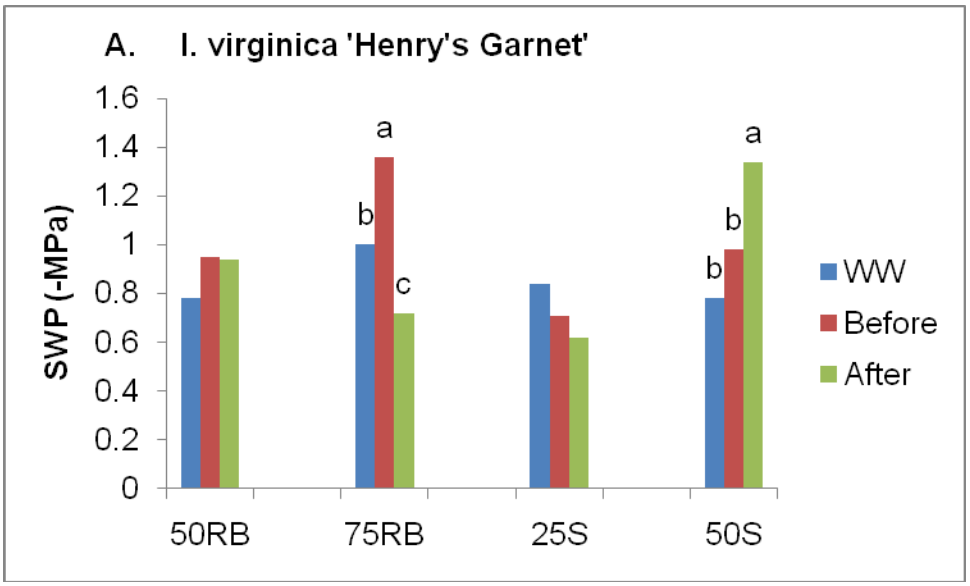


Figure 3. Effect of irrigation frequency on stem water potential (SWP) of (A) *Itea virginica* 'Henry's Garnet' grown in a field plot under 30% shade and (B) *Rhododendron austrinum* grown in a field plot under 47% shade from 13 Mar. 2008 – 25 June 2009. Irrigation frequency treatments included: root ball and surrounding soil maintained at or above 25 cb (centibar) (well-watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S). Stem water potential measurements were taken before and after irrigation 13 April 2009 - 25 June 2009. Letters represent means separation among treatments within species using LSD (P<0.05). If no differences then letters are omitted.



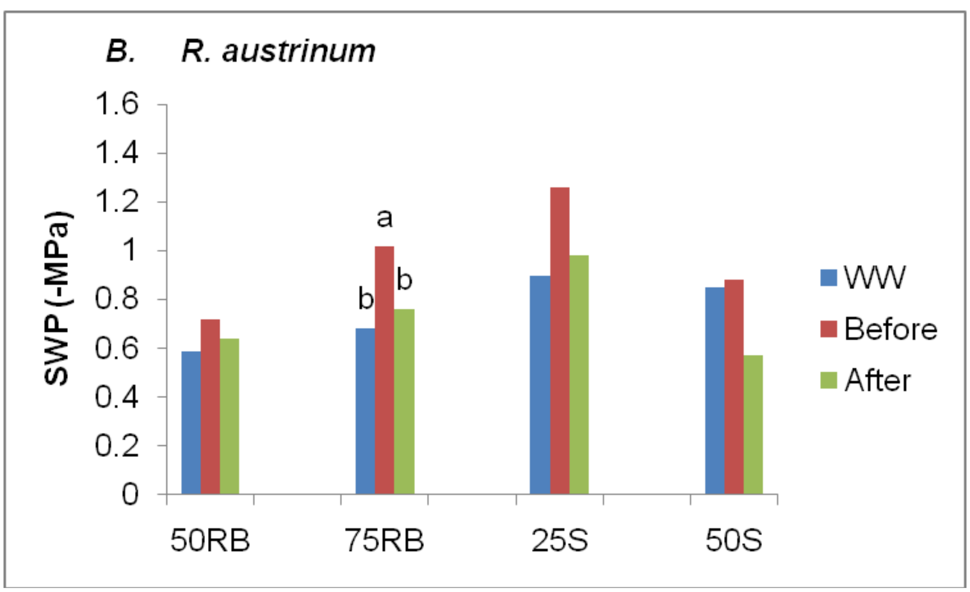


Figure 4. Rainfall amounts from June 2008 – June 2009. Two rain gauges were placed in each field plot with *Itea virginica* 'Henry's Garnet' and *Rhododendron austrinum*. Rainfall amounts were averaged between the 4 rain gauges for this graph.

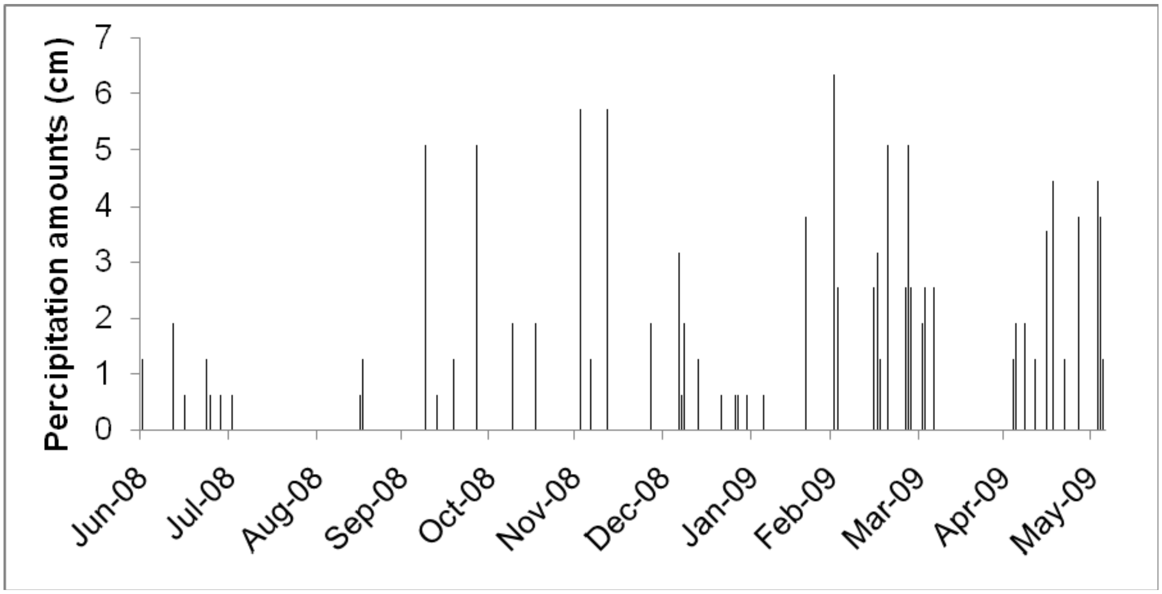
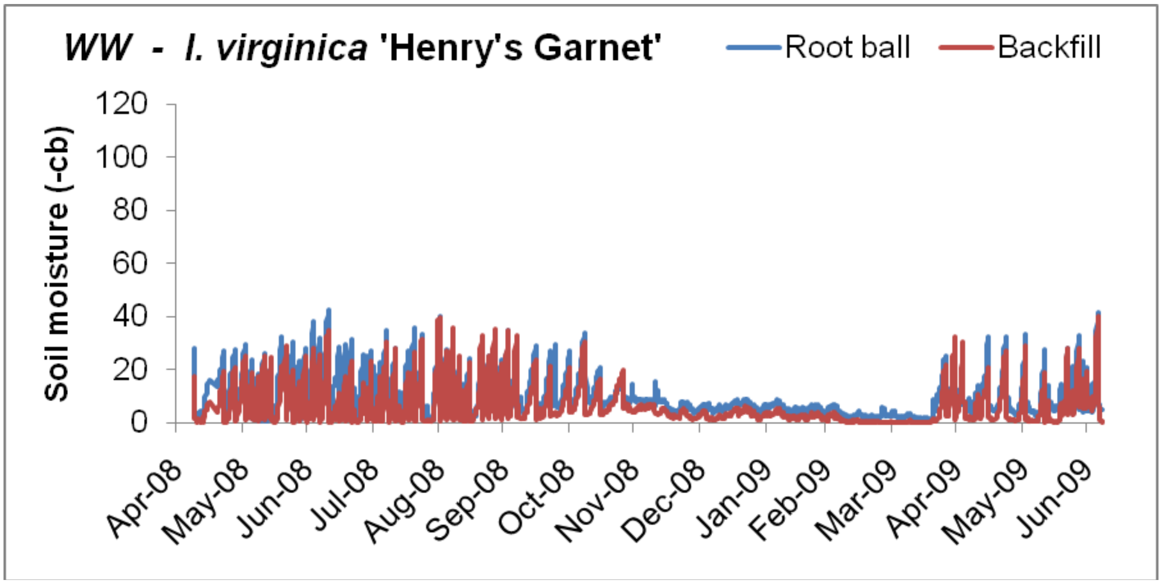
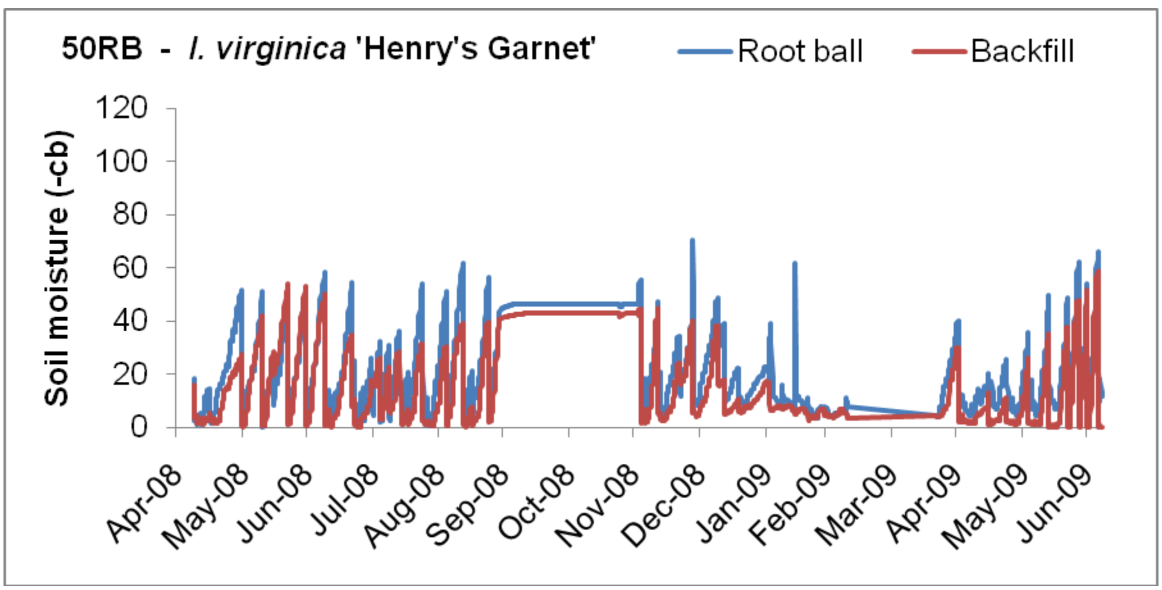
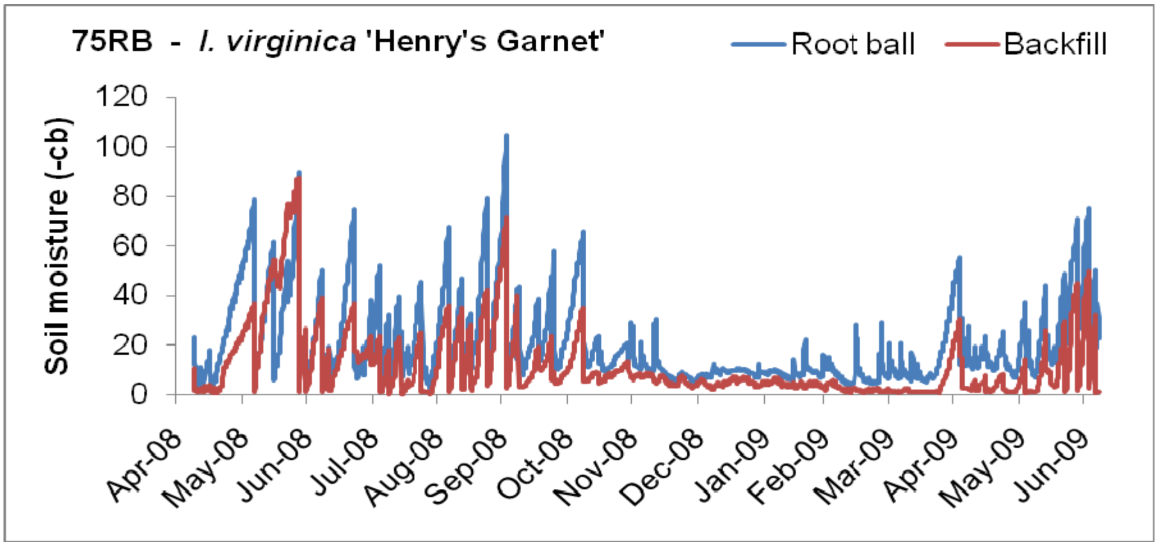
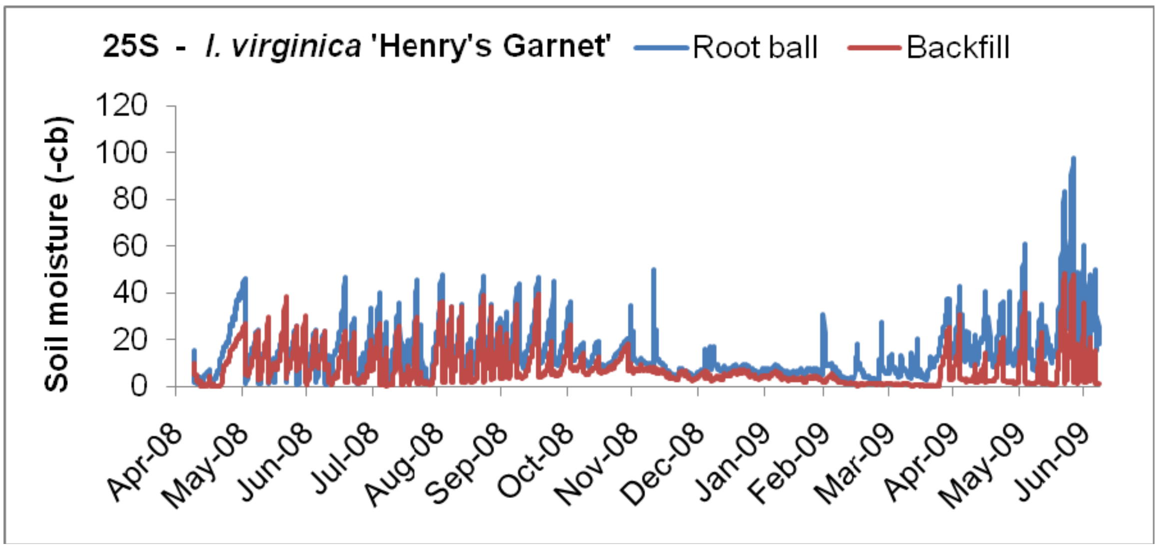


Figure 5. Effect of irrigation frequency soil moisture of *Itea virginica* 'Henry's Garnet' grown in field plots from 13 Mar. 2008 – 25 June 2009. Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S).






75RB - I. virginica 'Henry's Garnet'
Root ball
Backfill
Soil moisture (-cb)
120
100
80
60
40
20
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09


25S - I. virginica 'Henry's Garnet'
Root ball
Backfill
Soil moisture (-cb)
120
100
80
60
40
20
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09

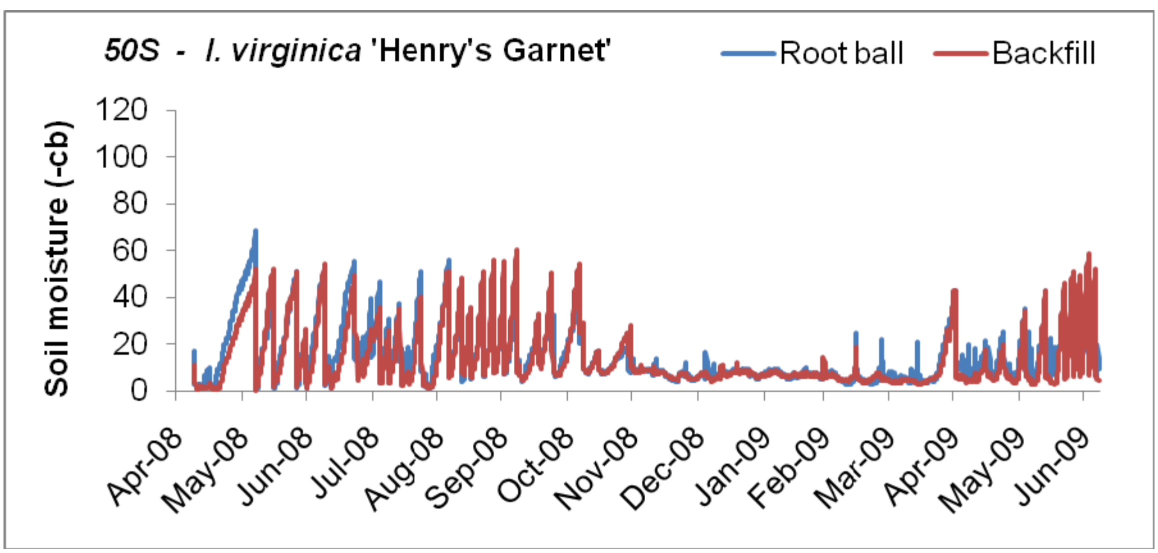
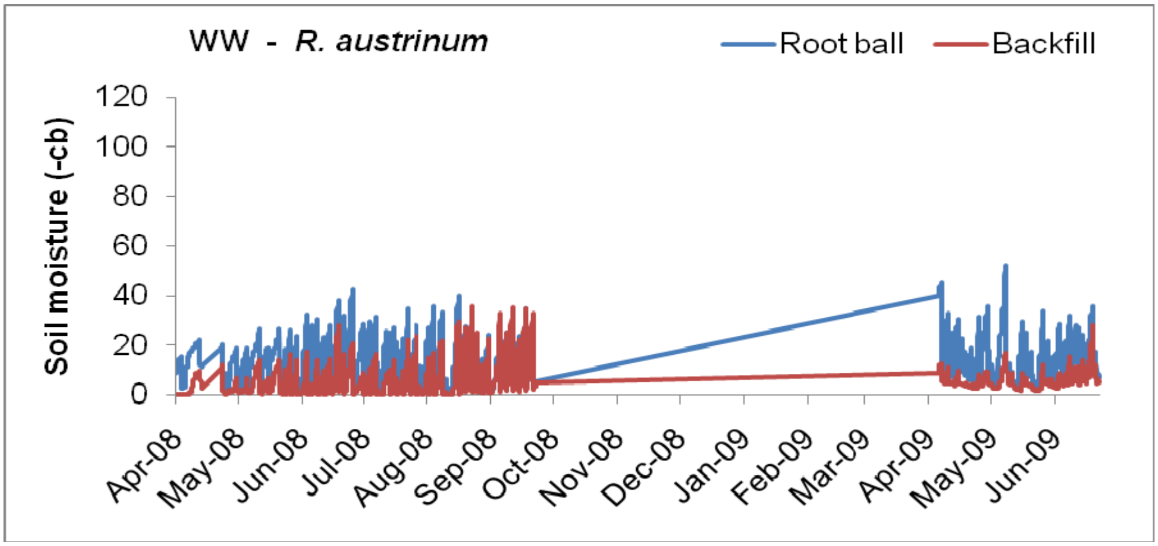
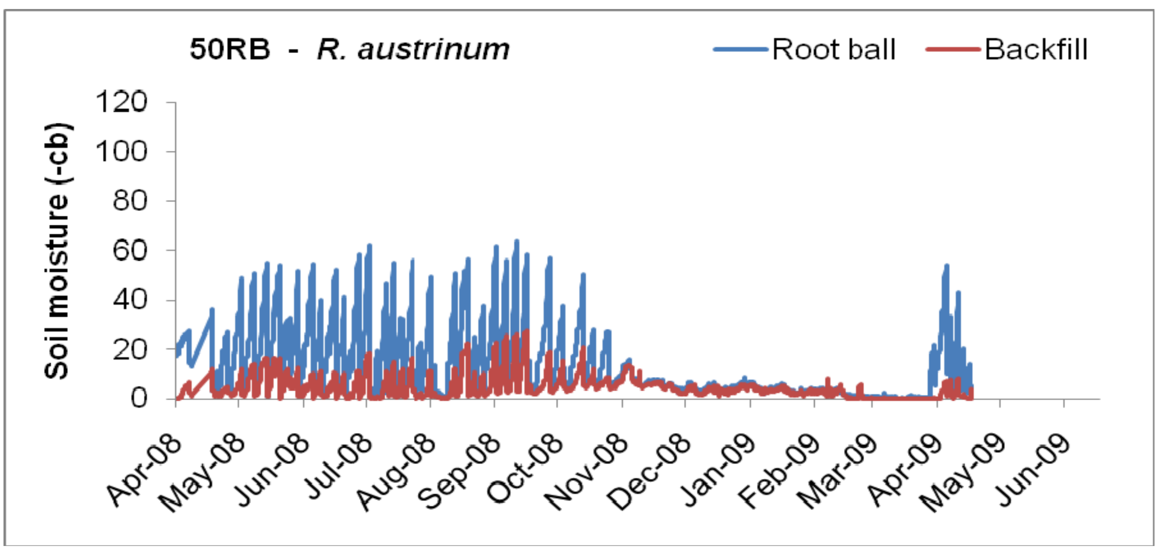
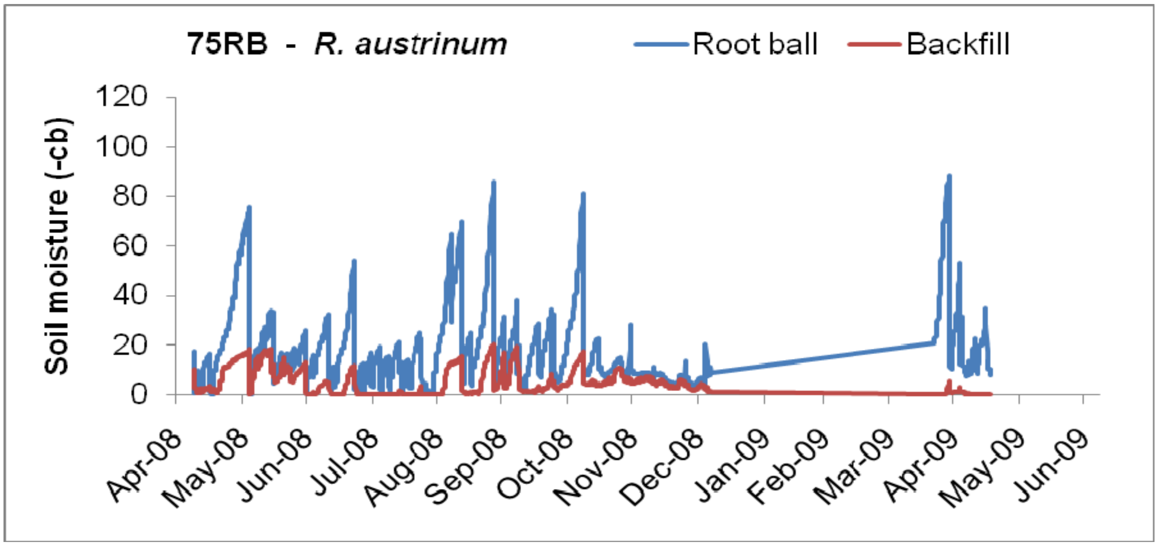

50S - I. virginica 'Henry's Garnet'
Root ball
Backfill
Soil moisture (-cb)
120
100
80
60
40
20
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09

Figure 6. Effect of irrigation frequency on soil moisture of *R. austrinum* grown in field plots from 13 Mar. 2008 – 25 June 2009. Treatments include: root ball and surrounding soil maintained at or above 25 cb (well watered, WW); root ball and surrounding soil re-watered when root ball moisture reached 50 cb (50RB) or 75 cb (75RB); root ball and surrounding soil re-watered when surrounding soil moisture reached 25 cb (25S) or 50 cb (50S).






75RB - *R. austrinum*
Root ball
Backfill
Soil moisture (-cb)
120
100
80
60
40
20
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
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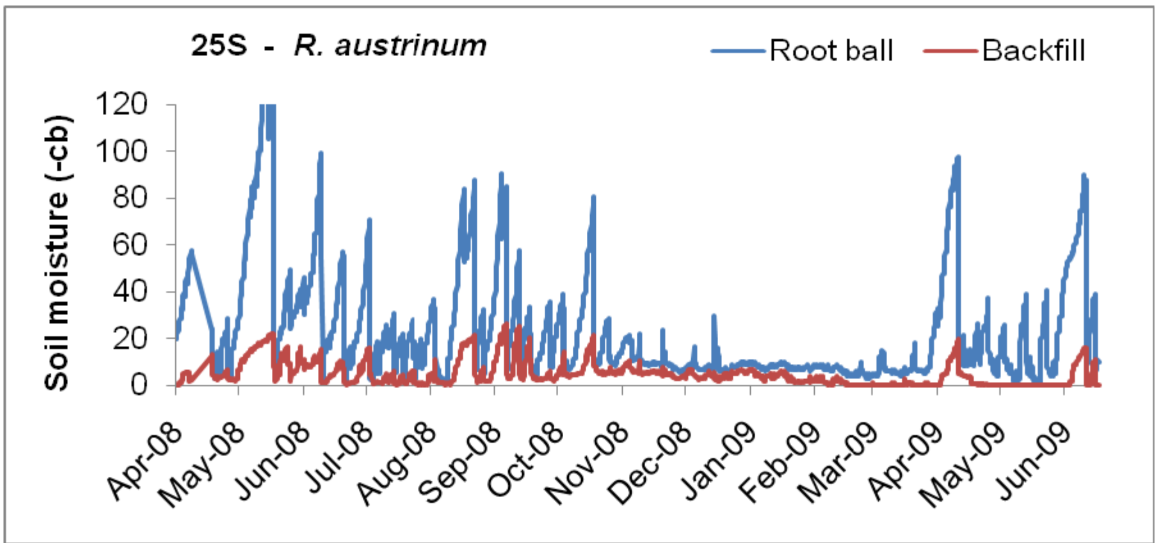
Apr-09
May-09
Jun-09


25S - *R. austrinum*
Root ball
Backfill
Soil moisture (-cb)
120
100
80
60
40
20
0
Apr-08
May-08
Jun-08
Jul-08
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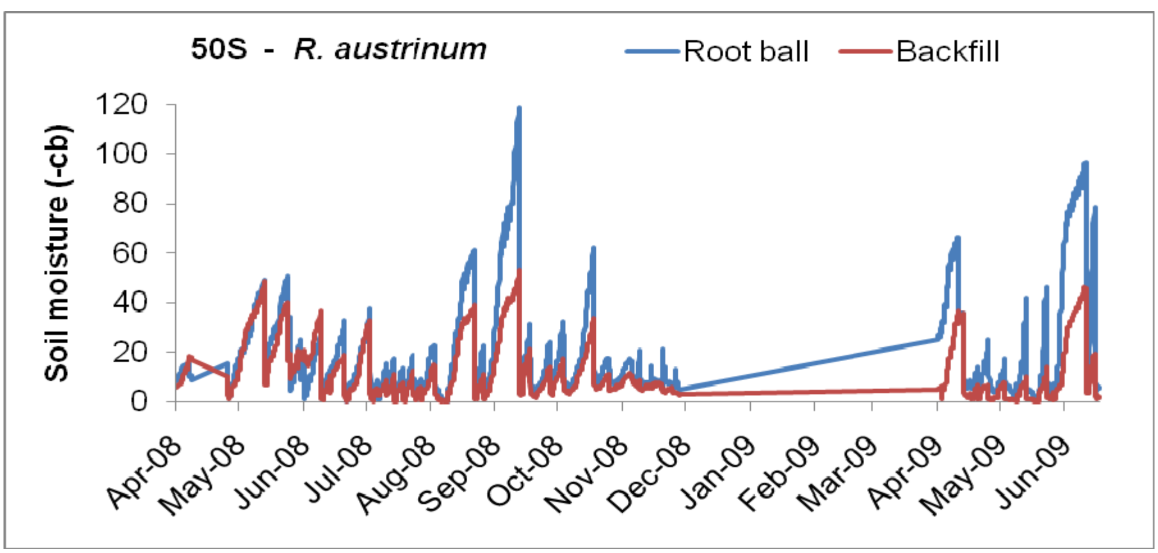
May-09
Jun-09


50S - *R. austrinum*
Root ball
Backfill
Soil moisture (-cb)
120
100
80
60
40
20
0
Apr-08
May-08
Jun-08
Jul-08
Aug-08
Sep-08
Oct-08
Nov-08
Dec-08
Jan-09
Feb-09
Mar-09
Apr-09
May-09
Jun-09