THESIS

RESPONSES OF FOUR SHRUB SPECIES TO FOUR LEVELS OF IRRIGATION IN A SEMI-ARID ENVIRONMENT

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ABSTRACT

RESPONSES OF FOUR SHRUB SPECIES TO FOUR LEVELS OF IRRIGATION IN A SEMI-ARID ENVIRONMENT

In response to a severe regional drought that afflicted much of Colorado in 2002, Colorado State University initiated a study to determine the impacts of progressively decreasing irrigation treatments on some common shrub species. Irrigation treatments were based on the evapotranspiration of a short reference crop (ET_o). In 2008, four shrub species were planted for trialing: *Cornus sericea* L. ‘Isanti’ (redosier dogwood), *Hydrangea arborescens* L. ‘Annabelle’ (smooth hydrangea), *Physocarpus opulifolius* (L.) Maxim. 'Monlo' (Diablo® ninebark) and, *Salix pupurea* L. ‘Nana’ (arctic blue willow). In addition to the shrubs, *Poa pratensis* L. (Kentucky bluegrass) was used as a control. After giving the shrubs and turf one growing season to establish, treatments were applied in 2009 and 2010. The study was comprised of a field component and a lysimeter component. The field component had four treatments based on ET_o (0%, 25%, 50%, and 100%) and the lysimeter component had three treatments (25%, 50%, and 100%). All four species were planted in the field component and only the redosier dogwood and smooth hydrangea were planted in the lysimeter component due to space limitations. Data collection in both components included canopy height and width, visual ratings, predawn leaf water potentials, end of season leaf area, and end of season leaf fresh/dry weights. The field component also included soil moisture readings, osmolality, and infrared readings of the Kentucky bluegrass. The lysimeter component required daily weight measurements during dry down periods. As watering amounts increased for the field dogwoods, ninebarks, and willows various characteristics (overall stress, aesthetic appeal, size, osmolality) were also positively affected. However, all tested replicates of these three species in the 0% treatment appeared

acceptable for landscape use, as well. The hydrangeas in the 100% treatment had the highest visual ratings. In addition, the water potentials were more negative in the 100% treatment. Due to the visual ratings and water potential data, it suggests that smooth hydrangea needs more than 100% ET_o to improve growth and performance. All of the field hydrangeas in the 0% treatment were unacceptable for landscape use and were close to death, however, 80% of the replications survived until the conclusion of the experiment. As such, the smooth hydrangea can survive a short period without water and should recover when water becomes available. The lysimeter dogwoods and hydrangeas adjusted their growth habits based on water availability. Water was used on a daily basis at a faster rate as the irrigation treatments increased. The lysimeter shrubs in the 100% treatment used more water on a daily basis than the 50% treatment and the 50% treatment used more than the 25% treatment. The increased water use affected plant growth and if more water was available to the dogwood and hydrangea, a larger plant resulted.

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INTRODUCTION

The demand for water in many urban communities is projected to increase as the population increases. Since the water supply is becoming more strained as the population increases, water must be conserved where possible. Specifically, water authorities in the municipalities located within the Front Range and Western Slope areas of Colorado encourage reductions in water use for the maintenance of residential and commercial landscapes. When water becomes scarce during prolonged periods of below normal precipitation, these municipalities often impose restrictions on landscape irrigation. When this occurs, the plant material in the landscape may succumb to a lack of water. Therefore, efficient use of water in semi-arid urban landscapes is dependent upon the plant species which are planted in these landscapes. Although shrubs are important components of urban landscapes in Colorado, little is known about the water needs of many of the popular shrub species distributed through local wholesale and retail nurseries. The purpose of the research conducted and outlined in this thesis was to evaluate the responses of some common shrub species that are marketed for planting in Colorado landscapes when subjected to progressively decreased amounts of irrigation.

LITATURE REVIEW

Water is a precious and limited resource in Colorado. With an average annual precipitation of 39.29 cm (15.47 in) a year for the state (U.S. Dept. of the Interior and U.S. Geological Survey, 2005), water must be conserved where possible. This fact is exacerbated since drought is common in Colorado and can occur in small areas or over the entire state (McKee, et al., 2000). The drought of 2002 affected most of the state due to the below average precipitation levels that created record lows for some areas, such as the southern Front Range. Further, the drought of 2002 was listed as the most severe drought year in the instrumental record back to the late 19th century (Pielke, et al. 2005).

What exactly is drought? The definition can vary depending upon the source. A basic definition of drought is "a shortage of water, usually associated with a deficiency of precipitation. Drought occurs when the demand for water exceeds the supply of water" (McKee, et al., 2000). Another definition of drought is "a condition of moisture deficit sufficient to have an adverse effect on vegetation, animals, and man over a sizable area" (U.S. Geological Survey, 2008). These two definitions are simple, however the definition of drought can be more complicated depending on the particular interest(s) of the person(s) that answers what drought is. A farmer, hydrologist, or an economist can have different definitions (Palmer, 1965). Therefore, there are different categories of drought including: meteorological, agricultural, hydrological, and socioeconomic (National Drought Mitigation Center, 2006). Meteorological drought occurs when the amount of precipitation received for a certain area over a period of time is less than what is normally received. Agricultural drought occurs when an agricultural crop has an insufficient water supply in the root zone for that crop's particular growth stage. For example, if a crop has just germinated and there is water in the zone where the seeds have germinated then no drought is present. However, if that crop reaches maturity and the roots have grown into deeper soil and there is insufficient water to supply the crop within that deeper soil, then a drought is in progress. A hydrological drought occurs when the water levels in surface or subsurface water areas are below what is normally expected, as in streams, rivers, lakes, and aquifers. Socioeconomic drought occurs when the demand for a particular good or service exceeds supply as a direct result of a lack of water. For example, if insufficient water is present for snow making for ski resorts, then the ski resorts may be unable to accommodate customer numbers with the amount of snow required to have all the ski paths open. In summary, the definition of drought can vary depending upon the interests of the person or persons involved. However, all cases of drought involve an insufficient supply of water. Droughts commonly occur in Colorado since "every year a portion of Colorado is in or on the verge of a major drought" (Bousselot, et. al, 2005). As a result, the efficient use of water is becoming increasingly more important as adequate amounts are not always available. Further, the water supply may not always be available in some areas even when a drought is not in progress. These facts are intensified since the demand for water is increasing as the population increases.

Water conservation is becoming more essential in Colorado as a result of the increasing population. In 2000, Colorado's estimated population was 4.301 million and by 2010 the population had increased to an estimated 5.029 million (U.S. Dept. Agr., 2011). The population increased from 2000 to 2010 by about 16.9%. As a result of this increase, the demand for water has also increased. To account for the increased demand, water conservation must be practiced. Even though agriculture is one of the largest users of Colorado's total water supply, water is also used for such things as hydroelectric power, industrial, recreation (ski resorts for snow making, swimming pools), and urban municipal use (McKee, et al., 2000). While the reduction of water use in some of these areas cannot be controlled by the general population, urban municipal water use for both residential and commercial landscapes can be. It is estimated that 7 to 10% of the total water supply for Colorado is used for landscape irrigation, and that the landscape water use in the summer could account for 50 to 75% of the total water supply in any given community (Whiting, 2011). Landscapes use so much water for a multitude of reasons, such as uneven irrigation coverage, broken sprinkler heads, and overwatering due to aesthetic reasons. In a study conducted by Utah State University, it was found that 91% of business owner respondents and 86% of household respondents thought it was important to maintain their landscapes "to make the landscape look pleasing/nice" as opposed "to increase the property value" or to "just keep the grass and plants from dying" (Endter-Wada, et al., 2008). Further, the majority of both respondent types thought it was either "important" or "very important" to maintain a lawn that was "lush green and uniformly green" (Endter-Wada, et al., 2008). However, maintaining a landscape that is "pleasing/nice" and "lush and uniformly green" does not necessarily have to use a lot of water. Water use can be reduced drastically by simply utilizing low water use plants.

Different plants require different watering amounts. Therefore, choosing correct plant materials for the landscape can be an effective way to reduce water use in the landscape. Plant water use is affected by evapotranspiration, also known as ET. Evapotranspiration is defined as the culmination of evaporation from the soil and plant surfaces and the transpiration from plants (Irmak and Haman, 2003). Knowing the ET rates of a particular plant species is useful because it can be used to predict soil water deficits so the irrigation amount to apply can be calculated (Schwab, et al., 1993). However, each species of plant is different in its water needs due to having different ET rates.

The evapotranspiration rate for a particular species, usually denoted ET_c, can be estimated by multiplying the short reference crop evapotranspiration (ET_o) by the crop coefficient (K_c) (California Irrigation Management Information System, 2009). These two numbers must be known in order to estimate the ET rate of a particular crop species (ET_c). ET_o is defined as a hypothetical grass reference crop at a height of 0.12 m and it can be calculated through several different methods that exist such as the ASCE-EWRI Standardized Penman-Monteith Equation (Howell and Evett, 2004). After the ET_o is calculated, the K_c can then be multiplied with the ET_o. The K_c accounts for the specific crop type and the different crop growth stages (initial, crop development, mid-season, and late season growth) which the crop goes through in a season to adjust the ET_o (Van der Gulik and Nyvall, 2001). Finding the ET_c works well for agricultural uses to optimize plant growth rates and crop yields, since many of the K_c values for agricultural crops are known from research (Pittenger and Shaw, 2004a). However, the K_c values of most ornamental plant species in landscapes are not known, since little research has been conducted on the water requirements (Henson, et al., 2006; Pittenger and Shaw, 2004a; Zollinger, et al., 2006). Further, even if the K_c values were known for each of the ornamental plant species, urban landscapes are not a field comprised of just one or a few plant species. Landscapes contain many different plant species. Therefore, determining the ET_c rate and watering each plant in the landscape based on the individual needs of each plant species would not only be difficult but also impractical. In addition, finding the ET_c for ornamental plants isn’t needed because optimizing plant growth and yield in the landscape is not necessarily the main goal, however the plants should have a good appearance and function in the landscape (Pittenger, and Shaw, 2004b). As a result, landscape species that are planted together with similar water needs and irrigated based on percentages of a standard value that is well known is easier and more realistic. More specifically, planting and irrigating landscapes based on percentages of ET_o would be beneficial. Currently, many water purveyors, water agencies, landscape architects, and landscape maintenance personnel are already using ET_o to schedule and estimate irrigation needs in the landscape (Pittenger and Shaw, 2004a). Since planning and maintaining landscapes based on percentages of ET_o is easier and more practical, as well as the fact that many are already utilizing this concept for landscapes, watering based on ET_o would be beneficial as becoming a standard for irrigation management in urban landscapes.

General watering guidelines are easy to find for a particular area, however, knowing specific water requirements for each landscape so that all plants are sufficiently hydrated is more difficult. The specific amount of water to use for a particular species, or even a particular genus, of ornamental plant is not widely known. However, water use estimates for many plants do exist as to whether a plant is a "high," "medium," or "low" water user. Organizations such as the Green Industries of Colorado (GreenCO) have compiled results from a survey asking the estimated water use of several commonly grown ornamental landscape plants in Colorado. The results to the survey is located in the appendix of the Best Management Practices (BMPs) manual (GreenCO and Wright Water Engineers, Inc. 2008). GreenCO states plants that require supplemental irrigation to rehydrate 75% or greater of the moisture lost based on ET_o is a "high" water user, a plant that requires 50 to 75% of ET_o is a "medium" water user, 25 to 50% ET_o is a "low" water user, and a plant that needs less than 25% ET_o is a "very low" water user (GreenCO and Wright Water Engineers, Inc. 2008). Using these lists is a good start to determine appropriate plants that use less water in the landscape. Unfortunately, GreenCO's compiled list is subjective data, as the compiled information came from a survey where respondents returned ratings that were based solely upon visual observations or opinions. Quantifiable scientific data does not exist to support the assumptions as to whether a plant is a “high,” “medium,” “low,” or “very low” water user in GreenCO’s survey. This is not unique to GreenCO, because very little research has been done on ornamental landscape plants, so the actual water use of most landscape plants is not known. Since qualitative as well as quantitative data does not exist for landscape plants on how much water a plant uses based upon a percentage of ET_o, more research must be conducted to determine the water use of common landscape plants.

Researching the water needs of landscape plants is difficult as water stress can affect many different plant characteristics. Stress to plants caused from a shortage of water develops slowly and the intensity of the stress increases with time (Munné-Bosch and Alegre, 2004). Over a short period visual assessments are made to decide if a plant is sufficiently hydrated, such as the presence of wilting or leaf senescence. However, if the plant is not wilting or dropping leaves, the plant may exhibit other stress symptoms that are less obvious over a longer period. Some of these symptoms could include reduced shoot growth, smaller leaves, and increased root to shoot ratios (Chaves et al., 2003). In addition, some other physiological responses to water stress are more difficult to determine unless measured and analyzed, such as plant water potential. Since plants often have less obvious symptoms to water stress, it is difficult to ascertain whether plants are water stressed in an urban landscape or not. Even if the water currently applied to a plant is perceived to be sufficient and it appears to look hydrated, that is not always the case and the plant may actually be stressed. Additionally, if drought occurs and water is further cut back, then that already stressed plant has an increased chance of death. In summary, it is important to know how a plant will precisely respond with different amounts of water.

Some research has been conducted with ornamental plants that are commonly planted in landscapes to determine how these species would respond to various drought treatments. One experiment conducted at UC Davis with *Spirea x vanhouteii* (Vanhoutte spirea), *Viburnum tinus* (laurustinus), *Arctostaphylos densiflora* (Vine Hill manzanita), and *Leucophyllum frutescens* (silverleaf) were tested under well-watered and drought conditions in containers. It was concluded that all of these species were affected by reduced irrigation but the severity varied depending upon the plant. It was found that the Vanhoutte spirea and laurustinus were affected more visually than Vine Hill manzanita and silverleaf. However, Vanhoutte spirea could survive extreme drought conditions as it can releaf and regrow when more moisture becomes available (García-Navarro, et al., 2004).

In another study conducted by the University of California at the Quail Botanical Gardens in Encinitas, California, 30 different species of ornamentals were trialed in the ground when irrigated with three different amounts based on ET_o (36%, 18%, and 0%). Among other results, it was found that *Prunus caroliniana* (Carolina cherry laurel) and *Pyracantha koidzumii* 'Santa Cruz' (Santa Cruz pyracantha) did well within the 0% treatment and would be acceptable for landscapes. The *Rhaphiolepis indica* (Indian hawthorn) did not do as well in the 0% treatment, however, when it received 18% of ET_o it performed well and would be acceptable for landscapes. However, not all species did well in the experiment since *Hibiscus rosa-sinensis* (rose of China) and *Ligustrum japonicum* 'Texanum' (Texas privet) appeared under-watered in even the highest irrigated treatment (36% of ET_o) (Pittenger and Shaw, 2004a).

Utah State University conducted a drought study on six common herbaceous perennials. They tested *Echinacea purpurea* (purple coneflower), *Gaillardia aristata* (blanket flower), *Lavandula angustifolia* (English lavender), *Leucanthemum x superbum* 'Alaska' (Shasta daisy), *Penstemon barbatus* ‘Rondo Mix’ (‘Rondo Mix’ penstemon), and *Penstemon x Mexicali* ‘Red Rocks’ (‘Red Rocks’ penstemon) in containers. There were three treatments to test drought tolerance. The pots that housed each perennial were watered to field capacity every one, two, or four weeks. The pots that were watered every week simulated well-watered conditions, every two weeks simulated moderate drought, and the pots watered every four weeks simulated severe drought. It was found that the ‘Rondo Mix’ penstemon performed the best as it withstood the simulated severe drought conditions, and as such can probably survive in a landscape with very little water. The ‘Red Rocks’ penstemon and English lavender performed well in the moderate drought conditions and poorly in the severe drought conditions due to high mortality rates. The Shasta daisy and blanket flower did not perform well in any treatment, but it was theorized that the plants did poorly due to the restricted rooting zone. The researchers concluded that these two species might do better if they were growing somewhere where the rooting area is not limited. Lastly, the purple coneflower was found to do poorly if given little water as severe wilting resulted to the plant when water was limiting (Zollinger, et. al, 2006).

Research conducted at Colorado State University trialed several annual species that were planted in the ground and trialed under progressively decreased amounts of irrigation based on percentages of ET_o. The irrigation amounts were 100%, 75%, 50%, 25%, and 0% of ET_o. Of the species tested, it was found that *Petunia x hybrid* ‘Merlin White’ (petunia) and *Glandularia* ‘Imagination’ (glandularia) had good growth with minimal visual signs of stress in the 0% treatment. *Impatiens walleriana* ‘Tempo White’ (impatiens) performed the worst. However, it was observed that the impatiens performed acceptably, with good visual ratings, growth, and low stress, when irrigated with 100% of ET_o (Henson et al., 2006).

Other research, also conducted at Colorado State University, tested seven species of shrubs and two species of turf subjected to decreasing amounts of irrigation. Similar to the other study conducted at Colorado State, this study also trialed different species in the field with different irrigation amounts based on percentages of ET_o. The treatments varied from the other study conducted at Colorado State University since there were four treatments instead of five. The four treatments were 0%, 25%, 50% and 100% of ET_o. The seven shrub species that were tested were *Amelancheir alnifolia* (Saskatoon serviceberry), *Caryopteris incana* 'Dark Knight' (blue mist spirea), *Chamaebatiaria millefolium* (fernbush), *Perovskia atriplicifolia* (Russian sage), *Rhus trilobata* (three leaf sumac), *Syringa meyeri* (Meyer lilac), and *Syringa vulgaris* (common lilac). The two turf species tested were *Poa pratensis* (Kentucky bluegrass) and *Festuca arundinacea* (tall fescue). All of these plants were tested in a field experiment. In addition to the field experiment, the common lilac, three leaf sumac, and both turf species were also tested in pots using a lysimeter. It was found that all species performed acceptably and had similar visual quality regardless of the irrigation amounts received in the field. In addition, the common lilac and three leaf sumac used significantly less water than both of the turf species in the lysimeter (Ounsworth, 2007).

The information from the studies mentioned above, along with some others, is useful so decisions can be made in planning landscapes by placing plants together with similar water requirements. Studies conducted varied in the way they tested ornamental plants with limited water. Some studies have tested how a plant responds to progressively decreased amounts of irrigation based on percentages of ET_o (Henson, et al., 2006; Ounsworth, 2007; Pittenger and Shaw, 2004a), and others on how a plant responds after an extended period without water and then is rehydrated (García-Navarro, et al., 2004; Zollinger, et al., 2006). Some research has been conducted with plants in containers (García-Navarro, et al., 2004; Ounsworth, 2007; Zollinger, et al., 2006) and others in the ground (Henson, et al., 2006; Ounsworth, 2007; Pittenger and Shaw, 2004a). These published studies cover only a small percentage of the number of plants that are used in landscapes and more research is needed. Furthermore, these studies were conducted in different areas of the United States and under different climates. However, it may be possible to apply some conclusions from previous studies around the country to other members of the same genus. Ultimately, more research is required to update plant lists with scientifically backed data that states whether a plant is a "high" or "low" water user in order to build a larger list of appropriate plants that can be utilized in landscapes to reduce water use.

CHAPTER 1: FIELD STUDY

Methods and Materials

The study was conducted at the Colorado State University Plant Environmental Research Center (PERC) located at 630 W. Lake St., Fort Collins, CO 80523. The coordinates are 40º 34' 8" N, 105º 5' 24" W. The study was initiated in 2005 with plants that were thought to be more drought tolerant, however, was modified in 2008 to trial species that were thought to be more water demanding. The species that were thought to require more moderate amounts of water were planted in 2008 and studied through 2010.

The field portion of the study tested four different species of shrubs and one species of turf. The shrub species tested were: *Cornus sericea* L. 'Isanti' (redosier dogwood), *Hydrangea arborescens* L. 'Annabelle' (smooth hydrangea), *Physocarpus opulifolius* (L.) Maxim. 'Monlo' (Diablo® ninebark) and, *Salix pupurea* L. 'Nana' (arctic blue willow). *Poa pratensis* L. (Kentucky bluegrass) was also used in the study as the control. This turf species was chosen because it is one of the most widely used turfgrass types in the United States (Christians, N. E. 2007). A grass was important for this study because treatments were based on reference evapotranspiration (ET_o), which is a hypothetical crop that closely resembles the surface of a uniform green grass (Irmak and Haman, 2003). Furthermore, for ornamental horticulture the reference evapotranspiration is based on a cool-season grass, specifically Kentucky bluegrass (GreenCO and Wright Water Engineers, Inc., 2008). The Kentucky bluegrass used was a mix containing the varieties Blue Velvet, Moonlight SLT, Rampart, and Orseo.

All of the test shrubs were planted and the sod was laid during the summer of 2008. The smooth hydrangeas were provided by Alameda Wholesale Nursery (Englewood, CO) and were in 7.57 L (2 gal) pots; the Diablo® ninebarks came from Arbor Valley Nursery (Brighton, CO) in

18.93 L (5 gal) pots; the redosier dogwoods came from Fort Collins Wholesale Nursery (Fort Collins, CO) in 18.93 L (5 gal) pots; the arctic blue willows came from James Nursery Company (Denver, CO) in 18.93 L (5 gal) pots; and the Kentucky bluegrass sod came from Turf Master Sod (Fort Collins, CO). Each particular plant taxa were uniform in size.

The shrubs were planted over the course of two days (July 10, 2008 and July 11, 2008) and all shrubs were planted using Best Management Practices (GreenCO and Wright Water Engineers, Inc., 2008). The planting holes were at least two times the size of the root ball, the root ball was planted 2.54 to 5.08 cm (1 - 2 in) above grade, the root ball was scored and loosened, and 20% of the backfill was amended with Sun Gro Sunshine soil mix. The root ball was placed on firm, compacted soil, and 18.93 L (5 gal) of water was applied to each shrub after planting. Additionally, all of the shrubs were watered with 100% of evapotranspiration of a short reference crop (ET_o) for the remainder of the 2008 growing season to allow for establishment.

The sod was laid on July 31, 2008. The soil on which the turf was laid was leveled and loosened to allow proper root penetration but yet firm enough to walk on. The soil area was then moistened prior to sod placement, but not so much as to make the area muddy. After the sod was placed, it was heavily watered (Christians, 2007; Landschoot, 2011). Soil was then placed around the perimeter of each sod replication to prevent desiccation around the edges of the sod since exposed edges can quickly dry out (Hardebeck and Reicher, 1998). The sod was established according to recommended specifications that the sod roll and soil underneath the sod must remain moist but not saturated (Christians, 2007; Cornell Cooperative Extension, 2007; Plant*talk* Colorado™, 2010). The first week after the sod was laid, the turf was watered with 100% of ET_o twice a day. The second week the sod was given 100% of ET_o once a day. Then on weeks three, four, and five the turf was watered twice a week with 100% ET_o. On week six, water treatments began on the turf.

Plot Plan

There were four treatments in the field study which received varying amounts of supplemental irrigation based on the ET of a short reference crop (ET_o). The four treatments were 0%, 25% 50%, and 100% of ET_o. These particular numbers were chosen based on the GreenCO Foundation's reference (Table 1.1) to what a high, medium, low, and very low water use plant requires (GreenCO and Wright Water Engineers, Inc., 2008).

Table 1.1: GreenCO Foundation's definition for water use of plants

Plant Water Use	% of ET_o
High	> 75%
Medium	50% - 75%
Low	25% - 50%
Very Low	< 25%

Each treatment plot contained five rows. Each of the five rows contained one replication of all of the tested taxa of plants. A layout of the treatment plots and the plants within each treatment can be viewed in Figure 1.1. Each plant was planted at least 1.83 m (6 ft) away from any other plants. The layout design was a complete randomized design.

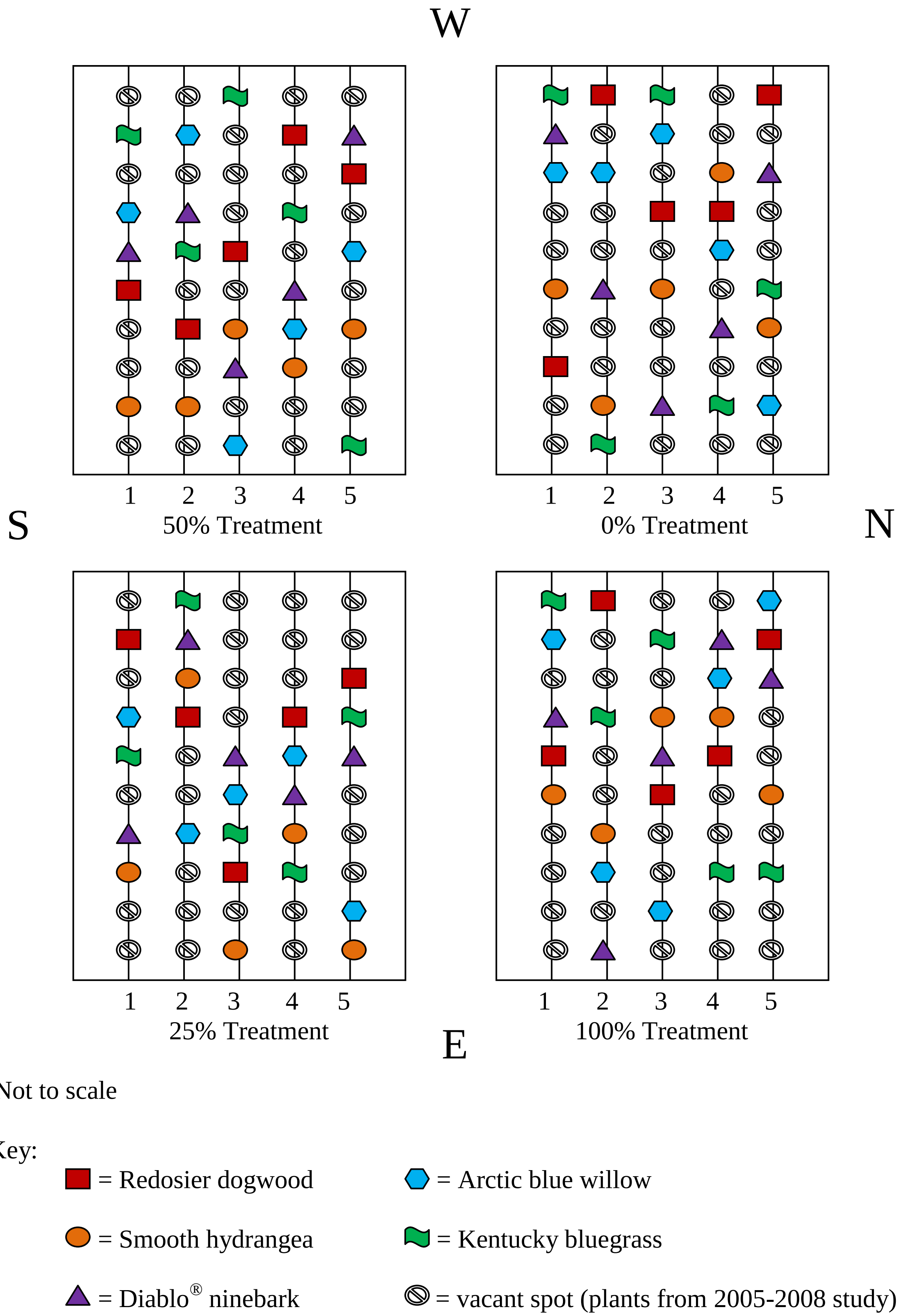

Figure 1.1: Field plot layout and planting plan

Maintenance and Site Specifications

Weeds were managed through two different methods. Weeds were controlled either by hand removal or through spraying using a backpack sprayer with Ranger Pro (Glyphosate). Weeds were not sprayed within 0.35 m (1 ft) of the plant to prevent any possible herbicide drift damage. Any weeds that were located within the 0.35 m (1 ft) radius of the plant were hand pulled.

On July 24, 2009 and May 8, 2010 each shrub was fertilized with 118 grams (0.26 lbs) of Scotts 15-9-12 Osmocote Pro, which is an eight to nine month slow release fertilizer. The fertilizer was placed evenly around each plant.

On August 6, 2009 the turf was fertilized with Hi-Yield Ammonium Sulfate (21-0-0). On May 8, 2010 the turf was again fertilized with Scotts Turf Builder Lawn Fertilizer (32-0-4). In both instances the fertilizers were applied at a rate of 453 grams (1 lb) of nitrogen per 92.90 m^2 (1000 ft^2) based upon recommended guidelines (Koski and Skinner, 2007).

Soil samples were collected and submitted to the Colorado State University Soil, Water, and Plant Testing Laboratory. The soil is a loam. The complete soil test report is in Appendix C. The United States Department of Agriculture Natural Resources Conservation Service also has recorded this area as having a loam soil. More specifically, it is an Altvan-Satanta loam with 0 to 3% slopes (U. S. Dept. of Agr. Natural Resources Conservation Service, 2009).

The water used in the experiment was non-potable water. The source of the water was from College Lake in Fort Collins, Colorado. To prevent water leaching from one treatment plot to another and to prevent water leaching into the study from the surrounding soil outside of the study a polyethylene plastic barrier was buried around the perimeter of each treatment plot. The barrier went to a depth of 0.91 m (3 ft).

Calculating Treatments

During 2009 and 2010 treatments were calculated once a week using the Irrigator's Equation; Equation 1.1 (Martin, 2006).

Equation 1.1:

$$Area * Depth = Flow\ Rate * Time$$

Area is the area that is to be watered. Depth is the amount of water lost from the soil due to ET minus any precipitation. Flow Rate is the rate at which water is applied. Time is the amount of time that the irrigation system runs. The shrubs were watered using a drip irrigation system with a programmable timer, and as such, Equation 1.1 was rearranged to solve for Time (Equation. 1.2). The 100% treatment received the full amount of time, the 50% treatment received half the time the 100% treatment received, the 25% treatment received one forth the time that the 100% treatment received, and the 0% treatment received no time on the timer.

Equation 1.2:

$$Time = \frac{Area * Depth}{Flow\ Rate}$$

Automatic sprinkler pop-up heads were not a viable option for the Kentucky bluegrass turf since the turf area was smaller than the smallest area pop-up heads were designed to evenly cover. As a result, the turf was watered by hand using a hose with a watering breaker with an attached flow meter (Figure 1.2). Time did not need to be determined for turf treatments. All that was needed was the volume of water to apply. Equation 1.3 was used to determine watering amounts for the turf. The turf in the 100% treatment received the full volume in gallons, the 50% received half the amount of the 100% treatment, the 25% received a fourth of the 100% treatment, and the 0% treatment received no additional water.

Figure 1.2: Watering breaker with attached flow meter

Equation 1.3:

$$Volume = Area * Depth$$

The Area for Equation 1.2 for the shrubs was based on the estimated rooting area, and the area for Equation 1.3 for the turf was based on the area that the turf covered. It was assumed that the shrub rooting area was circular in nature, and as such the rooting radius was estimated. Through using a soil probe and by hand excavation using a hand trowel, in both 2009 and 2010, the rooting radius was estimated by going to the furthest point where roots were present from the plant. In 2009 the shrub rooting radius used was 22.86 cm (9 in), and in 2010 the radius had increased to 33.02 cm (13 in). The turf area was 1.22 m by 1.52 m (4ft by 5 ft) for both 2009 and 2010.

The rooting area varied for each species of shrub. Due to the limitations of the irrigation system, the number used for Area in Equation 1.2 was the species specific rooting diameter from the smallest shrub. For example, the dogwoods had the largest rooting diameter of the four species, which was roughly a 38.1 cm (15 in) radius in 2009, and the hydrangeas had the smallest rooting diameter, which was roughly a 22.86 cm (9 in) radius. If treatments were based on the larger radii then the dogwoods would have received the right amount while the hydrangeas would have received too much irrigation. However, if treatments were based on the smaller radii then the hydrangeas would have been correctly watered and the dogwoods would have been under-watered. The latter scenario was deemed preferable since the purpose of the research was to determine the effects of water stress, and to determine which category the plant falls into for water use (Table 1.1). Therefore, under-watering some of the plants helped determine which category of water use was the minimum for the plant to survive.

Each shrub had 2 x 3.79 L (1 gal) per hour drip emitters, and as a result the flow rate was effectively 7.57 L (2 gal) per hour. In 2009, the emitters were tested to determine if the flow matched what the emitters were rated at. The water from each emitter was collected and measured. It was found that the emitters in the 25% were 96.69% efficient, the emitters in the 50% treatment were 98.80% efficient, and the emitters in the 100% treatment were 98.13% efficient. As a result of the different efficiencies for each treatment, the Flow Rate was multiplied by 0.9669, 0.9880, and 0.9813 for Equation 1.2 for the 25%, 50%, and 100% treatments, respectively.

The depth was determined by monitoring the ET_o and precipitation on a daily basis. Equation 1.4 (Schwab, et al., 1993) was used to more accurately determine the number to use in Equation 1.2 and Equation 1.3 for the calculation of Depth. Data collected from a weather station maintained by Northern Colorado Water Conservancy District (NCWCD), located in Rolland Moore Park, Fort Collins (40º 33’ 29” N, 105º 5’ 59” W) was used to collect the daily ET_o rates and precipitation amounts. Even though this weather station is roughly 1.5 kilometers (0.93 miles) away from the study site, this was the nearest weather station to the site that not only collected all of the necessary data to determine the Depth portion for Equation 1.2 and Equation 1.3, but also posted the calculated ET rates on their website on a regular basis (http://www.ncwcd.org/ims/ ims_Weather_form.asp). NCWCD calculates ET rates using the ASCE-EWRI Standardized Penman-Monteith equation (Howell and Evett, 2004).

Equation 1.4:

$$D_i = D_{i-1} + (ET - P_e)_i$$

Where:

D_i = total depth of water removed from the soil after i days

D_{i-1} = total depth of water removed from the soil after i-1 days

ET = evapotranspiration for day i

P_e = effective precipitation for day i

Precipitation events that exceeded ET_o rates were also accounted for. If the precipitation amounts exceeded ET_o rates since the last watering event, the soil moisture deficit was assumed to be zero and the excess precipitation was lost due to runoff. Further, if the precipitation amounts exceeded the ET_o rates since the last watering event, treatments were not applied for that particular week.

The mean weekly amount of liters (gallons) of water applied per shrub and turf plot replicate in each treatment during 2009 and 2010 are represented in Table 1.2.

Table 1.2: Mean liters (gallons) of water applied per week for each shrub and turf replicate in each treatment of the field study during 2009 and 2010

Treatment Period (Dates)	Precipitation cm (in)		0%	25%	50%	100%
2009 (May 12, 2009 – Sept. 29, 2009)	25.50 (10.04)	Shrub	0 (0)	0.64 (0.17)	1.29 (0.34)	2.61 (0.69)
		Turf	0 (0)	9.05 (2.39)	18.06 (4.77)	36.11 (9.54)
2010 (May 17, 2010 – Oct. 5, 2010)	12.34 (4.86)	Shrub	0 (0)	2.38 (0.63)	4.66 (1.23)	9.39 (2.48)
		Turf	0 (0)	12.30 (3.25)	24.61 (6.50)	49.21 (13.00)
Precipitation data source: http://www.ncwcd.org/ims/ims_Weather_form.asp						

Data Collection

In order to determine if treatments had any effect on the tested plants, numerous data were collected. The data that were collected included plant height and plant width, relative percent soil moisture, infrared (IR) temperatures of the turf, visual ratings accompanied with pictures, water potential using a pressure chamber, osmolality, end of season sample leaf area, end of season sample leaf fresh and dry weights, and above ground plant fresh and dry weights.

Height and width measurements were taken at the beginning and the end of the experimental seasons during 2009 and 2010. During each measurement, each shrub had one height measurement and two width measurements taken. The height measurement was taken by measuring the tallest branch on the plant. The two width measurements varied by compass orientation. The first measurement was taken of the shrub from north to south and the second measurement was taken from east to west. The two width measurements were then averaged together to get an average width of the plant. The stems measured were representative of the plant and did not include any branches that were broken and sprawling on the ground. All measurements were taken to the closest 5 cm (1.97 in) increments.

Soil moisture was monitored using a Diviner 2000® made by Sentek Environmental Technologies Pty Ltd (Stepney, South Australia). The Diviner 2000® is a capacitance probe that utilizes frequency domain reflectometry (FDR) and the default calibration equation that came pre-programmed (derived by Sentek from sands, loams, and clay loams) in the unit was used. As a result, all data collected was relative and was expressed as percent relative water content. Access tubes for the Diviner probe were present in all treatment plots. All of the tested species (shrubs and turf) in each treatment had an access tube in three of the five replications, except for one species in one treatment. With the five ninebarks in the 50% treatment plot, only two replications had access tubes for data collection. This difference was taken into account during statistical analysis. Data were collected before and after water treatments every other week.

The stress of the Kentucky bluegrass was monitored by measuring the surface infrared temperatures. Turf with an ample water supply transpires more and causes the canopy temperature to be lower. Conversely, a stressed turf will be higher in temperature as it is not transpiring due to a lack of water (Kirkham, 2005). An Omega OS534 Handheld IR Thermometer (Stamford, CT) was used on the turf to collect temperatures in degrees Celsius. The emissivity was set to 0.95 since the manual stated that "most organic materials… have an emissivity of about 0.95" (Omega Engineering, Inc., 2006). The thermometer was held so that the sensor was parallel to the ground at a height that was roughly 55.8 cm (22 in). At this height the thermometer's field of view was 2.54 cm (1 in) (Omega Engineering, Inc., 2006). During each data collection, three measurements were collected from every turf replicate in every treatment. Each of the three measurements were then averaged together in order to obtain an average temperature of each turf replication in each treatment. Each measurement was taken aiming the thermometer at live grass. The turf in the 0% had a lot of dieback by the middle of summer and the thermometer was aimed at what live grass was present. At times very little turf was present in the 0% treatment and every effort was made to avoid getting the temperature of the surrounding soil. However, some of the data came back high and may have been reading the temperatures of the turf, as well as the temperatures of the surrounding soil. Data were generally collected within an hour of solar noon before treatments were applied and generally within an hour of solar noon the day after treatments were applied every week.

Visual ratings and pictures of all of the plants were taken every other week. Each plant was rated on a scale of 1 to 10. The breakdown of each rating is described in Table 1.3. The rating for each plant species in each treatment plot were then averaged together to result in an average rating for each species in each treatment.

Table 1.3: Visual ratings score descriptions

Rating	Description
1	Plant appears dead, no visible signs of life
2	Close to death, at least one green leaf present
3	Looks terrible with major dieback (> 50%) present
4	Looks poor with much dieback (up to 50%) present, heavily stunted in growth
5	Plant is in decline i.e. some dieback (up to 20%) present, stunted in growth
6	At least one major flaw present, i.e. multiple dead stems, chlorosis, bare stems with few leaves, dieback
7	Looks average i.e. could be more full, dead stem, dead broken stem, minor chlorosis on some leaves
8	Looks good, two or fewer noticeable flaws present i.e. one small dead stem, slightly uneven in stem growth (not symmetrical), broken stem that is alive
9	Looks great, flourishing, two or fewer minor flaws present i.e. few discolored leaves, few torn leaves present, small broken twig that is still growing
10	Looks perfect and is flourishing, no flaws are noticeable

A pressure chamber made by PMS Instrument Company (Model 1000, Albany, OR) was used to monitor the water potential of the shrubs throughout the growing season. A pressure chamber is a good instrument to use because it measures the total water potential of the tested samples (Turner, 1988). The pressure chamber works by exerting positive pressure on a leaf in an effort to exude the sap out of the leaf petiole. The more pressure that is introduced into the chamber to exude the sap out of the leaf, the more tightly the plant is holding onto that water and the less available that water is to be given up. The pressure required to exude the sap out of the petiole is directly proportional to the water potential value, except that the water potential value is negative (Scholander, et al., 1965).

Using the pressures chamber, water potential readings were taken at predawn. Every shrub was tested by collecting two leaf samples from each replicate of each species in all of the treatments. The two readings from each plant were then averaged together in order to get a mean reading for each individual plant. Since the arctic blue willow leaves had petioles which were too short to use with the instrument, a branchlet (preferably with fresh growth) containing 10 to 12 leaves was used for each test. Data collection was limited during 2009 as a result of the inclement weather and hail damage. During 2009, water potential readings were collected every week in August and the first two weeks in September for a total of seven data sets. In 2010, water potential readings were collected twice a month in June, July, August, and September and once in October, for a total of nine data sets.

In 2010, the total dissolved solutes, or the osmolality, of the sap within the shrubs were tested. Leaves were collected and the sap was extracted by squeezing the leaves. Leaves were collected from each shrub (80 total) and placed in individually labeled 20 cc syringes. At the bottom of each syringe a small amount of fiberglass was present to act as a filter for the solid material when the sap was extracted. After collecting the leaves at predawn and placing the leaves in the syringes, the syringes were placed in a freezer set at -14.44º C (6º F) and remained for at least seven days. After removing the syringes, the samples were allowed at least 30 minutes to defrost. Each syringe was then squeezed to extract the sap onto a Petri-dish and the sap was measured using a 10 micro liter pipette. The 10 micro liters of sap were then placed onto a solute-free paper disc, which is what was used for each measurement in a vapor pressure osmometer (Model Vapro 5520, Wescor, Inc., Logan, UT). The osmolality of the shrubs was tested once a month during July, August, and September. The method used was similar to Bauerle, et al. (2003) with a few modifications. Each sap sample was tested twice with a new paper disc in the osmometer and the two numbers were averaged together to get a more accurate reading for each sample.

At the end of the 2009 and 2010 experimental periods, leaf samples were collected from every replicate of each species that leaf area, leaf fresh weights, and leaf dry weights could be determined. In both instances the leaf collection process described was the same for both 2009 and 2010. A total of 10 leaves were collected from every shrub in the study. Generally the fifth and sixth leaves from the apex of a stem on the north side, east side, south side, west side, and center of the plant were collected from the smooth hydrangea, Diablo® ninebark, and arctic blue willow. Because most of the dogwood stems had fewer than six leaves, the third and forth leaf from the apex of each stem were collected from the redosier dogwood. In some instances, very few leaves were present and whatever leaves were present on a given species were collected. Each leaf was placed in a labeled Ziploc bag, placed in a Coleman cooler, then placed in a walk-in refrigerator that was set at 4.44º C (40º F). Each leaf was then weighed fresh using an Ohaus Adventurer Pro AV114C scale (Ohaus Corporation, Pine Brook, NJ) and then the leaf area was measured. Leaf area was measured by scanning each leaf in a computer scanner at a resolution of 300 dpi then run through a program written in the programming language Java using

NetBeans (Oracle Corporation, 2009). The Java program essentially counted the number of pixels that were not white and calculated the area based on the number of non-white pixels that were in the image. The program was calibrated using objects of a known area. The code for the Java program is located in Appendix G. After all of the fresh weights and leaf scans were completed, the leaves were placed in a drying oven set at 70º C (158º F) for at least 72 hours. Then, the leaves were removed and dry weights were collected using the same scale as what was used to collect the fresh weight data.

At the end of the 2010 experimental season, each plant was cut back to ground level and collected so that entire above ground fresh weight and dry weight could be evaluated. Every plant was cut down to the base and placed in labeled brown paper grocery bags. All of the bags came from the same source, same shipment, and were the same weight. All the bag's weights were subtracted out from the data collected. All of the plants' fresh weights were collected as soon as possible after harvest. After the bagged samples were weighed they were placed in a drying oven set at 70º C (158º F) for at least seven days. After the samples were dried, the dry weight was measured immediately after removing the samples from the drying oven. All weights were collected using an Ohaus Adventurer Pro model AV2101C scale (Ohaus Corporation, Pine Brook, NJ).

Data Analysis

Data analysis was conducted using the SAS/STAT® software with SAS 9.2 for Windows (SAS Institute Inc., 2010). The Mixed Procedure was used on all data to run an analysis of variance (ANOVA) and to compare the least square means. Data were determined to be statistically significant with a p-value less than 0.05.

Results and Discussion

The results for the field component of the study had some variations from 2009 to 2010. During 2009, difficulty was encountered primarily as a result of inclement weather. Table 1.4 shows the mean high and low temperatures, the total precipitation, and the cumulative reference evapotranspiration (ET_o) rates for each month during the 2009 and 2010 experimental periods. When comparing the two years, 2009 had cooler temperatures, lower cumulative ET_o rates, and more precipitation. These factors affected the way the plants responded to treatments, which aided in keeping all the test plants sufficiently hydrated. As a result, treatments had little effect during 2009. The weather during 2010 was more cooperative for conducting a plant water stress experiment than during 2009 since average temperatures were higher and there was less rainfall.

Data collected during 2009 was also affected by heavy hail damage. On June 7, 2009 heavy amounts of hail fell that was up to 2 cm (0.79 in) in diameter. Since the hail size was so large and so abundant (Figure 1.3a) damage occurred on all test shrubs. The foliage and stems on all of the shrubs was damaged. The hydrangea and ninebark were essentially defoliated (Figure 1.3b and Figure 1.3c, respectively). The willow and dogwood also lost leaves, but not to the extent of the ninebark and hydrangea. Unfortunately, many of the leaves that remained on the dogwood were shredded. Since the hail caused so much damage to the shrubs in the beginning of the 2009 experimental season, data collection (water potential data, visual ratings, soil moisture readings, and infrared temperatures of the sod) were delayed until the plants had re-leafed. Treatments were still applied while the plants re-leafed. The stem damage on the willows and dogwoods was permanent since the damage was still visible on the stems in 2010. The damage was uniform among all plant species in all treatments, and as such there was no

Table 1.4: Weather data from Rolland Moore Park weather station in Fort Collins, CO in 2009 and 2010

Weather Data for Fort Collins, CO During the 2009 and 2010 Seasons					
		Mean High Temp in ºC (ºF)	Mean Low Temp in ºC (ºF)	Precipitation in cm (in)	Total ET_o in cm (in)
2009	May	21.87 (71.37)	7.21 (44.98)	4.59 (1.81)	13.16 (5.18)
	June	24.76 (76.57)	9.58 (49.25)	12.37 (4.87)	12.88 (5.07)
	July	28.46 (83.23)	12.42 (54.36)	8.05 (3.17)	14.33 (5.64)
	August	28.32 (82.98)	10.82 (51.48)	0.56 (0.22)	12.98 (5.11)
	September	24.64 (76.35)	7.18 (44.93)	1.70 (0.67)	9.58 (3.77)
	Season Total	**25.62 (78.12)**	**9.46 (49.03)**	**27.28 (10.74)**	**62.92 (24.77)**
2010	May	19.38 (66.89)	4.46 (40.02)	4.80 (1.89)	12.62 (4.97)
	June	27.57 (81.63)	11.23 (52.22)	5.13 (2.02)	14.58 (5.74)
	July	30.78 (87.41)	13.37 (56.06)	3.23 (1.27)	15.44 (6.08)
	August	30.55 (86.99)	13.05 (55.49)	2.87 (1.13)	14.15 (5.57)
	September	27.47 (81.44)	6.93 (44.48)	0.10 (0.04)	10.95 (4.31)
	Season Total	**27.14 (80.86)**	**9.82 (49.67)**	**16.13 (6.35)**	**67.74 (26.67)**
http://www.ncwcd.org/ims/ims_Weather_form.asp					

advantage gained by any of the shrubs in any given treatment. Therefore, the damage had no effect on the overall outcome of the experiment.

At the conclusion of the 2010 season, it was found that a large portion of the ninebarks were infested with dogwood borer (*Synanthedon scitula*). On October 13, 2010, when the plants were being cut down to soil level for collection of above ground plant fresh and dry weight, it was noted that 14 of the 20 ninebarks had evidence of borers (frass, tunneling) or the presence of the borers themselves at the base of each plant. While evidence was found on 14 plants, more plants may have been infested. The borers could have been present in 2009, but it was during 2010 that a general decline was noticed in the ninebarks. Some of the ninebark replications in each treatment had some decline as the season progressed. For example, some branches on one side of the plant would unexpectedly and quite suddenly dieback with no apparent cause.

Figure 1.3a: Study looking southeast after hail storm (June 7, 2009)

Figure 1.3b: Smooth hydrangea after hail storm (June 7, 2009)

Figure 1.3c: Diablo® ninebark after hail storm (June 7, 2009)

Despite these problems caused by the borer infestation, certain trends were found and some conclusions were still able to be made.

As the experiment progressed, the arctic blue willow became increasingly more chlorotic. At least some chlorosis was noticed on 95% of the arctic blue willows by the conclusion of the experiment in 2010. The willows suffered from iron chlorosis since the leaves turned yellow while the veins remained green on either one branch, one side of the plant, or the entire plant

(Kuhns and Koenig, 2003). The soil in which the willows were planted had a pH greater than 7.0 (Appendix C), and soils with a pH above 7.0 often makes iron become less soluble, and thus more difficult for the plant to absorb (Kansas State University, 2003; Kuhns and Koenig, 2003). The chlorosis appeared to be uniform in frequency among treatments. The effects on the outcome of the experiment were minimal since no one treatment had an advantage over another.

Some of the plants in the 50% treatment plot were possibly affected by the soil, which caused the plants not to grow and remain dwarfed. Dogwood, ninebark and willow appeared to be affected, while the effect on the hydrangea appeared minimal. Dwarfed plants were only noticed in the 50% plot while no other shrubs in the other treatment plots appeared to have been affected. Since the plants were dwarfed in the 50% plot, some data were affected. The graphs of the data showed that the other treatments followed a pattern as the irrigation increased where as the 50% treatment fell outside that pattern for some of the data. It is unknown as to the precise cause of the dwarfed plants in the 50% plot, however, it is hypothesized that it was soil related. The soil in the 50% plot was consistently more compacted than any of the other treatment plots when manually digging in the research plots. As a result of this hypothesis, a soil compaction test was conducted on October 29, 2010 using a Field Scout™ SC 900 Soil Compaction Meter (Spectrum Technologies Inc., Plainfield, IL). Within 30.48 cm (12 in) of every plant, the soil compaction down to a depth of 25.40 cm (10 in) was tested. The results were inconclusive. No compaction rating differences were present when the 50% treatment was compared to the other treatments (Appendix D). However, the test only went down 25.40 cm (10 in) and a hard soil pan could be below this depth.

The turf served as the control for the experiment, therefore, it was important to monitor stress levels in the various treatments so a valid comparison could be made with the shrubs. To monitor stress, infrared temperature of the turf's canopy was measured. Canopy temperature is a good measure of stress in a plant because the lower the temperature, the lower the stress. If water is available to the plant the stomata are open, the plants transpire, and the canopy temperature is reduced. Conversely, if water is not available the stomata are closed, the plant does not transpire, and the temperature of the canopy is higher (Kirkham, 2005).

The average infrared temperatures of the turf for each of the four treatments during 2009 and 2010 are shown in Figure 1.4a and Figure 1.4b, respectively. The data were collected before treatments were applied and the day after water treatments were applied. Measurements began on July 14 in 2009 and on May 25 in 2010. Data collection was delayed in 2009 as a result of the hail damage incurred to the shrubs. The ambient temperatures depicted in Figure 1.4a and Figure 1.4b were collected at the same time as the temperatures collected for the turf. The ambient temperatures were recorded from the Wadsworth Weather Mast located on the roof of the Plant Environmental Research Center (PERC) greenhouses.

The temperatures of the turf rose and fell with the ambient temperature. Both years are similar in results in that the temperature decreased as the irrigation amounts increased. The Kentucky bluegrass receiving 100% of ET_o generally had the lowest temperature. The low temperature means the turf in the 100% treatment was the least stressed, and, as such, probably had the best root system of the four treatments. Since treatments occurred once a week, watering events were infrequent and deep for the 100% treatment. This is important because infrequent and deep watering promotes root growth in turf, which results in better health and better drought tolerance (Gross and Swift, 2008; Christians, 2007). Interestingly, the turf in the 25% and 50% treatments resulted in no significant differences, since they nearly overlap each other during both years. The 0% turf treatment had the highest temperatures. Whether the temperatures were taken before or after treatments appeared to make little difference on the overall results for all the treatments. Additionally, the temperatures of the turf do appear high, since even the 100% treatment is higher in temperature than the ambient temperature. However, if the ambient temperature and overall values are ignored, a definite trend is still present among both years. Watering treatments undeniably had an effect on the leaf temperatures of the turf, wherein more moisture lowered the temperature (and thus the stress levels) of the turf.

The soil moisture data collected using the Diviner 2000® suggested that the soil moisture around each species in each treatment was fairly similar during both seasons (Appendix B). This result means that the treatments were calculated and applied uniformly during both years. Similar results were obtained even when utilizing different rooting areas for Equation 1.2 during the two growing seasons. However, even though soil moisture levels were similar during both years, the performance of the shrubs varied greatly from 2009 to 2010 since the shrubs did not have similar growth during both years. Table 1.4 shows the mean high and low temperatures and the cumulative ET_o rates were lower and the precipitation rate was higher during 2009 than 2010.

The Kentucky bluegrass in all of the water treatments (25%, 50%, and 100%) resulted in the same general pattern where water content abruptly increased at the 30 cm (11.81 in) depth. This suggests that the turf did not access the water at depths beyond 30 cm (11.81 in). This is not surprising since Kentucky bluegrass generally roots to an average depth of about 30.38 cm (12 in) (Harivandi, 2009). The turf in the 0% treatment did not follow the same trend as the water treatments. The water content in the 0% treatment slowly increased as depth increased down to 50 cm (19.69 in). It is hypothesized that the majority of the 0% turf died and what had remained had a very weak root system as was indicated by the increase in infrared temperature measurements (Figure 1.4a and Figure 1.4b). These higher temperatures are further detrimental

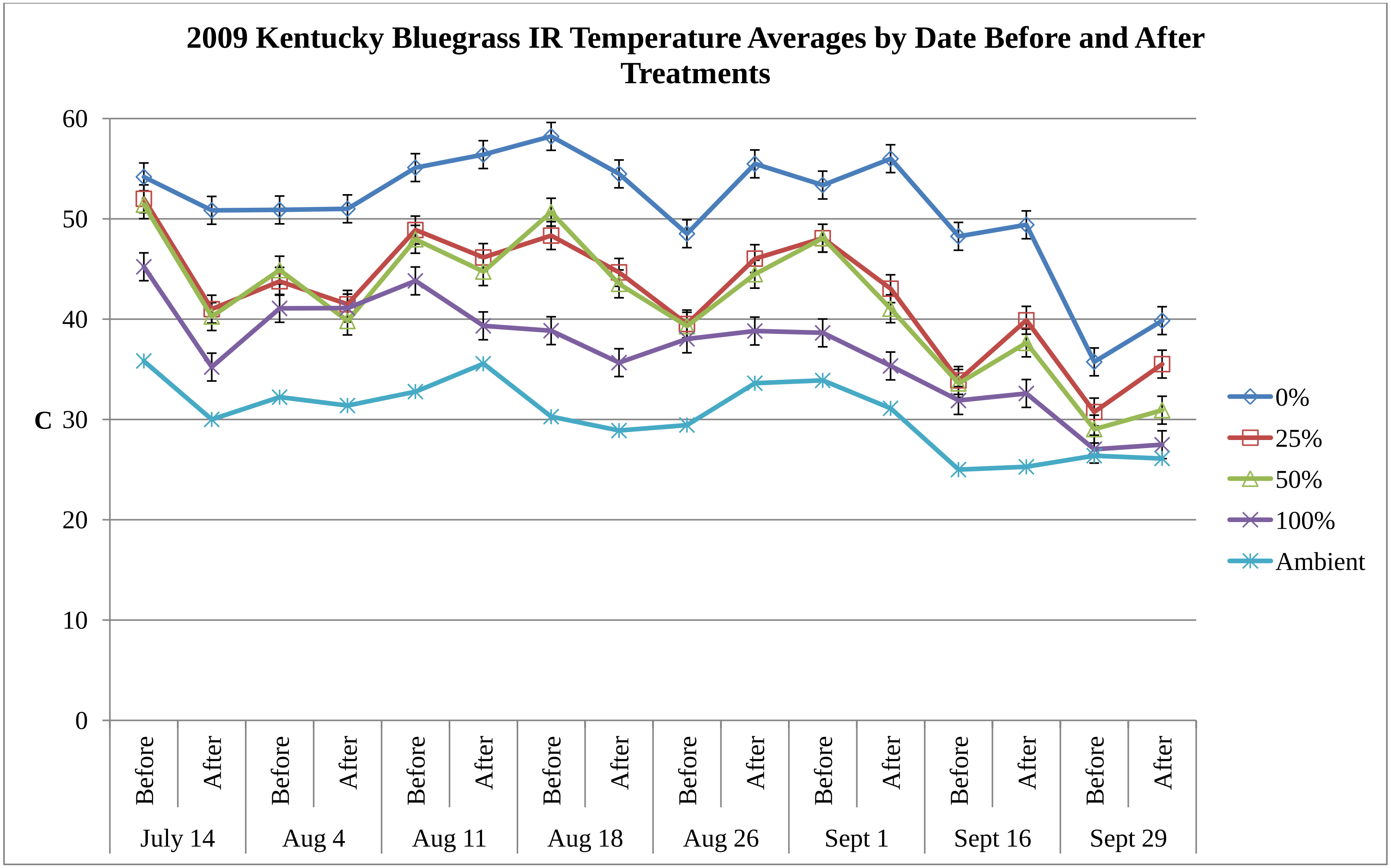

Figure 1.4a: Weekly infrared temperatures of Kentucky bluegrass during 2009 experimental season (p<0.05)

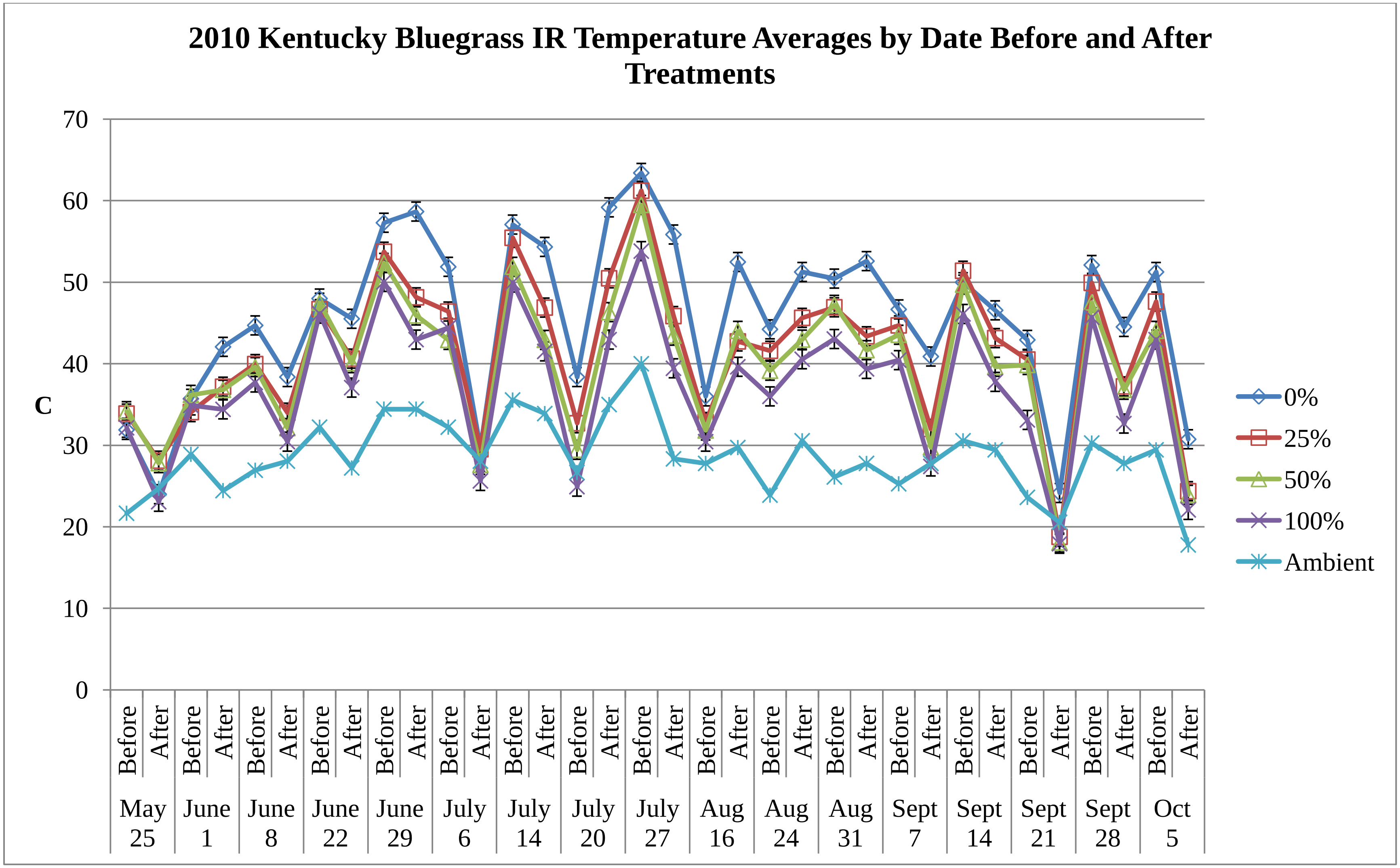

Figure 1.4b: Weekly infrared temperatures of Kentucky bluegrass during 2010 experimental season ($p<0.05$)

to the turf because “higher temperatures can cause dieback of the root system of cool season grasses” (Christians, 2007). As a consequence of the turf being mostly dead in the 0% treatment, little water would have been extracted from the soil.

The soil moisture readings for the redosier dogwood and Diablo® ninebark were fairly similar in the way each species responded to the treatments. The 0%, 25%, and 50% treatments appeared to have had no differences and the water content was fairly equal at all depths. The dogwoods and ninebarks in the 100% treatment matched the other treatments in water content once the depth went beyond 20 cm (7.87 in). The 100% treatment had lower soil moisture readings in the top 20 cm (7.87 in), which meant that a lot of moisture was being extracted from shallower soil levels. However, the soil moisture levels returned to a similar pattern as the other treatments beyond the 20 cm (7.87 in) depth. The main difference is that dogwood and ninebark in the 100% treatment were extracting more moisture from shallower soil.

The soil moisture for the arctic blue willow did not have much variation. The willows in the 0% treatment resulted in moisture levels that generally increased as depth increased.

The hydrangeas consistently had lower soil moisture readings in the top 10 cm (3.94 in) of the soil profile. It appeared that the hydrangeas absorbed the majority of their water at shallower depths (up to 20 cm), which may mean that the majority of the root system was closer to the soil surface.

Height and width measurements of all of the shrubs in every treatment were taken during the 2009 and 2010 seasons to determine if watering treatments had any effect on the overall size of the shrubs. The beginning and end dates for height and width data for 2009 were delayed due to hail damage. During 2009, beginning heights and widths were measured on June 17th and end of season measurements were taken on October 20th. During 2010, beginning heights and widths were measured on May 28th and end of season measurements were taken on September 29th. Even though measurements were taken during different time periods in 2009 and 2010, both growing years had a similar total number of growing days. The varying time frames resulted in a total of 126 days for 2009 and 125 days for 2010.

Treatments appeared to have had minimal effect on the heights of the redosier dogwood (Figure 1.5a and Figure 1.5b), however, widths were affected (Figure 1.5c and Figure 1.5d). By the end of the 2009 season, the shrubs in the 100% treatment were wider than the 0%. By the end of 2010, the effects continued so that the 100% was wider than not just the 0%, but also the 25% and 50%. This trend also followed in the 100% treatment when comparing the width at the beginning of the season versus the width at the end of the season for both years. While all treatments appeared to have increased in width when comparing the beginning of the season to the end of the season, only the 100% treatment was statistically larger by season's end. As a result, more growth results to dogwoods at a faster rate if watered with 100% of ET_o, however, no differences in growth will result if watered with 50% or less.

The hydrangeas had little size and growth differences in 2009, but they grew differently in 2010. In 2009 the hydrangeas had no height or width differences at the end of the season, nor did any of the plants increase in size statistically by the end of the season when compared to the beginning of the season. However, the 2010 watering treatments resulted in a significant impact on how the plants grew. By the end of the 2010 season, the hydrangeas in the 100% were significantly larger in height and width than the other three treatments. All of the water treatments (25%, 50%, and 100%) were wider than the 0%. Further, the 100% treatment resulted in significantly more growth by the end of 2010 when compared to the beginning of the season.

As a result, any amount of water given to hydrangeas above 0% will affect their overall size, but if given 100% of ET_o the shrubs will be the largest.

Treatments resulted in few height differences with Diablo® ninebark for both years, however the width of the plants was affected by treatments. Despite ninebark in the 50% treatment appearing erroneous at the beginning and end of the season during both years (probably due to the aforementioned soil issue), the general trend is that width increased as watering amounts increased. However, statistically only the 100% was greater in width than the 0% treatment. When comparing the beginning height and width data with the end of season height and width for both years, sizes did increase for both years for all treatments. It appears that the more water given to ninebarks will increase their overall width, but once ninebarks are established, growth in height and width will still occur throughout a season regardless of the amount of water they receive.

The growth habits of the arctic blue willow were similar in both 2009 and 2010. There was no pattern nor any differences in the seasonal growth increment from the beginning of the season versus the end of the season in any treatment. It appeared that watering treatments up to 100% ET_o may have no effect on overall size, however, further testing is needed to determine if this is truly the case. It is possible that the size of arctic blue willow might be affected if they receive greater than 100% ET_o.

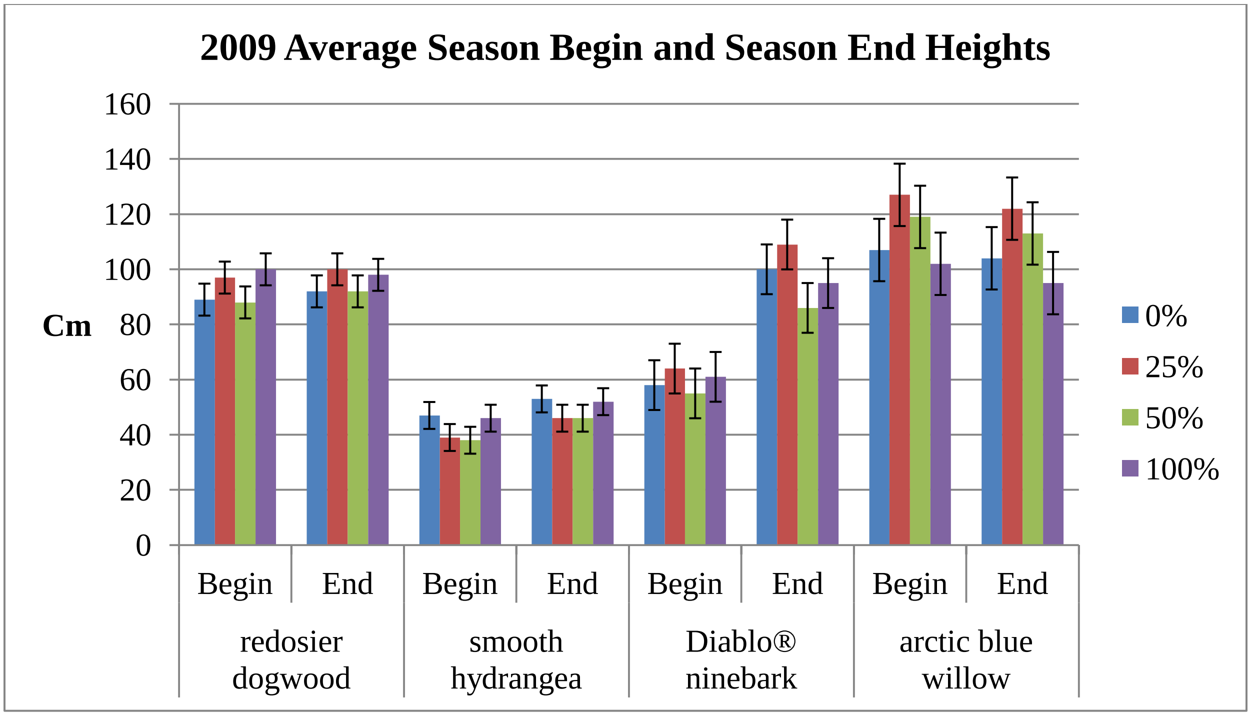

Figure 1.5a: 2009 Average begin (June 17, 2009) and end (Oct. 20, 2009) of season heights ($p<0.05$)

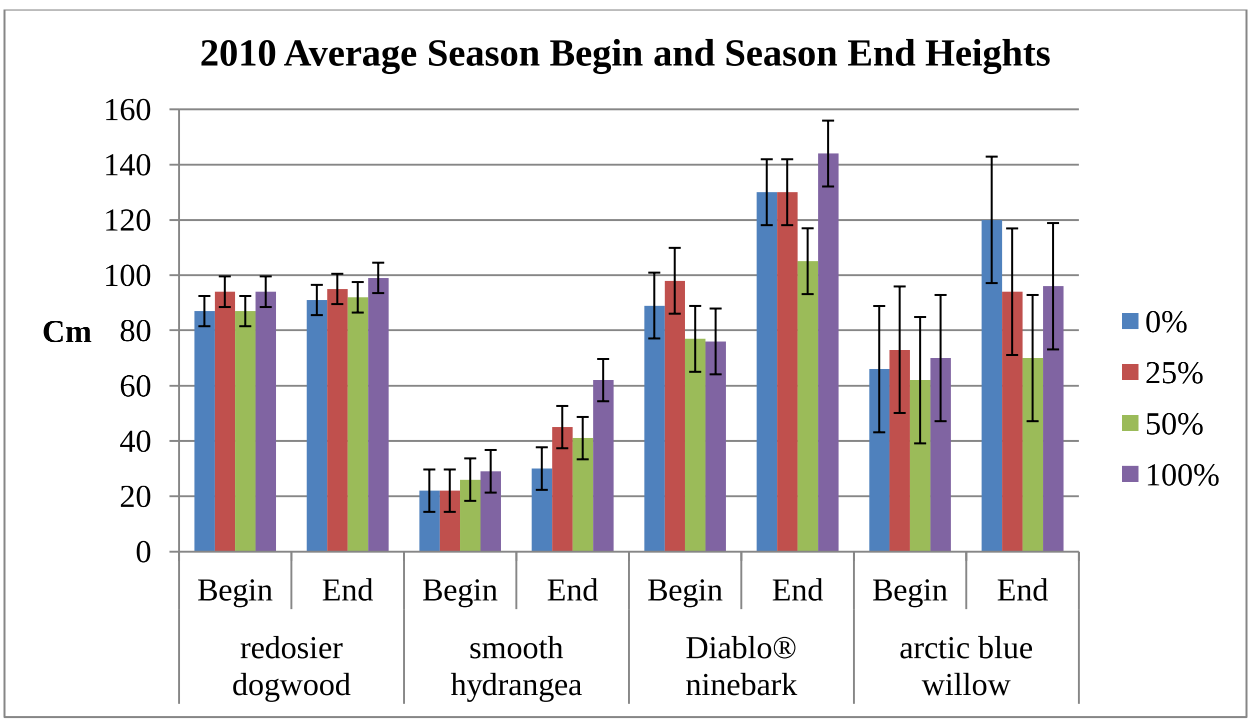

Figure 1.5b: 2010 Average begin (May 28, 2010) and end (Sept. 29, 2010) of season heights ($p<0.05$)

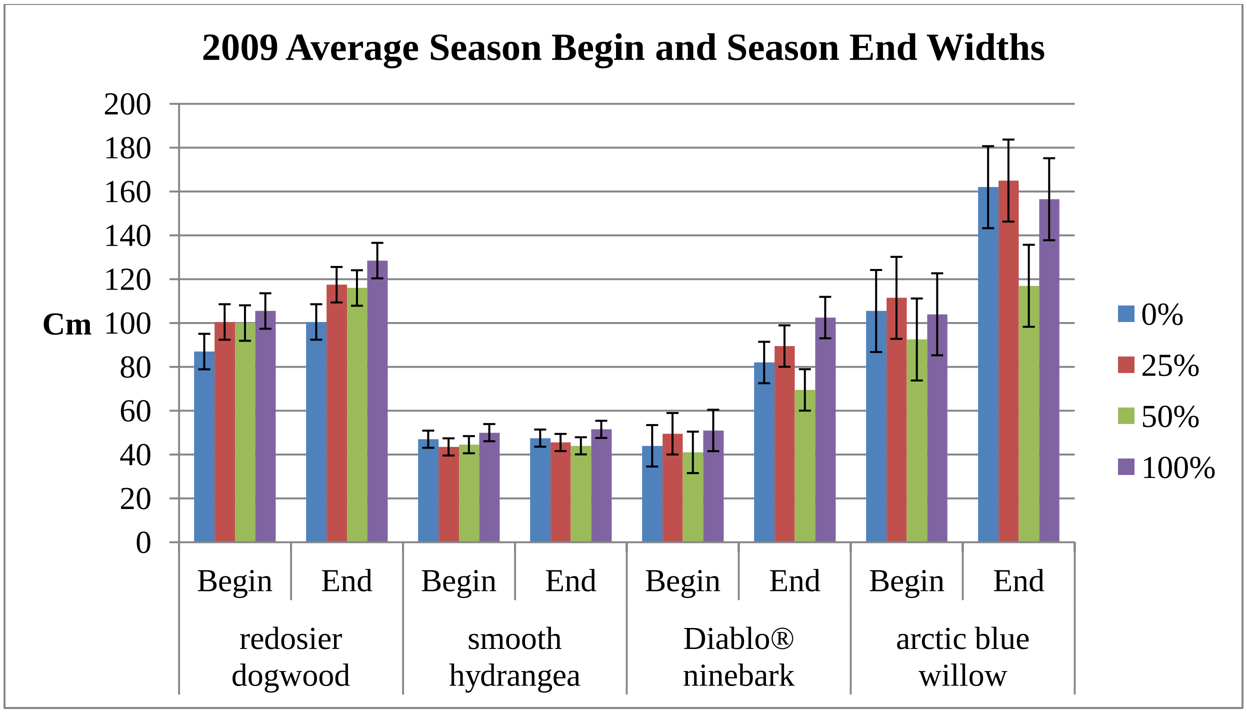

Figure 1.5c: 2009 Average begin (June 17, 2009) and end (Oct. 20, 2009) of season widths ($p<0.05$)

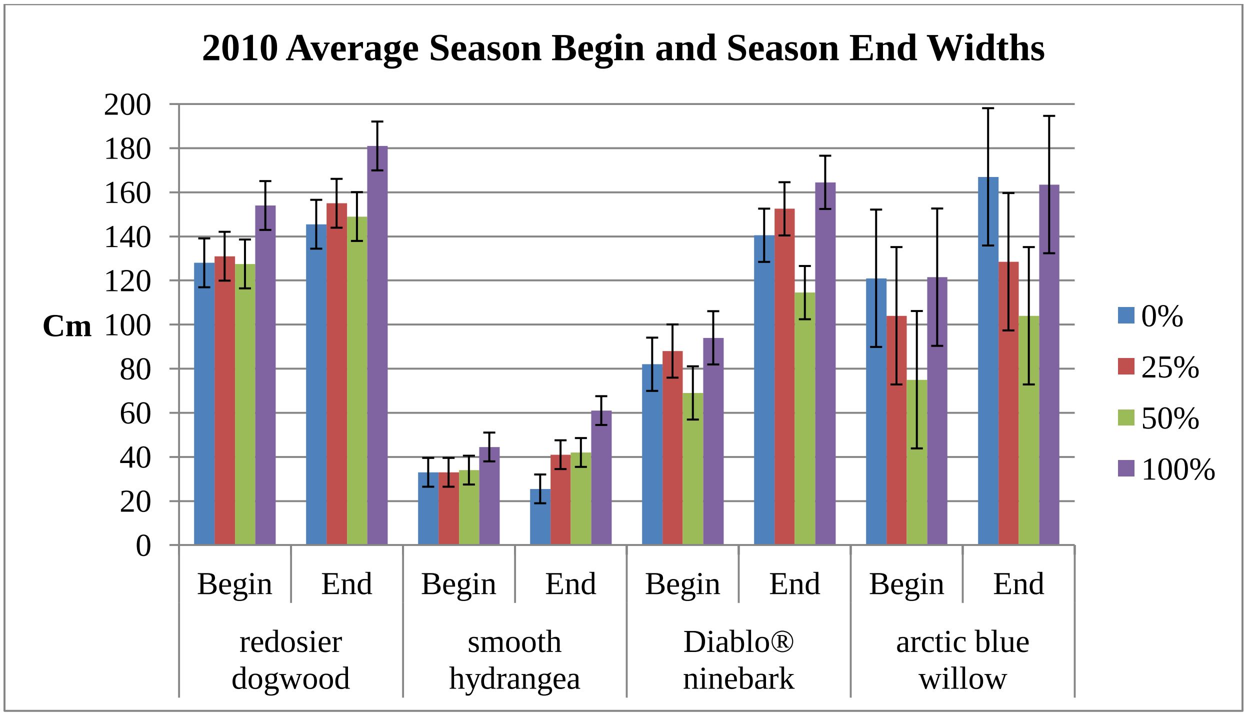

Figure 1.5d: 2010 Average begin (May 28, 2010) and end (Sept. 29, 2010) of season widths ($p<0.05$)

Visual ratings were assessed and recorded during both years to determine if treatments affected the overall aesthetics of the plants. The results for both years are shown in Figure 1.6a and Figure 1.6b. Representative photographs of the shrubs and turf in each treatment at the conclusion of the experiment are shown in Appendix A. As can be seen from the figures and the photographs, the Kentucky bluegrass increased in visual ratings as irrigation amounts increased. This trend is similar to the results of the infrared temperatures of the Kentucky bluegrass (Figure 1.4a and Figure 1.4b). However, this result is not surprising since treatments were based on percentages of what a cool season grass requires (GreenCO and Wright Water Engineers, Inc., 2008). Surprisingly, the willow and ninebark showed little statistical differences in visual ratings among the four treatments in either year. The dogwood looked the best in the 100% during 2009 and 2010, but in 2010 all treatments appeared suitable for landscape use. In addition to the dogwood, the ninebark and willow looked quite acceptable for landscape use after two years of establishment. The hydrangea looked the best in the 100% treatment. However, they weren't as aesthetically acceptable as the other species tested. It appears that the hydrangea needs greater than 100% ET_o to further increase visual ratings.

Survival rates for all shrub species were good. With the exception of one hydrangea replication in the 0% treatment, all tested shrub replications had a 100% survival rate at the conclusion of 2010. Even though one hydrangea was lost, there was still an 80% survival rate in the 0% treatment. It appears that all of the tested shrub species are able to survive with 0% ET_o after two years of establishment. Even though the hydrangeas in the 0% treatment were not visually acceptable for use as landscape plants, they will likely be able to survive a short period with no additional water. As a result, all these shrub species would most likely have good survival rates even during periods when water is extremely limited.

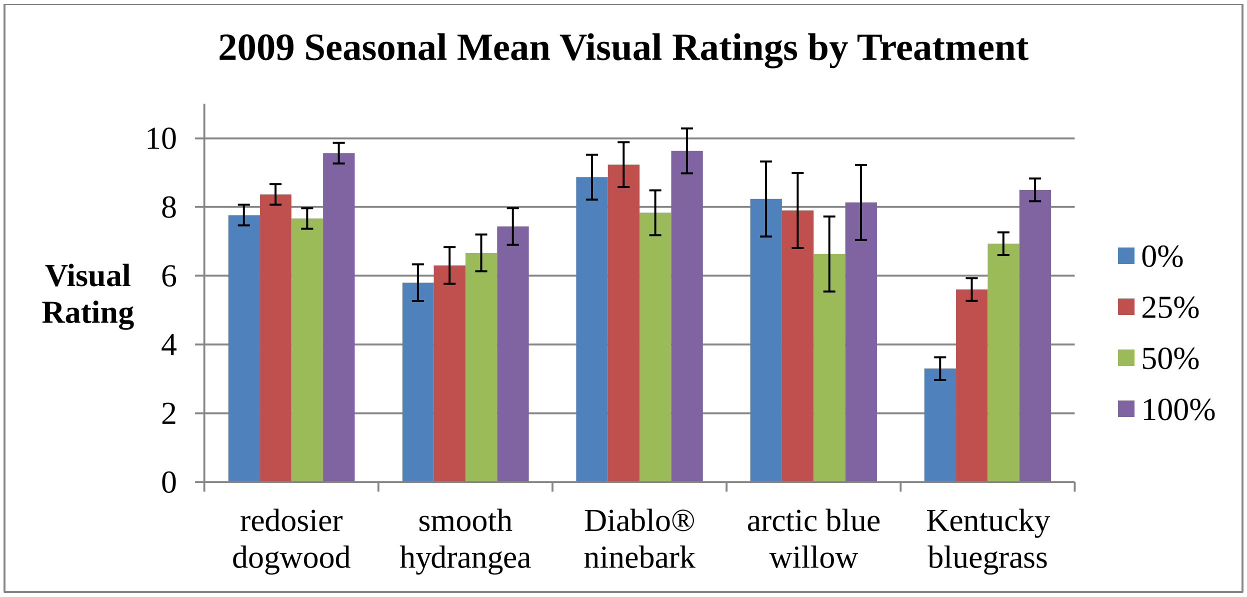

Figure 1.6a: 2009 Seasonal mean visual ratings by treatment ($p<0.05$)

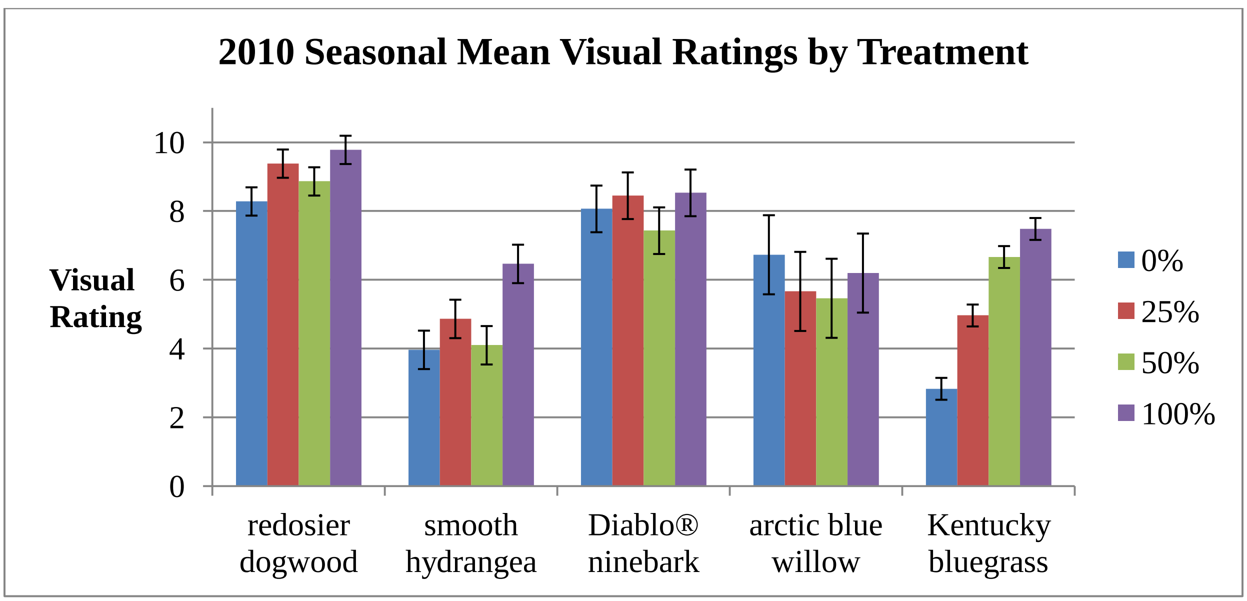

Figure 1.6b: 2010 Seasonal mean visual ratings by treatment ($p<0.05$)

Plant water stress was monitored by determining the water potential of each species using a pressure chamber. Water potential is important because shrub water potential directly relates to the stress level of the plant. A lower water potential equates to higher plant stress and a higher water potential equates to lower plant stress (PMS Instrument Co., 2011).

During 2009, few differences occurred with leaf water potential readings between treatments for any particular species. However, 2010 did display differences. The lack of differences in 2009 (Figure 1.7a) can be attributed to the weather (Table 1.4). As a result, all species in all treatments remained equally hydrated during 2009. However, the 2010 weather was more cooperative for conducting water stress studies and each species had more varying results among treatments (Figure 1.7b). In 2010, the dogwood, ninebark and willow in the 100% treatment had the least negative readings (least stressed) than their counterparts in the 0%. Additionally, the dogwood and willow in the 100% treatment had less negative readings (less stressed) than the 25% and 50% treatments. The ninebark in the 100%, 25%, and 0% treatments had a general decreasing trend as water became more limited. The ninebark in the 50% treatment did not follow this trend, probably as a result of the soil issues mentioned earlier. As a result, it appears that water potentials become less negative if more water is provided to these three species.

The hydrangeas performed differently than the dogwood, willow, and ninebark in 2010. The hydrangea had similar readings for the 0%, 25%, and 50% treatments, but the most negative readings were in the 100% treatment. This equates to the 0%, 25%, and 50% being equally stressed and the 100% treatment being the most physiologically stressed. This counterintuitive result can be explained by the size differences during 2010. The 100% treatment hydrangeas were significantly larger in height (Figure 1.5b), width (Figure 1.5d), and overall plant fresh and dry weights (Figure 1.11a and Figure 1.11b, respectively) than any of the other treatments. The larger size resulted in an increase in transpiration, and thus water demand for the shrub (Irmak, 2009). Since the larger hydrangeas were more stressed, it is possible that hydrangeas require more than 100% ET_o to perform the best.

As was stated earlier, the mean predawn leaf water potentials for each species during 2009 (Figure 1.7a) had no differences among treatments, however differences among species were present. During 2009 the hydrangea generally resulted in the lowest water potential readings of the four shrubs, and the willow had the highest water potential readings. Since one of the major factors influencing water potential is the osmotic potential (Taiz and Zeiger, 2006), the osmolality was tested in 2010. Osmolality

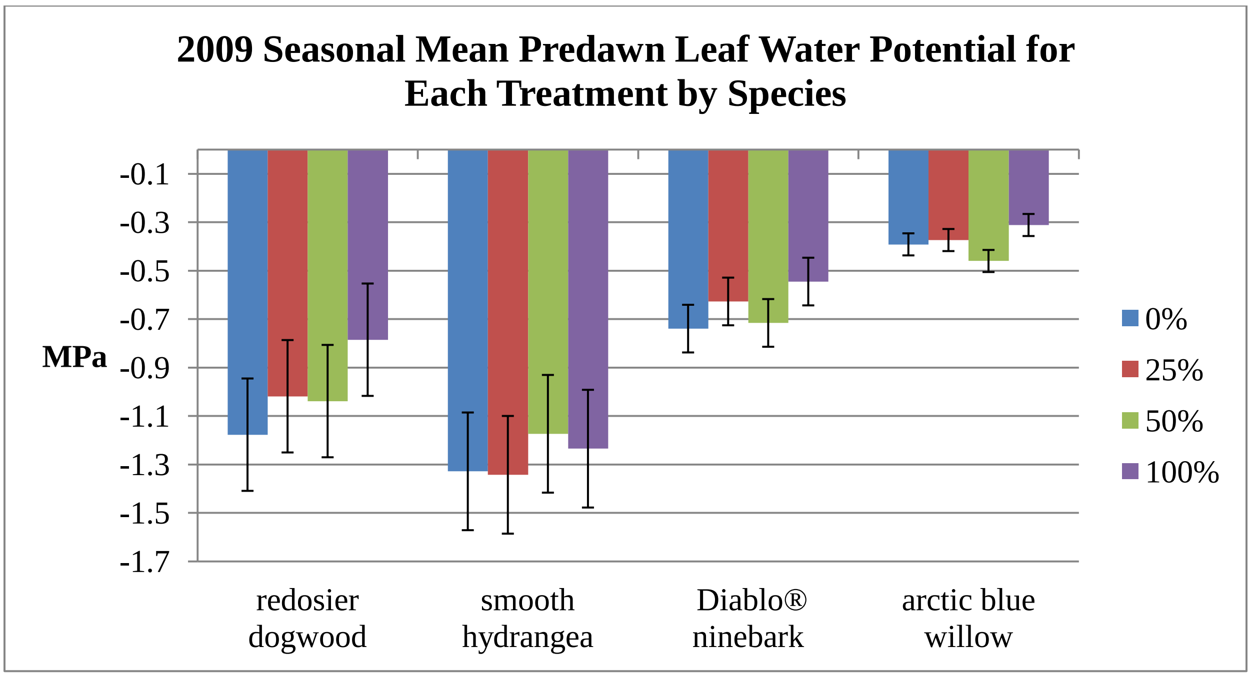

Figure 1.7a: 2009 Seasonal mean predawn leaf water potential for each treatment by species ($p<0.05$)

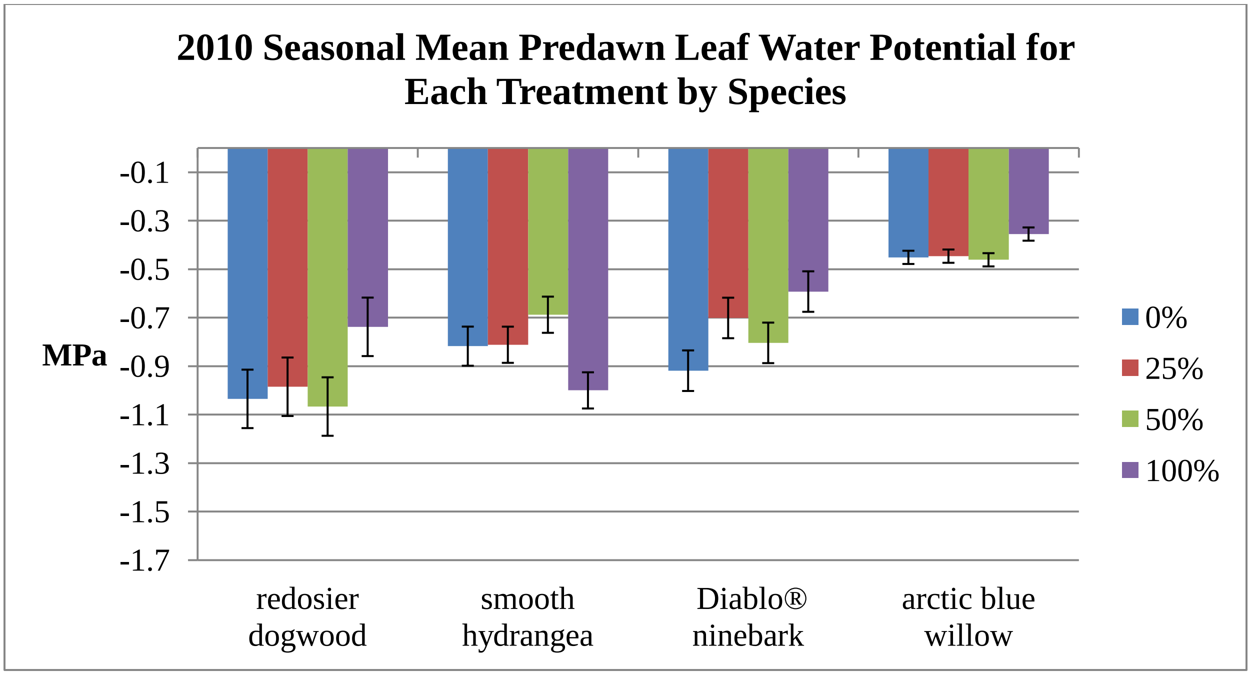

Figure 1.7b: 2010 Seasonal mean predawn leaf water potential for each treatment by species ($p<0.05$)

determines the concentration of dissolved solutes in the plant sap, and if the concentrations varied it could cause varying water potential readings among species.

Figure 1.8 displays the results for the 2010 seasonal mean osmolality of the four species in each treatment. As watering amounts decreased, solute concentrations generally increased. This trend was especially noted with the dogwood, hydrangea and ninebark. The trend is not surprising, however, since one of the responses to drought stress is for a plant to undergo an osmotic adjustment (Chaves, et al., 2003). Plants that increase their solute concentration in their cells lower their water potential so that the plants can absorb the more tightly held moisture in the soil. This action causes the water potential in the plant to become more negative (Figure 1.7b) as solute accumulation increases. This, in turn, causes the water in the soil to pass into the plant through osmosis (Taiz and Zeiger, 2006).

The osmolality in the arctic blue willow was also affected by the treatments, but not to the extent as with the other species. The willow did not result in a linear relationship as the other species. The arctic blue willow probably underwent some osmotic adjustment like the other three species since the shrubs in the 100% treatment were lower in solute concentrations than the 0% treatment. However, since the willow had similar water potential readings in the 0%, 25% and 50% treatments (Figure 1.7a and Figure 1.7b), and solute concentrations did not follow a decreasing trend as treatments amounts increased, osmotic adjustment does not appear to be as influential with this species as the others.

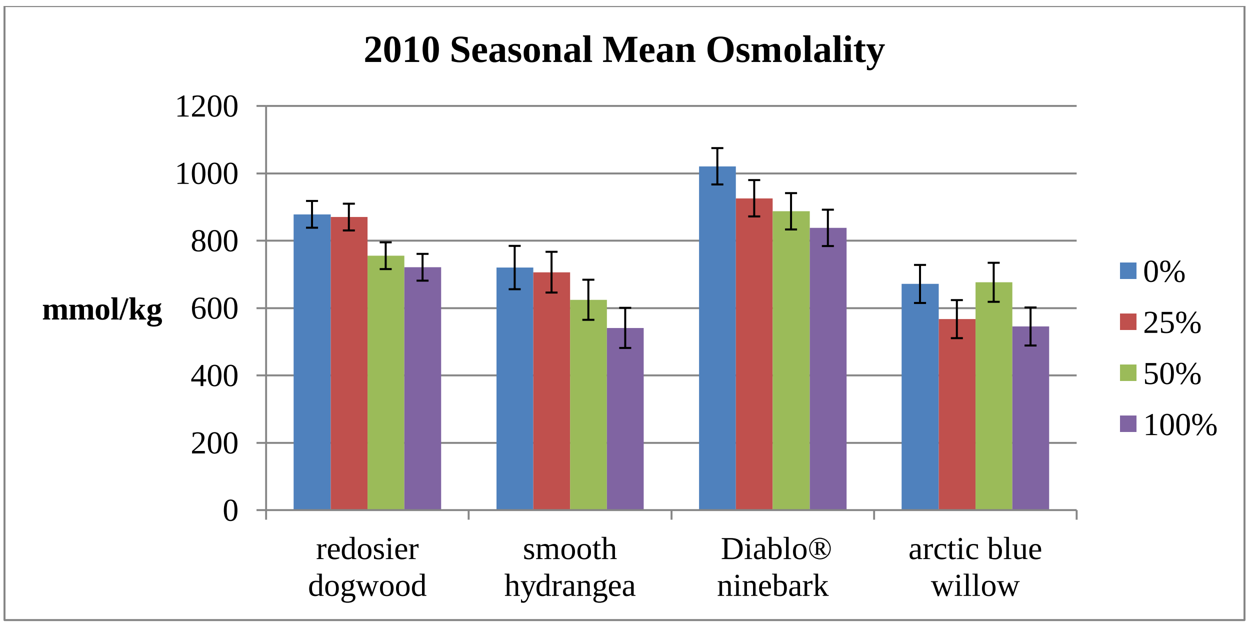

Figure 1.8: 2010 Seasonal mean osmolality ($p<0.05$)

At the end of each season, leaves were collected from each plant to determine average leaf area, average leaf fresh weight, and average leaf dry weight of each shrub species in each treatment. These data were collected to determine if watering treatments affected the growth habits of the foliage for each species by affecting the overall size, total biomass, and water holding capacities per leaf.

Leaf area had some variations due to the treatments during both years, however, the differences are more pronounced during 2010 (Figure 1.9b) when compared to 2009 (Figure 1.9a). Very little differences for leaf area were present for the arctic blue willow, and it appears water treatments had no effect. The ninebark also had little statistical differences among treatments except that during 2010, the 100% treatment had larger leaves than the 25% and 50% treatments. However, during both years the graphs follow a general pattern (not statistically) that the 100% ninebark had the greatest leaf area. As a result, more water may have affected the overall leaf area for ninebark, but further testing is needed. In 2010, hydrangea and dogwood leaves were the largest in the 100% treatment, demonstrating that the more water given to these two species resulted larger leaves. This trend also occurred during 2009 for the hydrangea, however no statistical differences resulted. In conclusion, the more water given to dogwoods, hydrangeas, and possibly ninebarks will result in larger leaves when receiving 100% of ET_o.

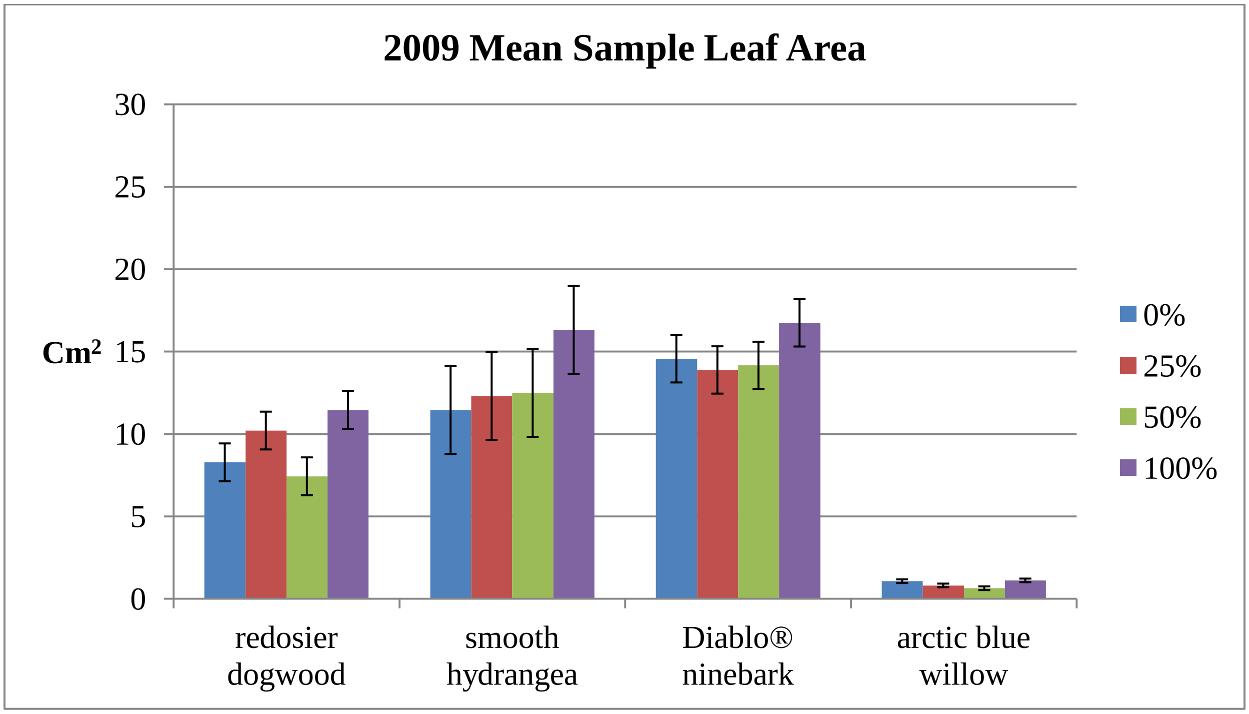

Figure 1.9a: 2009 Mean sample leaf area (p<0.05)

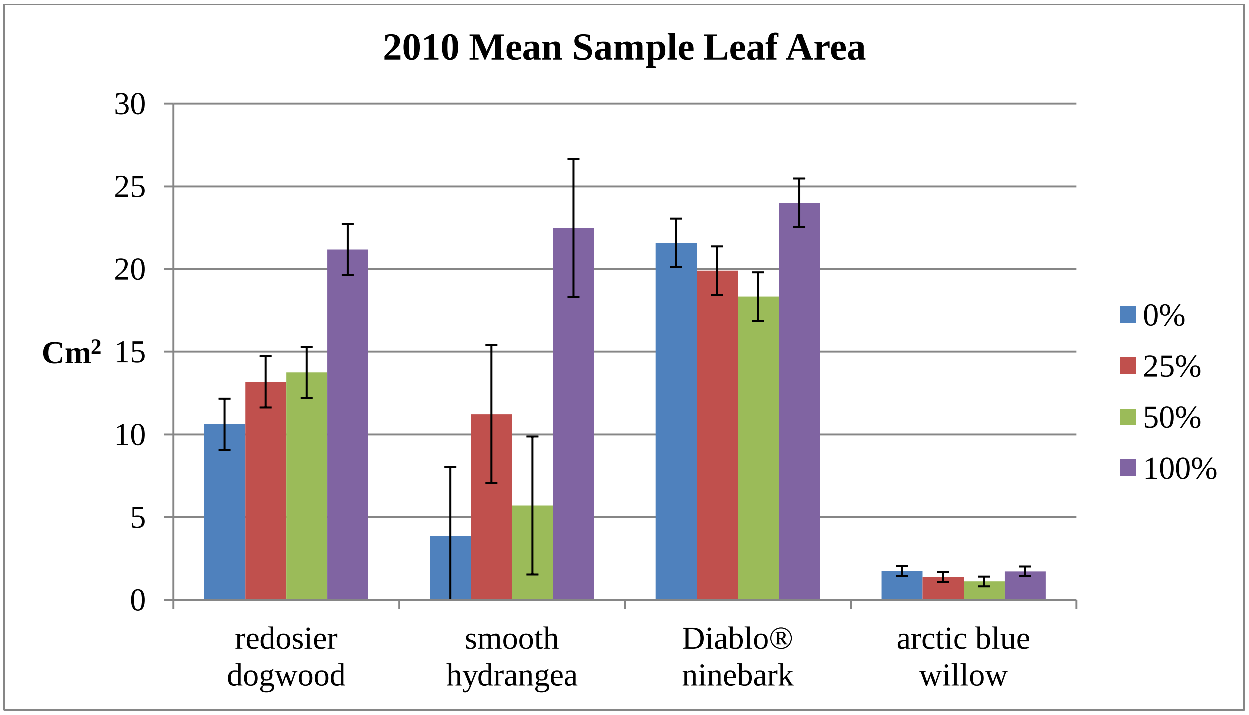

Figure 1.9b: 2010 Mean sample leaf area ($p<0.05$)

Figure 1.10a through Figure 1.10d demonstrates that the fresh and dry weight of leaf samples followed similar patterns from 2009 to 2010. The dogwood had heavier leaves in the 100% treatment during 2009 but even more so in 2010. During 2009 as irrigation amounts increased, leaf weights generally increased for the dogwoods. The 50% treatment fell outside of this pattern since the leaves from the 50% were lower in fresh and dry weights than the 25% treatment during 2009. It is theorized the soil issues discussed earlier affected the leaf characteristics since the 0%, 25%, and 100% treatments had an increase in weight as irrigation amounts increased. Despite the difference in the 50% treatment during 2009, during 2010 the 100% was greater than the 0%, 25%, and 50% in both fresh and dry weights. It appears dogwoods will grow leaves that have greater water holding capacity and biomass once irrigation reaches 100%. Watering had no statistical effect on leaf weights when the shrub received less than 100%.

The ninebark had a similar trend to the dogwood except the difference occurred in 2010 versus 2009. During 2009, the 100% was greater than the 0%, 25%, and 50%, but during 2010, the 100% was only greater than the 25% and 50%. This result could be due to the dogwood borers since the borers were most likely only an issue during 2010. However, after two years of growth it appeared that more water given to ninebarks also increased their leaf fresh and dry weight. Further, if the ninebark received 50% or less of ET_o, leaf weights were not influenced.

Like the dogwood, the hydrangea resulted in more significant differences in 2010 than 2009. The only significant leaf weight differences with hydrangea in 2009 were a slightly greater leaf fresh weight in the 100% treatment versus the 0% treatment. This result changed in 2010; the 100% was significantly greater than all of the other treatments for both fresh and dry weight. This result equated to the same as for the dogwood and ninebark, in that the hydrangea grew leaves that were higher in water holding capacity and biomass once irrigation reached 100%. Watering had no statistical effect on leaf weights if the shrub received 50% or less of ET_o.

The willow had no significant differences in leaf weight other than the 50% typically resulted in the lowest weight. The 50% fell outside of the pattern from the other treatments probably as a result of the soil issues in the 50% treatment plot. Since no significant differences resulted with the fresh or dry weight, it appears that leaf water holding capacity and leaf biomass is unaffected by watering treatments when irrigated up to 100% ET_o.

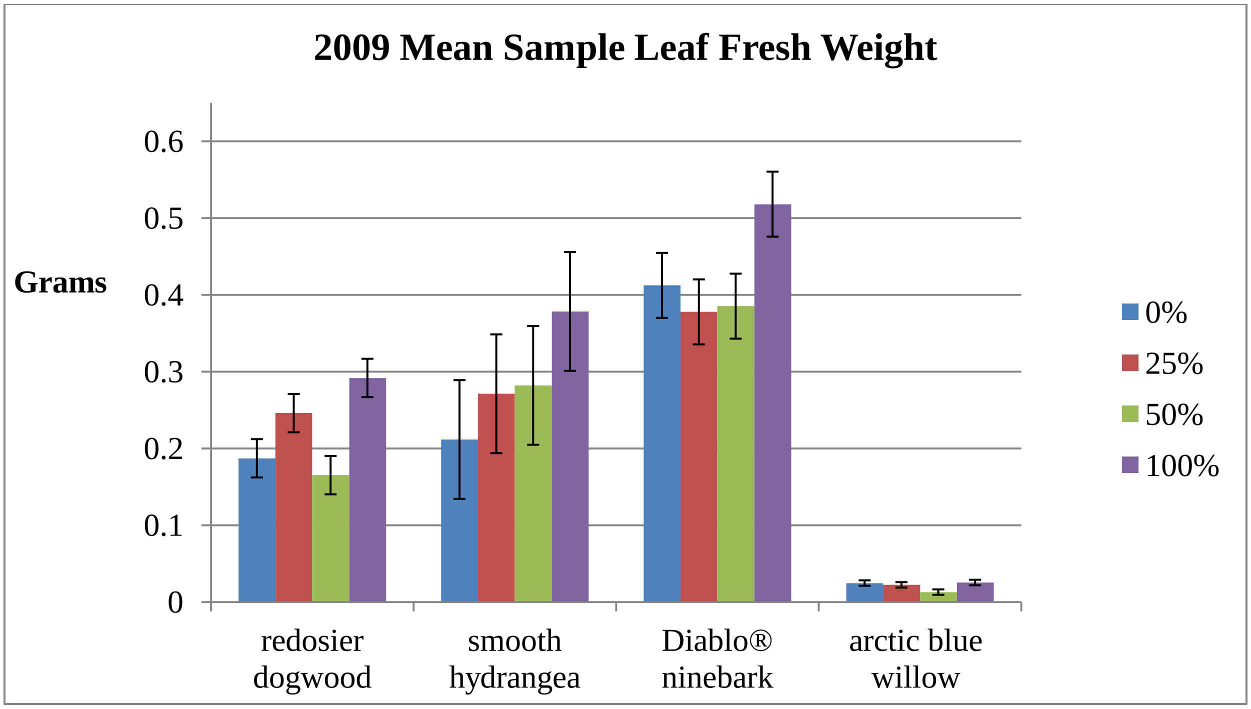

Figure 1.10a: 2009 Mean sample leaf fresh weight ($p<0.05$)

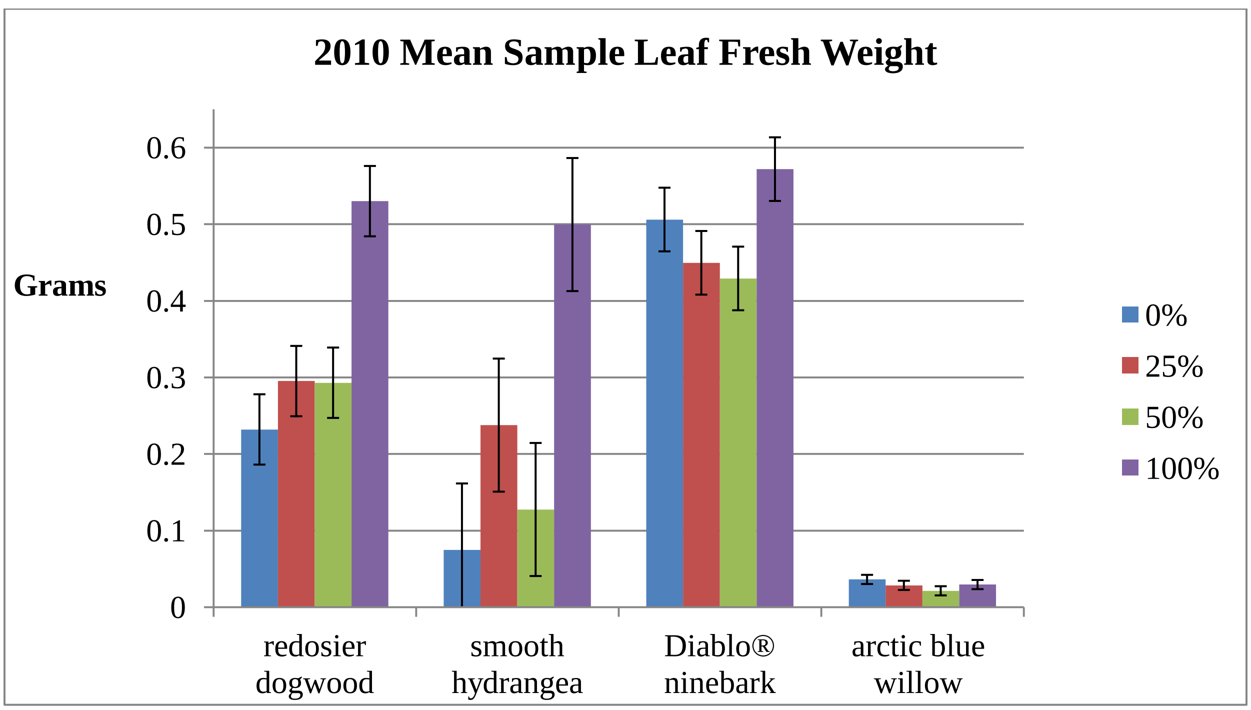

Figure 1.10b: 2010 Mean sample leaf fresh weight ($p<0.05$)

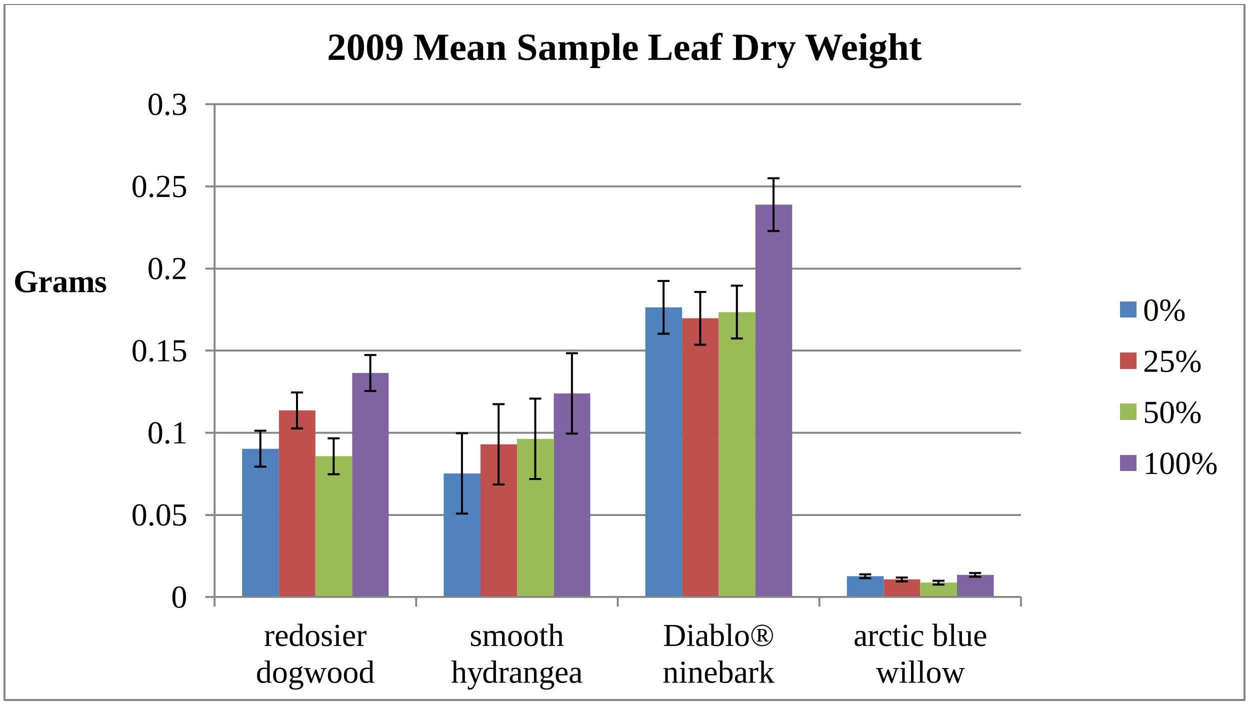

Figure 1.10c: 2009 Mean sample leaf dry weight ($p<0.05$)

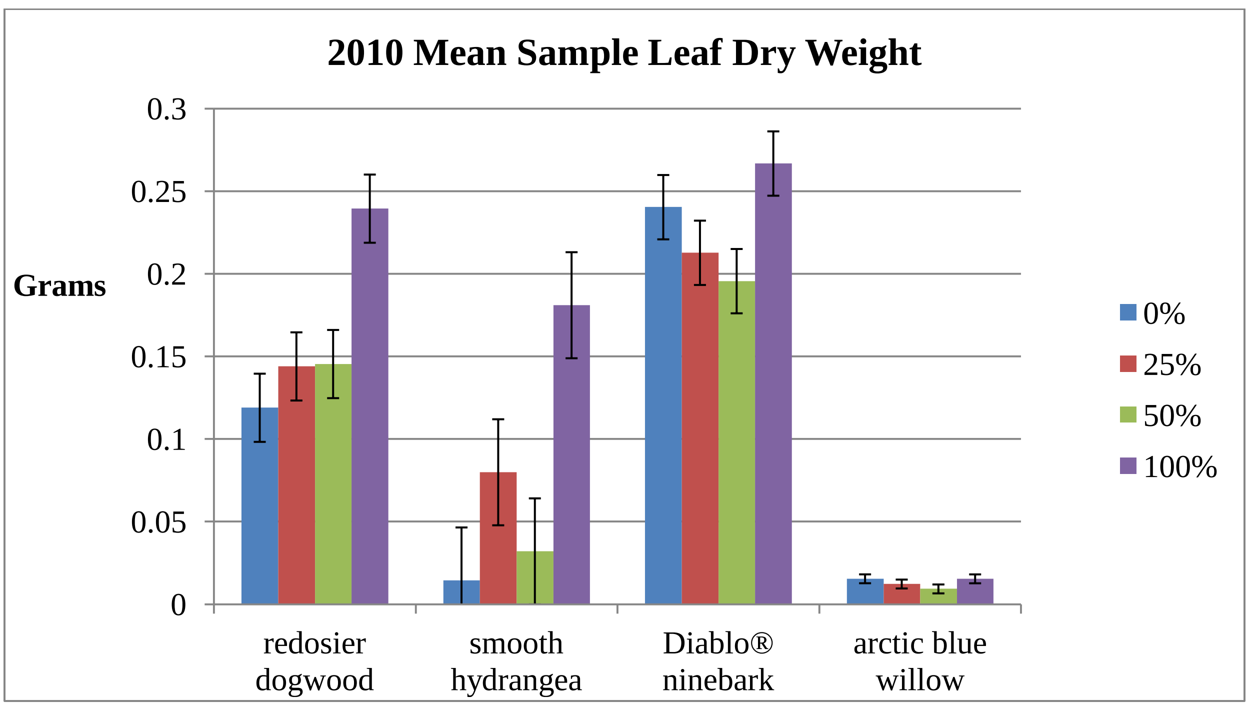

Figure 1.10d: 2010 Mean sample leaf dry weight ($p<0.05$)

At the conclusion of the experiment, all of the plants were harvested down to soil level. Fresh and dry weights were then measured and recorded to observe if watering treatments had any effect on the above ground biomass of each species. This measuring technique was destructive, therefore it was only done in 2010. The data is represented in Figure 1.11a and Figure 1.11b. The dogwood and ninebark had similar results. The fresh and dry weights in the 100% treatment were greater than the 0%. Further, the general trend (although not statistically different) of the weights is that they increased as watering amounts increased, with the exception of the 50% treatment. Once again, the 50% treatment was probably affected from the soil issues mentioned earlier. The hydrangea in the 100% had the greatest fresh and dry weights when compared to the other treatments. There was no statistical difference among treatments for the fresh or dry weight for the willow. However, this study only tested 0% to 100% of ET_o and further research is needed with the willow to determine if different results are yielded when tested with numbers beyond 100% ET_o. In summary, it appears when dogwood, hydrangea, and ninebark are given more water, more shoot biomass will result.

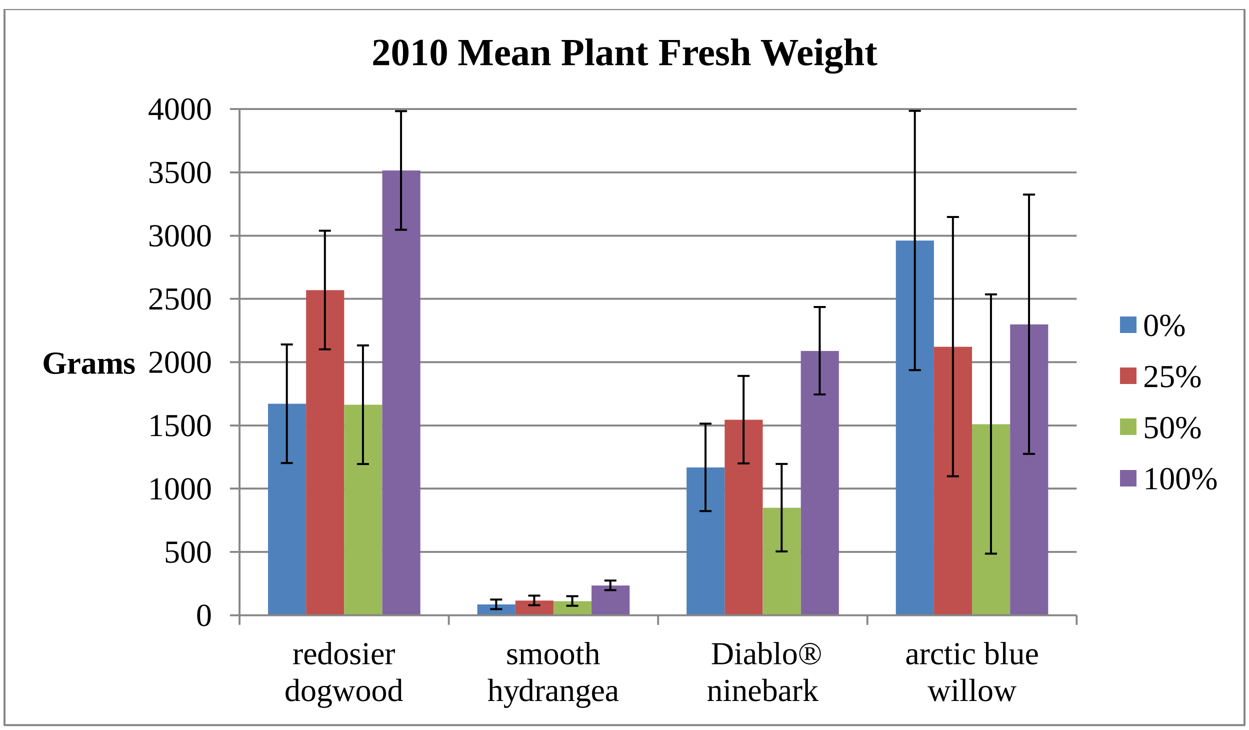

Figure 1.11a: 2010 Mean plant fresh weight ($p<0.05$)

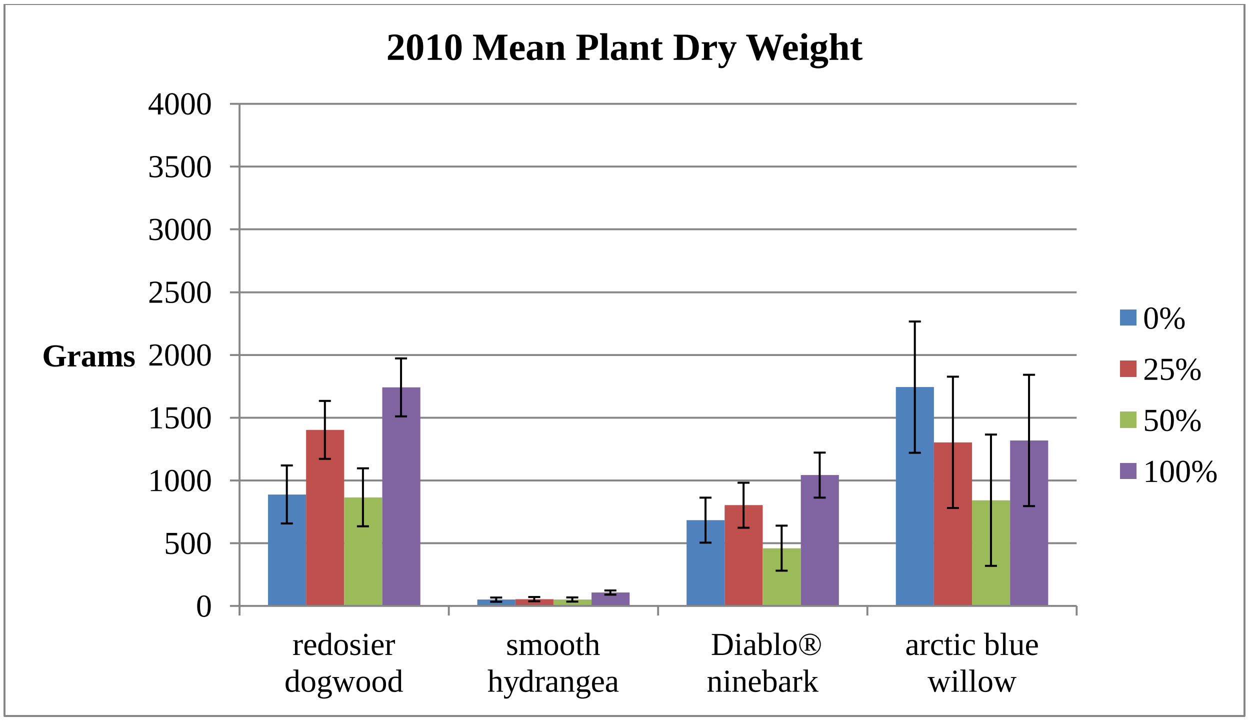

Figure 1.11b: 2010 Mean plant dry weight ($p<0.05$)

The field component of the study tested four species of shrubs to determine if they can survive, grow, and look acceptable in a landscape setting with decreased amounts of irrigation. The shrubs were researched while actively growing in the ground as well as being watered based on different percentages of ET_o as some other studies have (Henson, et al., 2006; Pittenger and Shaw, 2004a; Ounsworth, 2007). Since the shrubs were trialed while in the ground when watered based on percentages of ET_o, more accurate data has been gained on the water use redosier dogwood, smooth hydrangea, Diablo® ninebark, and arctic blue willow require. These plants have research based data, rather than just visual observation or opinions on their water demand. As such, these plants can be better classified into a category of water use that these plants fall into, such as when compared to water use categories as defined by GreenCO (Table 1.1). It is important to know if a plant can do well with less water in a landscape so that more informed decisions can be made for plant selections for a low water use landscape. "Many commonly grown landscape plants are capable of maintaining aesthetic and functional value when irrigated at substantially less than 100% of ET_o" (Hilaire, et al., 2008). The research conducted confirmed this with three of the four species tested (redosier dogwood, Diablo® ninebark, and arctic blue willow) after these shrubs had two years of establishment during non-drought years (Smith and Klett, 2011).

Redosier dogwood does well in the landscape after two years of establishment, regardless of the water amounts it received. The plants in all of the watered treatments (25%, 50% and 100%) were similar in visual ratings However, dogwood in the 0% treatment was also quite acceptable in visual ratings for landscape use. Plant biomass, leaf weights, leaf area, and the growth incurred during one season increased when receiving 100%. The 0%, 25%, and 50% treatments were equal in these categories. Plant growth characteristics appear to only be impacted if dogwood receives 100%. Water potential was generally greater when the dogwoods were watered with 100% ET_o. The osmolality was lower when the dogwoods received at least 50%. These results suggest that the dogwood is less stressed physiologically when receiving at least 50% of ET_o. Currently, the redosier dogwood is categorized as a "medium" water user (GreenCO and Wright Water Engineers, Inc. 2008). While the plant can survive with no irrigation and still perform adequately in the landscape, this shrub appears to more closely follow the characteristics of a "low" water user after two years of establishment.

Smooth hydrangea requires the most water of the four species tested. All of the growth characteristics were affected as irrigation amounts increased. The growth rate, overall size, plant biomass, leaf weights and leaf area were the greatest in the 100% treatment. Physiological characteristics were also affected in the 100% treatment. The osmolality was lowest in the 100% but the water potential was most negative (most stressed) in the 100%. Since the hydrangea increased its growth when watered at 100% of ET_o and osmolality decreased, it appears that more water was beneficial to maintain this plant. However, the water potential was most negative (most stressed) with the 100%, therefore, greater than 100% may be needed to maintain the plants when they increase their size. Additionally, even though the visual ratings of the hydrangeas in the 100% were the highest, they could still have used some additional water to be more ascetically appealing. It is possible that the calculation for determining water treatments was insufficient. The value used for Area in Equation 1.2 was based on estimated rooting area. In future experiments, it is recommended that the value used for Area to calculate treatments be based on estimated leaf area. Currently the smooth hydrangea is rated as a "medium" water user (GreenCO and Wright Water Engineers, Inc. 2008). Based on this research, it is recommended that this category be changed to a "high" water user as 100% of ET_o for growth was still insufficient for this plant.

Despite the hydrangea's apparent high water needs, it seems to be able to survive short drought periods. The hydrangeas had a 100% survivability rate in the 25%, 50% and 100% treatments and an 80% survivability rate in the 0% treatment. Due to the result of such a high incidence of survival, especially in the 0% treatment, it appears that established plantings have a high chance of survival even after a short dry period. Once wet conditions return the plant should recover. The hydrangea probably has a higher demand for water due to its large leaf size and smaller root system. Larger leaf areas lead to increased transpiration rates (Irmak, 2009). As water amounts increased so did the leaf size (Figure 1.9b) and leaf biomass (Figure 1.10b and Figure 1.10d). Since the leaves in the lower water treatments were smaller, the plants appeared to have adjusted their growth characteristics to account for having less available water. This mechanism of having decreased leaf area is a response to drought stress (Chaves, et al., 2003; Taiz and Zeiger, 2006). This is further influenced by the possible shallow root system as is evident in Appendix B. If hydrangeas do have more shallow root systems, then this would help explain why hydrangeas would have an increased water demand in the upper soil levels, as the plant would be unable to access water from deeper levels in the soil profile.

The Diablo® ninebark resulted in good growth after two years of establishment, regardless of the water amounts it received. The ninebark had greater plant biomass in the 100% when compared to the 0% treatment. It appears that more water does affect plant growth, but more testing is needed as a result of the borer infestation with this species. Despite the infestation, all treatments, during both years, still increased in size when compared to the season begin and season end heights and widths. It appears the ninebark will still grow regardless of water amount received after the plant is established. The osmolality was lower and the water potential was greater (less stressed) in the 100% than the 0%, as well. More water appears to reduce physiological stress once irrigation treatments reach 100%. Currently, the ninebark is considered as a "low" water user (GreenCO and Wright Water Engineers, Inc. 2008). Based on the findings of the study, this plant should continue to be rated as a "low" water user once the plant becomes established.

The arctic blue willow appears to do well in the landscape after two years of establishment, regardless of the amount of water it received. The willow did not have significant differences in height, width, seasonal growth increments, leaf area, leaf weights, or plant biomass among any of the treatments. Since growth characteristics were fairly similar, the plant may not have been physiologically stressed. They may not have been stressed because one of the ways plants cope with drought stress is to alter its growth characteristics by inhibiting shoot growth, and reducing transpiration area by growing smaller leaves (Chaves, et al., 2003). Since the plants were essentially equal in size, and the leaf area did not vary among treatments, all the plants were probably sufficiently hydrated to maintain adequate plant status. Osmolality did fluctuate with treatments and water potential was less negative in the 100% than the 0%. As a result, the plant performed better physiologically when it received 100%. However, since all plants in all treatments not only survived, but also looked quite acceptable for landscape use, this plant could very well be a "low" or "very low" water user. Currently, the willow is considered as a "medium" water user (GreenCO and Wright Water Engineers, Inc. 2008) and this rating may be too high.

Since the willow performed similarly in all of the treatments, the plant probably stayed relatively hydrated in all treatments for similar growth to occur. Furthermore, the osmolality did not follow a pronounced pattern like the other species. The other species increased in osmolality as irrigation amounts decreased. The willow did not increase in osmolality to the same extent as the other species. While there was some osmotic adjustment, it appeared to be limited. This plant needs further testing to definitively state which category of water use it falls into. In any event, when the willows were given more water, the overall outcome had little impact on the growth and the plant appeared acceptable in all treatments for landscape use.

CHAPTER 2: LYSIMETER STUDY

Methods and Materials

The Lysimeter portion of the study was conducted at the same location as the field portion of the experiment (refer to Chapter 1). This lysimeter study tested two different species of shrubs in a pot-in-pot system (Parkerson, 1990). The shrub species that were tested were *Cornus sericea* L. 'Isanti' (redosier dogwood) and *Hydrangea arborescens* L. 'Annabelle' (smooth hydrangea). The smooth hydrangeas and the redosier dogwoods came from the same sources as the plants used in the field experiment (refer to Chapter 1). Due to space limitations and to increase the number of replications for each of the trialed species, only two species of shrubs were tested. The hydrangea and dogwood were chosen over the ninebark and willow for two primary reasons. First, the dogwood and hydrangea had larger petioles on the leaves than the willow. The larger petioles made it easier to test water potentials using the pressure chamber. The hydrangea was also chosen over the ninebark and willow because it was hypothesized that this species was the most water demanding of the four species. As such, the hydrangea could be more closely monitored on a daily basis if in the lysimeter component of the study, as well. The second primary reason that these species were chosen is that these two species were more readily available from the cooperators of the study.

All shrubs were transplanted into larger #15 size pots using Best Management Practices (GreenCO and Wright Water Engineers, Inc., 2008). All of the pots used in the study had the same dimensions. The top radius of each pot was 21.59 cm (8.5 in) and the bottom radius was 19.05 (7.5 in). The soil in each pot went to a depth of 33.02 cm (13 in.) When each plant was transplanted, the root balls were scored and loosened, 20% of the backfill was amended with Sun Gro Sunshine soil mix (the remaining 80% was field soil from the site), and the pots were watered until saturation and allowed to drain to container capacity after planting. All of the shrubs were planted on July 22, 2008. All of these shrubs were watered with amounts equivalent to 100% evapotranspiration of a short reference crop (ET_o) for the remainder of the 2008 growing season to allow for establishment.

Plot Plan

There were three treatments in the lysimeter component which received varying amounts of supplemental irrigation based on ET_o. The three treatments were 25%, 50%, and 100% of ET_o. These particular numbers were chosen based on the GreenCO Foundation's reference (Table 1.1) to what a high, medium, low, and very low water use plant requires (GreenCO and Wright Water Engineers, Inc., 2008).

There were five replications for both species in each of the three treatments. A total of three rows were present; each row was one treatment (refer to Figure 2.1 for a map layout of the shrubs). In addition to the 10 tested shrubs in each row, an eleventh shrub in a 56.78 L (15 gal) pot was present on the western most side of the row, which acted as a border plant to the adjacent turf for other studies being conducted at PERC and were not part of the study. A fourth row on the southern side of the lysimeter study plot was also present. This row contained six pots of soil with no plants. The remaining 5 of the 11 pots were also border plants that were not part of the study. There were two soil pots for each treatment amount. Two pots were watered with 25%, two pots were watered with 50%, and two pots were watered with 100%. The soil pots were used in an effort to estimate evaporation rates during dry downs. Each plant was placed at least 1.22 m (4 ft) away from any neighboring plants. The design was a complete randomized design.

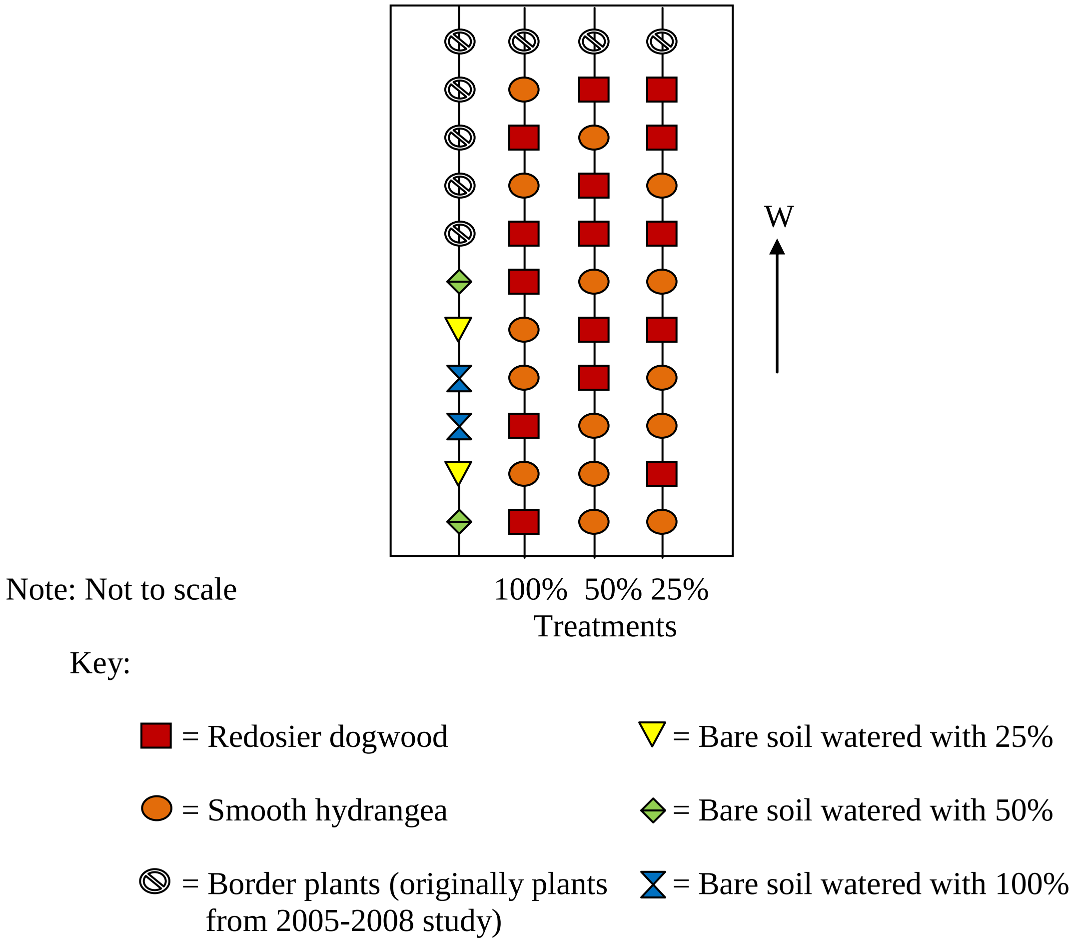

Figure 2.1: Lysimeter plot layout and planting plan

<u>Maintenance and Site Specifications</u>

Weeds were controlled either by hand removal or by spraying using a backpack sprayer containing Ranger Pro (Glyphosate). All weeds within the pot were hand pulled. Spraying was not done within the pot to prevent any possible herbicide damage. Weeds outside of the pot were sprayed. Mulch was also placed around the outside of all pots to aid in the control of weeds.

On July 24, 2009 and May 8, 2010, all shrubs were fertilized with 118 grams (0.26 lbs) of Scotts 15-9-12 Osmocote Pro, which is an eight to nine month slow release fertilizer. The fertilizer was placed evenly in each pot around each plant.

Soil samples were collected and submitted to the Colorado State University Soil, Water, and Plant Testing Laboratory. It was found that the field soil used for 80% of the backfill in the pots is a loam. The full report is in Appendix C. Additionally, the United States Department of Agriculture Natural Resources Conservation Service also has it recorded that the area has soil that is a loam, but more specifically it is an Altvan-Satanta loam with 0 to 3% slopes (U. S. Dept. of Agr. Natural Resources Conservation Service, 2009).

The water used in the experiment was non-potable water. The source of the water was from College Lake in Fort Collins, Colorado.

Calculating Treatments

During 2009 and 2010 treatments were calculated using the same equations described in Chapter 1 (Equation 1.1 and Equation 1.2). However, the entire lysimeter study was one irrigation zone, and as a result, the time that all of the plants were watered was the same. Time was calculated based on what the 100% treatment needed. Treatments, therefore, were controlled by changing the flow rate for each treatment. The 100% treatment had 4 x 3.79 L (1 gal) per hour emitters per pot, the 50% treatment had 2 x 3.79 L (1 gal) per hour emitters per pot, and the 25% had 1 x 3.79 L (1 gal) per hour emitter per pot.

The number used for Area for Equation 1.2 was based on the available rooting area of the shrubs in 2009, since all of the pots in the study were the same size. Each pot had a 21.59 cm (8.5 in) radius and this number was used to apply treatments in 2009 from May 12, 2009 through August 14, 2009. Unfortunately, it was unforeseen that this number would become insufficient for the plants over time as they grew. Towards the end of August, the 21.59 cm (8.5 in) radius used for Area in Equation 1.2 was deemed insufficient as even the 100% treatment was wilting after watering events. As a result, watering treatments were multiplied by a factor of two for the remainder of the 2009 experimental period (August 15, 2009 through Sept. 29, 2009) to prevent plant loss. Plant loss was deemed unacceptable because the plants were still needed for data collection for 2010.

During 2010, the number used for Area for Equation 1.2 was modified three times over the course of the experimental season to prevent the problem encountered in 2009. During the first experimental week in 2010 (May 24, 2010), the standard 21.59 cm (8.5 inch) rooting radius was used for Area for Equation 1.2 because the plants were still initially leafing out. After the first week, the number used for the Area portion of Equation 1.2 was estimated on leaf area per plant. Leaf areas were estimated on June 3, 2010 and July 7, 2010, and the Area was modified after each date.

On June 3, 2010 and July 7, 2010, total plant leaf area for both species of shrubs was estimated by collecting some leaves, measuring the leaves' area, and estimating the number of leaves present on each shrub. Through determining the average number of leaves per shrub and the average area per leaf, the average leaf area per shrub could be approximated. Only the leaf area from shrubs in the 100% treatment was estimated for equation 1.2 because the number derived from Equation 1.2 was used to determine what amount of time the 100% treatment required. As mentioned earlier, the entire study was one irrigation zone and, as a result, all treatments received irrigation for the same amount of time. The flow rate changed the treatment amounts. To determine the leaf area of the dogwoods, one dogwood in the 100% treatment was randomly selected. After a random dogwood from the 100% treatment was selected, one random branch on that shrub was selected and all of the leaves on that branch were counted. This step was repeated two more times so that the leaf count for three stems was determined. The leaf count was then averaged to obtain an average number of leaves per stem. Next, the total number of stems on the shrub was counted. The total number of stems was then multiplied by the average number of leaves per stem to approximate the number of leaves for the shrub. After the total number of leaves was estimated, two leaves were collected from each stem that was counted (six total leaves) and the leaf area was determined. Leaf area was measured by scanning each leaf in a computer scanner at a resolution of 300 dpi then run through a program written using the Java computer language using NetBeans (Oracle Corporation, 2009). The Java program essentially counted the number of pixels that were not white and calculated the area based on the number of non-white pixels that were in the image. The program was calibrated using objects of a known area. The code for the Java program is located in Appendix G. After the leaf area of each leaf was determined, the numbers from all six leaves were averaged together, which resulted in an average area per leaf for that particular shrub. The average leaf area and the average number of leaves were then multiplied to give an average total leaf area for the shrub. This process was done with two more randomly selected dogwoods in the 100% treatment. The estimated total leaf areas from each of the three dogwoods were then averaged together to give an average leaf area for the dogwoods. The entire process was then repeated for the hydrangeas. After the average estimated total leaf area per shrub was determined for the dogwoods and the hydrangeas, the two numbers were then averaged together to give an overall average leaf area per shrub for the treatment. The average of the two was used for Area.

In 2009, the emitters were tested to determine if the effective flow matched what the emitters were rated at. The water from each emitter was collected and measured. It was found that the emitters were 104.44% efficient. As a result of the flow rate not being precisely 3.79 L

(1 gal) per hour for each emitter, Equation 1.2 was modified through multiplying the flow rate portion by 1.0444.

The depth was determined the same way as was done in the field experiment. Precipitation was also accounted for the same way as was done in the field experiment.

The mean weekly amount of liters (gallons) of water applied per shrub in each treatment during 2009 and 2010 are represented in Table 2.1.

Table 2.1: Mean liters (gallons) of water applied per week per shrub for lysimeter study during 2009 and 2010

	Treatment Period (Dates)	25%	50%	100%
2009	May12 – Aug. 14*	0.61 (0.16)	1.17 (0.31)	2.35 (0.62)
	Aug. 15 – Sept. 29[+]	1.36 (0.36)	2.76 (0.73)	5.53 (1.46)
2010	May 17 – May 24*	1.02 (0.27)	2.04 (0.54)	4.13 (1.09)
	May 25 – July 8**	3.82 (1.01)	7.61 (2.01)	15.26 (4.03)
	July 9 – Oct. 5**	9.77 (2.58)	19.53 (5.16)	39.10 (10.33)

*watering amounts calculated using estimated rooting area
**watering amounts calculated using estimated leaf area
[+]watering amounts calculated using estimated rooting area then doubled

<u>Data Collection</u>

The data collected were plant height and width, visual ratings accompanied with pictures, daily pot weights during dry downs, water potential using a pressure chamber during dry downs, end of season sample leaf area, end of season sample leaf fresh and dry weights, and whole above ground plant fresh and dry weights.

Height and width measurements were taken at the beginning and the end of the experimental seasons during 2009 and 2010. The procedure for taking height and width measurements were identical to that done for the field experiment (refer to Chapter 1).

Visual ratings and pictures of all of the shrubs were taken every other week. Each plant was rated using the same scale as was used for the field experiment. The ratings of the scale used can be seen in Table 1.3. The ratings for each species in each treatment were then averaged together.

During 2009 and 2010 the shrubs in the lysimeter study went through several dry down periods. During dry downs the shrubs were watered with their respective treatment amounts and after being watered the plants were closely monitored during each sequential day to evaluate increasing stress levels as the plant used the available water in the pot. During the time period of each dry down, none of the plants were watered in any of the treatments (25%, 50% and 100%) until the dry down had concluded. Every plant was weighed in their pot and every plant was tested to determine the predawn water potential using a pressure chamber made by PMS Instrument Company (Model 1000, Albany, OR) on a regular basis during each dry down. Dry downs lasted anywhere from several days to just over a week. The plants were monitored until the plants displayed severe stress through heavy wilting and water potential readings of around -3MPa at predawn. After the plants were severely stressed, the shrubs were rehydrated with their respective treatment amounts. During 2009, two dry downs occurred in July, two occurred in August, and one occurred in September (for a total of five dry downs). In 2010, one dry down occurred in June, two in July, one in August, and one in September (for a total of five dry downs).

Pictures were taken during each dry down. Daily pictures were taken of every shrub in the lysimeter study beginning the day the dry down started and ending the day after the last day of the dry down (after the plants were rehydrated). Each day during the dry down, including the day of watering, all of the study pots containing the tested shrubs, as well as the pots containing bare soil, were weighed. Through weighing the pots every day, the weight loss (due to water loss) could be monitored. The pots were weighed using an S-beam load cell (Model ZB1-250-

000, Sentran, LLC, Ontario, CA) and the weights were displayed on a digital indicator (Model 250, Sentran, LLC, Ontario, CA). The load cell was suspended from a portable A-frame mounted on wheels. The A-frame in use can be seen in Figure 2.2. The pots were weighed every day during late afternoon.

During the dry downs, a pressure chamber was also used to monitor the water potential of the shrubs. Readings were taken at predawn. Every plant was tested by collecting two leaf samples from each replicate of each species in each of the treatments. The two readings from each plant were then averaged together to get an average for each plant. Data were collected every day or every other day depending on how the dry down progressed. At the beginning of the dry down, readings were collected every other day. As the dry down progressed and the plants became more stressed, data were collected every day to better monitor the plant status and to better determine when each dry down should end as a result of the water potential readings.

Figure 2.2: Lysimeter A-frame used for weighing each pot in the study

Just like the field study, leaf samples were collected from every replicate so that leaf area, leaf fresh weights, and leaf dry weights could be determined during the end of the experimental seasons in both 2009 and 2010. During both years the leaf collection process described was the same, unless otherwise noted. A total of 10 leaves were collected from every shrub, when available. In 2009, the fifth and sixth leaves from the apex of a stem on the north side, east side, south side, west side, and center of the plant were desired for collection from the hydrangea and the dogwood. However, leaf quality and quantity were limited so leaves five and six were collected when available, but primarily the third and fourth leaves from the apex were collected from both species during 2009. In order to avoid the same possible issue during 2010, all leaves collected were the third and fourth leaves from the apex of each stem. In some instances, very few leaves were present and whatever leaves were present were collected. Leaves were then stored, measured, and dried using the same procedure as described in Chapter 1 for the field study.

In fall of 2010, each plant was cut to the base and collected so that above ground fresh weight and dry weight could be determined. The procedure for collection, drying, and measurements were the same as described for the field experiment in Chapter 1.

Data analysis

Data analysis was conducted using the SAS/STAT® software with SAS 9.2 for Windows (SAS Institute Inc., 2010). The Mixed Procedure was used on all data to run an analysis of variance (ANOVA) and to compare the least square means. Data were determined to be statistically significant with a p-value less than 0.05.

Results and Discussion

Some difficulty was encountered with the lysimeter component of the study over the duration of the experiment. Like the field component, the lysimeter component was affected by inclement weather. The abundant precipitation and cooler temperatures during 2009 (Table 1.4) affected the duration of some of the dry down periods and the way in which the shrubs reacted to treatments. However, since all of the plants were confined to pots with a limited rooting space and limited water holding capacities, the pots were able to dry out more quickly between rainfall events, unlike the field component. Further, due to all of the abundant rainfall, it was not discovered until nearly the end of the 2009 season that watering treatments using rooting area (as opposed to estimated leaf area) for Equation 1.2 was insufficient which resulted in a change in the way treatment amounts were calculated for the 2010 season. Refer to Chapter 2 Methods and Materials for more detail.

In addition to the abundant precipitation and cooler temperatures during 2009, all of the lysimeter shrubs were affected by heavy hail damage. On June 7, 2009, heavy amounts of hail fell (Figure 2.3a) that was up to 2 cm (0.79 in) in diameter. The damage incurred to the shrubs in the lysimeter component was equal to the damage incurred by the field component. The foliage and stems on all plants were damaged. The hydrangeas were essentially defoliated and most of the leaves on the dogwoods were damaged (Figure 2.3b and Figure 2.3c). Since the hail shredded most of the foliage on the plants in the beginning of the 2009 season, data collection was delayed in 2009. In addition to visual ratings, dry down periods were delayed until the plants re-leafed out since leaves were needed to determine the water potential of the shrubs using a pressure chamber. Further, the stem damage that the dogwoods received was permanent since the damage was still visible on the stems in 2010. The damage was not permanent for the hydrangea, however, because the hydrangea died back to the ground at the end of each season. Despite the damage incurred during 2009 and the permanent stem damage on the dogwoods, the damage was uniform among each plant species in all three treatments. Since neither plant species had any advantage over any of their counterparts in any of the other treatments, the study continued and treatments were still applied with the existing shrubs.

Figure 2.3a: Lysimeter study looking west after hail storm (June 7, 2009)

Figure 2.3b: Smooth hydrangea after hail storm (June 7, 2009)

Figure 2.3c: Redosier dogwood after hail storm (June 7, 2009)

Another problem that was encountered with the lysimeter component of the study was the limited pot size that the shrubs were planted in. The shrubs had essentially become pot bound and by the middle of the 2010 season, the water holding capacity of the pots was too small given the size of the shrubs. Watering treatments had to be conducted every few days because the #15 pots could not hold the amount of water calculated for treatments if the pots were only watered once a week. For example, nearing the end of the experiment in 2010, the 100% treatment was watered with roughly 39.10 L (10.33 gal) of water a week (Table 2.1). If this amount of water was applied in one application, much of the water from the 100% treatment would have drained through the bottom of the pot. Since the plants were unable to receive such a high amount of water at one time, the shrubs were watered every few days to prevent any drainage. Avoiding drainage was important because if drainage occurred, then treatment amounts wouldn't be true to the experimental parameters. As a result of the increased plant sizes in 2010, utilizing a larger pot size from the beginning of the experiment would have been beneficial. Watering events would not have been needed every few days in an effort to avoid the potential drainage problem if larger pots were used. However, watering the pots every few days was an effective means to prevent drainage since after watering events occurred, no drainage was observed and all water that was applied remained in the pots.

Nearby *Gleditsia triacanthos* var. *inermis* (honeylocust) trees shaded portions of the lysimeter study at different times of the year. Depending upon the time of the year, the earth's orientation to the sun affected the shading from two nearby honeylocusts. The effects of the shading on the lysimeter study can be viewed in Figure 2.4. Earlier in the season, no shading occurred to the research area from the honeylocusts, but later in the season the shading moved which covered the lysimeter study during the later hours of the day. There were five replications of each species in each treatment and these replications accounted for the effect of the shading that may have resulted. The data still had definite trends and does not appear to have been affected.

Figure 2.4: Shading from two nearby honeylocust trees (Aug. 22, 2009)

Like the field component of the study, height and width measurements of all shrubs in each treatment were taken each year to determine if watering treatments had any effect on the overall size of the shrubs. The beginning and end dates for the data collection of the shrub heights and widths for 2009 were delayed due to the hail damage. During 2009, beginning heights and widths were measured on June 16th and end of season measurements were taken on October 20th. During 2010, beginning heights and widths were measured on May 28th and end measurements were taken on September 29th. Despite the season begin and end heights and widths being collected during different periods from 2009 and 2010, both years had a similar total number of growing days between measurements. During 2009 the shrubs had 127 growing days and 2010 had 125 growing days.

Few height differences were present during 2009 for either species during the beginning or the end of the season (Figure 2.5a), however, during 2010 differences were present (Figure 2.5b). The results were similar for both the dogwood and hydrangea during 2010. Both the dogwood and hydrangea in the 50% and 100% treatments were taller than those in the 25% treatment during the beginning of the season and this trend continued through the end of the season. However, when the season begin heights are compared to the season end heights, only in the 25% treatment did dogwood put on more growth (in terms of height) for the season, while hydrangea increased in height in all treatments by the end of the season.

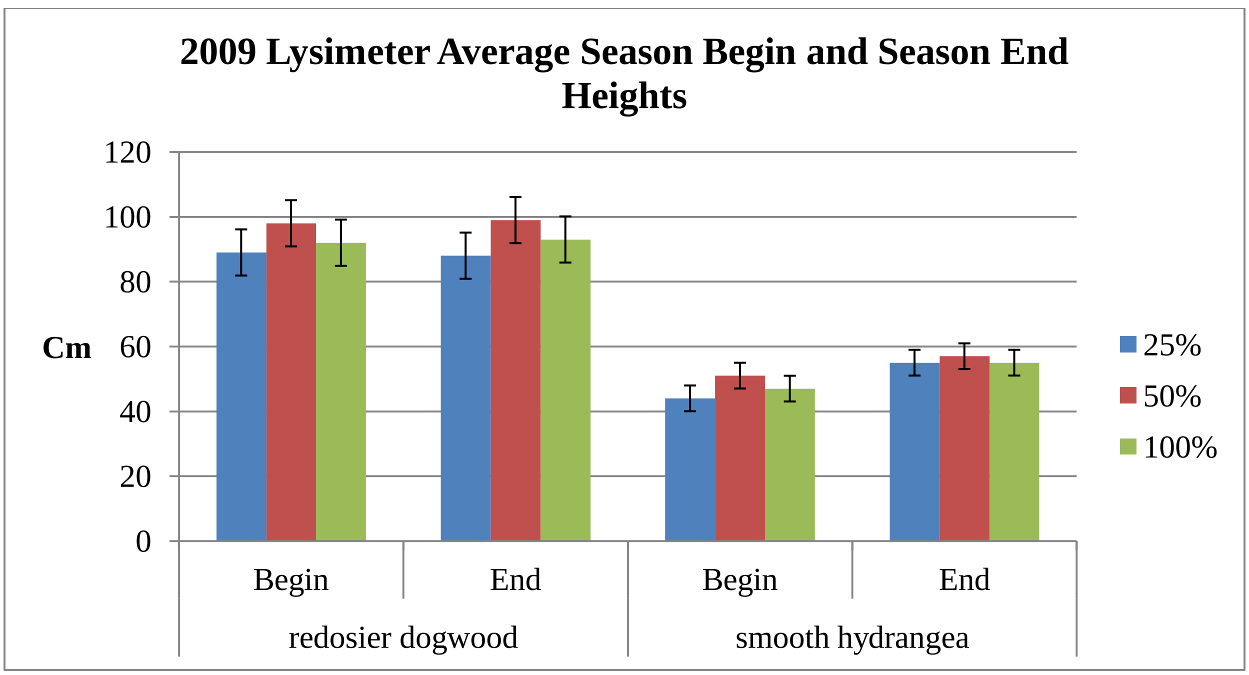

Figure 2.5a: 2009 Lysimeter average begin (June 16, 2009) and end (Oct. 20,2009) of season heights ($p<0.05$)

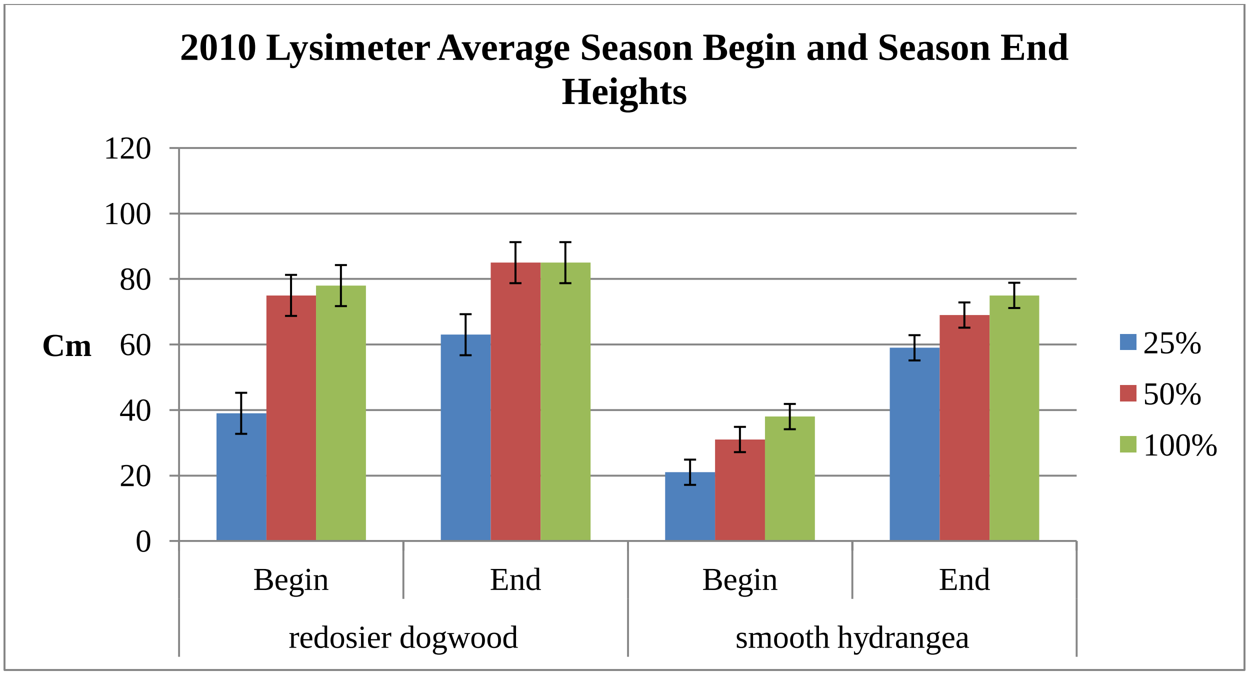

Figure 2.5b: 2010 Lysimeter average begin (May 28, 2010) and end (Sept. 29, 2010) of season heights ($p<0.05$)

As was the case for the height data, the width data also had few differences during 2009 for either species between the beginning and the end of the season (Figure 2.5c). However, during 2010 differences were present (Figure 2.5d). Similarly to the 2010 height, the 2010 width of hydrangea in the 50% and 100% treatments were wider than the hydrangeas in the 25% treatment at the beginning of the season. By the end of the 2010 season, widths changed in each treatment, increasing as the irrigation amounts increased. The data for the dogwood varied from the hydrangea since the dogwoods were statistically different in width in all treatments from the beginning of the season. The trend continued with the dogwood through the end of the season in that width increased as irrigation increased. In addition, both species did increase in width by the end of the season when compared to the beginning of the season regardless of the watering treatment. It appears that while more water will affect the overall width of both species, growth still resulted during a season for both species if given at least 25% of ET_o during non-drought years.

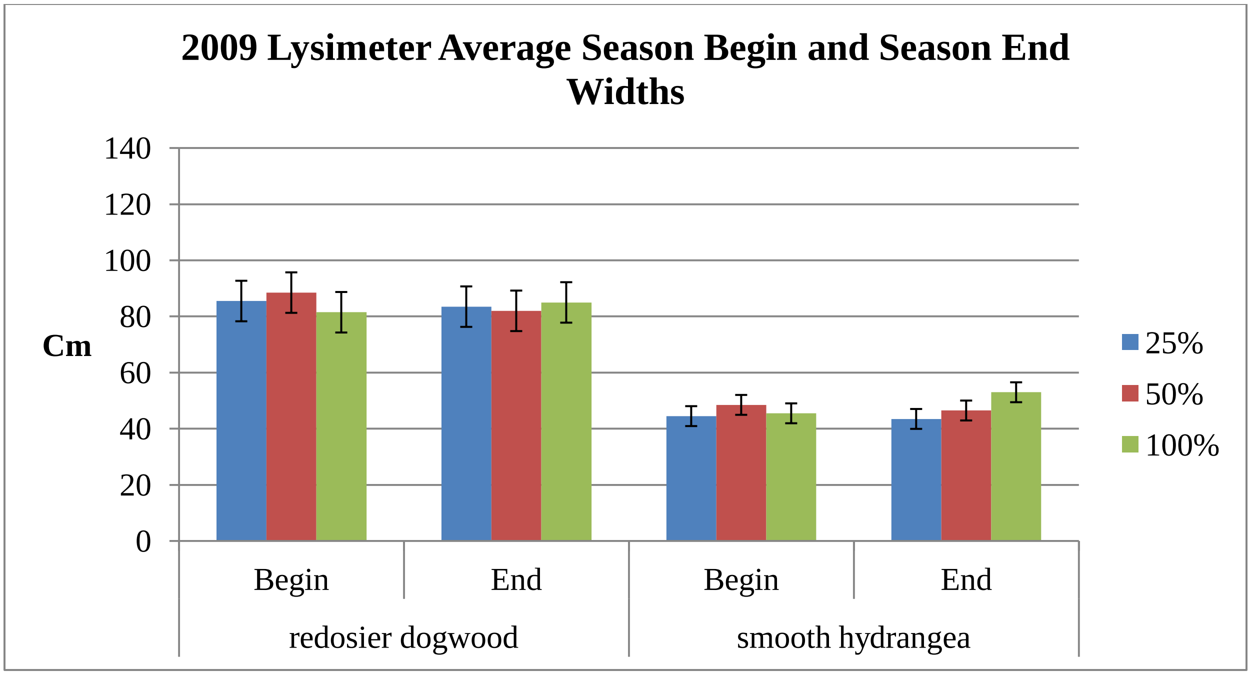

Figure 2.5c: 2009 Lysimeter average begin (June 16, 2009) and end (Oct. 20, 2009) of season widths ($p<0.05$)

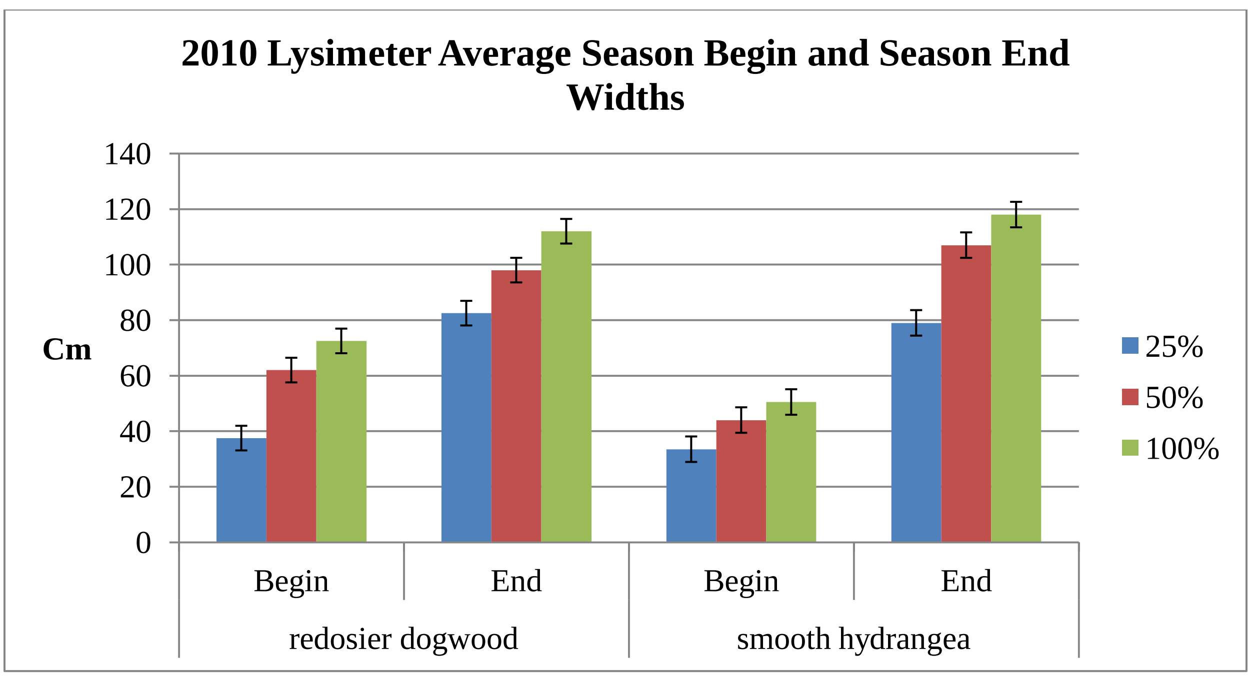

Figure 2.5d: 2010 Lysimeter average begin (May 28, 2010) and end (Sept. 29, 2010) of season widths ($p<0.05$)

Throughout the 2009 and 2010 experimental seasons, visual ratings were assessed and recorded. The results for both 2009 and 2010 are in Figure 2.6a and Figure 2.6b, respectively. Additionally, representative photographs are present to show both plant species in each treatment near the conclusion of the experiment in Appendix E. As can be seen from the data from 2009 and 2010 and the photographs in Appendix E, the visual ratings of the dogwood increased as irrigation amounts increased. The hydrangeas in 2009 also increased in visual ratings as irrigation amounts increased, but the hydrangeas performed differently during 2010. During 2010 hydrangea in the 25% treatment were statistically lower than hydrangea in the 50% and 100% treatments, while the 50% and 100% were statistically the same in ratings. Despite the hydrangeas in the 100% treatment being statistically the same to the shrubs in the 50% treatment, the shrubs in the 100% were still higher in ratings. This upward trend may continue and become

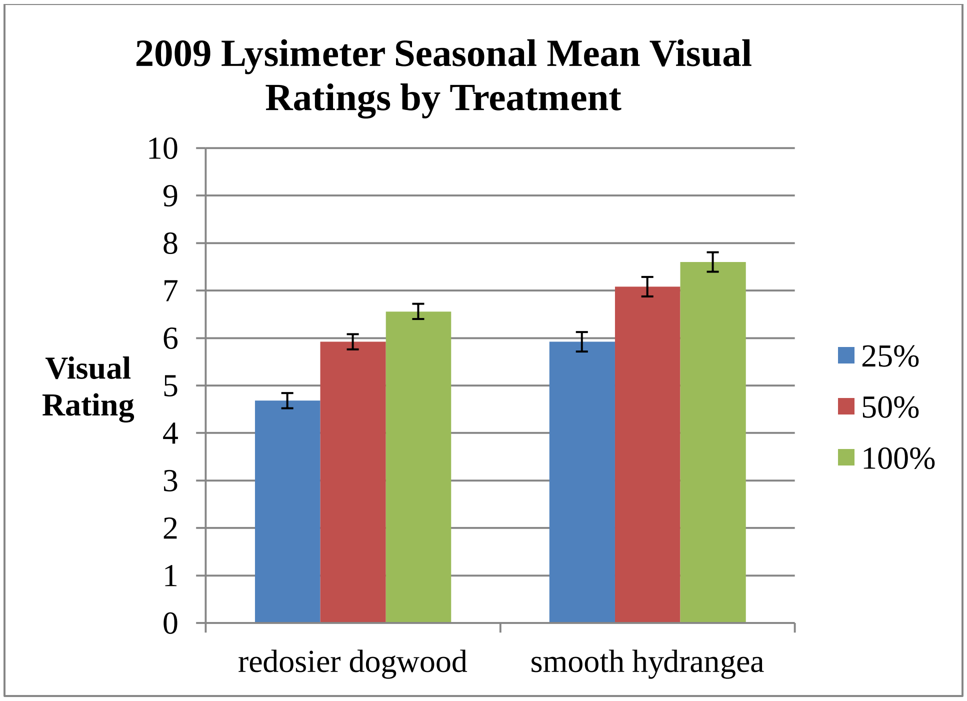

Figure 2.6a: 2009 Lysimeter visual ratings ($p<0.05$)

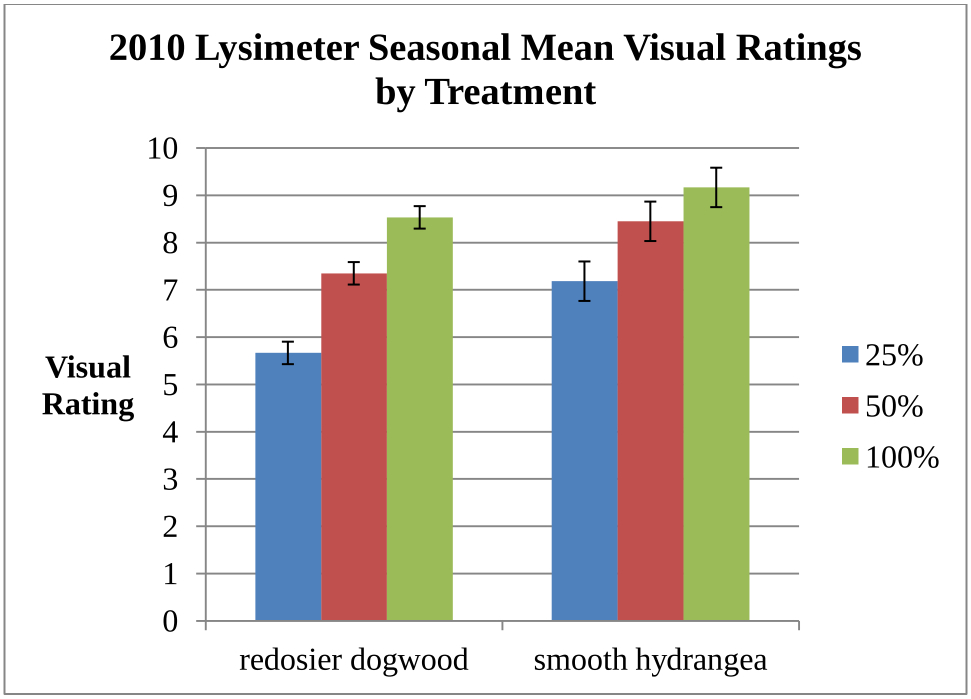

Figure 2.6b: 2010 Lysimeter visual ratings ($p<0.05$)

statistically different if the hydrangeas received greater than 100% of ET_o. However, further research is needed to determine this trend.

In addition to the data shown in Figure 2.5a through Figure 2.6b, it is also evident that as the irrigation increased, the size of the shrubs also increased as of July 21, 2010 when viewing Figure 2.7. Flowering on the hydrangeas was not measured in any way, but it appeared when the hydrangeas were provided with more water the frequency of the flowering increased.

Depending upon the treatment, the shrubs broke dormancy at different rates during 2010. In 2010, the plants receiving 100% of ET_o came out of dormancy more quickly than any of the replications in the 50% treatment, and the 50% treatment came out of dormancy more quickly than any of the other shrubs in the 25% treatment (Figure 2.8). Additionally, all of the redosier dogwood replications in the 25% died back to the ground and broke dormancy by starting new growth from the base of the plant. The dogwoods in the 25% treatment were water stressed,

Figure 2.7: Lysimeter component of the study containing the three watering treatments based on ET_o looking west (July 21, 2010)

since one symptom of water stress is twig dieback (Small, 2010). The hydrangeas in all treatments died back to the ground as well, however this is normal each year for this species. Both species in each of the three treatments went into dormancy in different states of stress. As a result, both shrubs broke dormancy the following Spring at different rates. If the shrubs had more water provided to them (100%), the shrubs broke dormancy the following spring about two to three weeks more quickly than those in the 25% treatment.

Figure 2.8: Difference in growth of redosier dogwood (left) and smooth hydrangea (right) in each treatment after breaking dormancy (May 25, 2010)

During the course of the experiment, a total of 10 dry down periods occurred where the shrubs were water stressed over a period of time and monitored to determine the effects. Conducting dry downs were useful because the effects of water usage, water shortage, and then water stress for both species of shrubs were more accurately monitored. In addition, through conducting the dry downs in a study that contained different treatment amounts, the long term effects of the shrubs receiving different amounts of irrigation could be monitored. During the time period of each dry down, none of the plants were watered in any of the treatments (25%, 50% and 100%) until the dry down had concluded. Table 2.2 displays the dates during which each dry down was conducted and the weather conditions during the period of each dry down. The length of each dry down was affected by the variable weather. Dry downs during hot, dry weather were completed in a shorter period of time. Conversely, dry downs during cooler temperature with some precipitation lasted longer. During 2009, dry down #2 received abundant precipitation. The precipitation exceeded the cumulative ET_o rate, and as a result, the containers might have received more water than the pots could hold. If the pots received more water than

Table 2.2: Weather data from the weather station at Rolland Moore Park in Fort Collins, CO during each lysimeter dry down in 2009 and 2010

Year	Dry Down #	Dates Conducted	Mean High Temp in ºC (ºF)	Mean Low Temp in ºC (ºF)	Precipitation in cm (in)	Cumulative ET_o in cm (in)
2009	1	July 13 – 17	30.87 (87.56)	12.92 (55.26)	0.00 (0.00)	2.87 (1.13)
	2	July 27 – 29	23.26 (73.87)	12.02 (53.63)	1.73 (0.68)	0.94 (0.37)
	3	Aug. 3 – 7	31.20 (88.16)	12.91 (55.24)	0.13 (0.05)	2.34 (0.92)
	4	Aug. 20 – 24	30.70 (87.26)	10.49 (50.88)	0.03 (0.01)	2.18 (0.86)
	5	Sept. 9 – 16	24.33 (75.80)	9.76 (49.56)	0.38 (0.15)	2.49 (0.98)
2010	1	June 17 – 21	28.33 (83.00)	12.63 (54.74)	0.00 (0.00)	2.87 (1.13)
	2	July 9 – 12	30.00 (86.00)	10.56 (51.00)	0.20 (0.08)	2.06 (0.81)
	3	July 26 – 30	32.29 (90.12)	15.73 (60.32)	0.43 (0.17)	2.39 (0.94)
	4	Aug. 20 – 22	33.17 (91.7)	12.02 (53.63)	0.00 (0.00)	1.50 (0.59)
	5	Sept. 6 – 10	26.22 (79.2)	6.74 (44.14)	0.03 (0.01)	2.08 (0.82)
http://www.ncwcd.org/ims/ims_Weather_form.asp						

they could hold then drainage may have resulted in some of the pots (particularly in the 100% treatment). As a result of the excessive moisture, the dry down was terminated early.

During each dry down, the weight loss from each pot was monitored on a daily basis. This was a good measurement of the water loss from each replication in each treatment, because each plant was self contained in a closed system whereby no additional water could enter the system through lateral flow from neighboring soil outside of the pot. As a result of each plant being self contained in its own pot of soil, the daily weight loss from one day to the next was equal to the amount of water that left each pot through evapotranspiration (Johnson, et al., 2005). In an effort to determine the weight loss due to the evaporative component of ET, pots containing just bare soil without any plants were also weighed during each dry down. Unfortunately, the pots containing just soil did not work well to determine evaporation rates as a result of the pots becoming saturated and draining after each watering event. The soil pots were watered with the same amount as the pots containing plants (see Chapter 2 methods and materials). Since the soil pots did not contain any plants, no moisture was removed from the pots through transpiration. The soil pots remained wet and never dried out between watering events. As a result, the soil became over-saturated after each watering event and water drained out of the pot over the course of a few days. The change in weight during each day of the dry down was due to the water that left the soil pots from evaporation as well as drainage. Since the amount of water that was lost due to drainage is unknown, the weight data collected from the soil pots to determine the amount of water lost from evaporation was not very useful. Despite this unforeseen issue, the dry down weights taken from each pot containing a plant was quite meaningful since these pots did not become over-saturated and no drainage occurred through the bottom of the pots.

In general, as watering amounts increased for the dogwood and hydrangea, mean daily water use also increased (Figure 2.9a through Figure 2.9d and Appendix F). Further, the amount of water used on a daily basis drastically increased from 2009 to 2010. This change is a result of the size differences of the plants (Figure 2.5a through Figure 2.5d). The increased size during 2010 resulted in a larger water demand, because larger plants require more water (Irmak, 2009). However, there were a few discrepancies in 2009 for both species. During dry down #3 in 2009 (Figure 2.9a), the 50% dogwood did not vary from the 25% treatment in weight loss as the dry downs preceding it had. It was discovered after the dry down had been initiated that one of the two drip lines malfunctioned for one of the replications. This caused one of the dogwood replications in the 50% treatment to receive less water than it should have received. That plant altered the means so that the 25% and 50% appeared to have used similar amounts of water on a daily basis during dry down #3. Another discrepancy was during dry down #4 for both species in 2009 (Figure 2.9a and Figure 2.9c). The mean weight loss during the dry down was not as pronounced as the other dry downs in the experiment. This change occurred because dry down #4 was the first dry down conducted after the treatments were altered to prevent plant loss. Equation 1.2 was modified by multiplying it by a factor of two (see Chapter 2 methods and materials). However, if these discrepancies are ignored, a definite trend is present during both years for both species that as watering amounts increased, daily plant water use also increased. This trend is also present in all of the tables in Appendix F. García-Navarro, et al. (2004) had a similar result when testing *Spirea x vanhouteii* (Vanhoutte spirea), *Viburnum tinus* (laurustinus), *Arctostaphylos densiflora* (Vine Hill manzanita), and *Leucophyllum frutescens* (silverleaf) in well-watered and water stressed conditions in containers. In the experiment conducted by García-Navarro, the shrubs in the well-watered conditions averaged a greater daily water use than the plants that received less water. In conclusion, if water is present then the plant will utilize it.

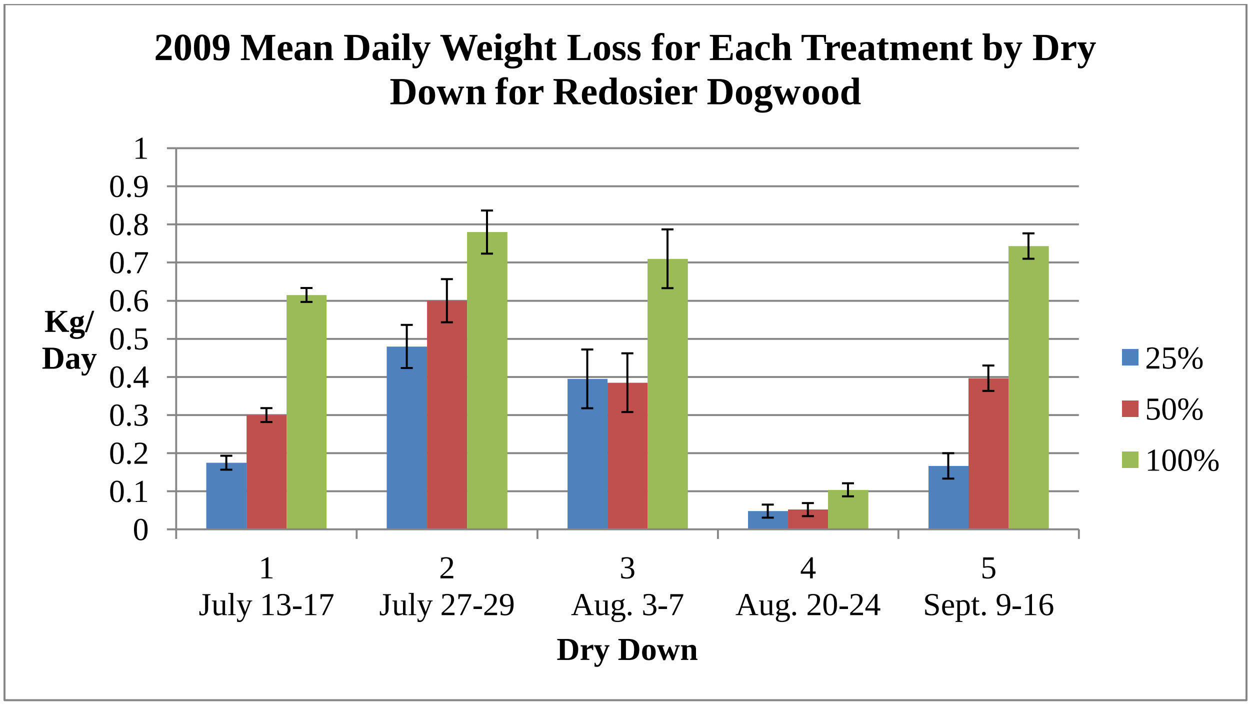

Figure 2.9a: Mean pot weight loss in 2009 for redosier dogwood ($p<0.05$)

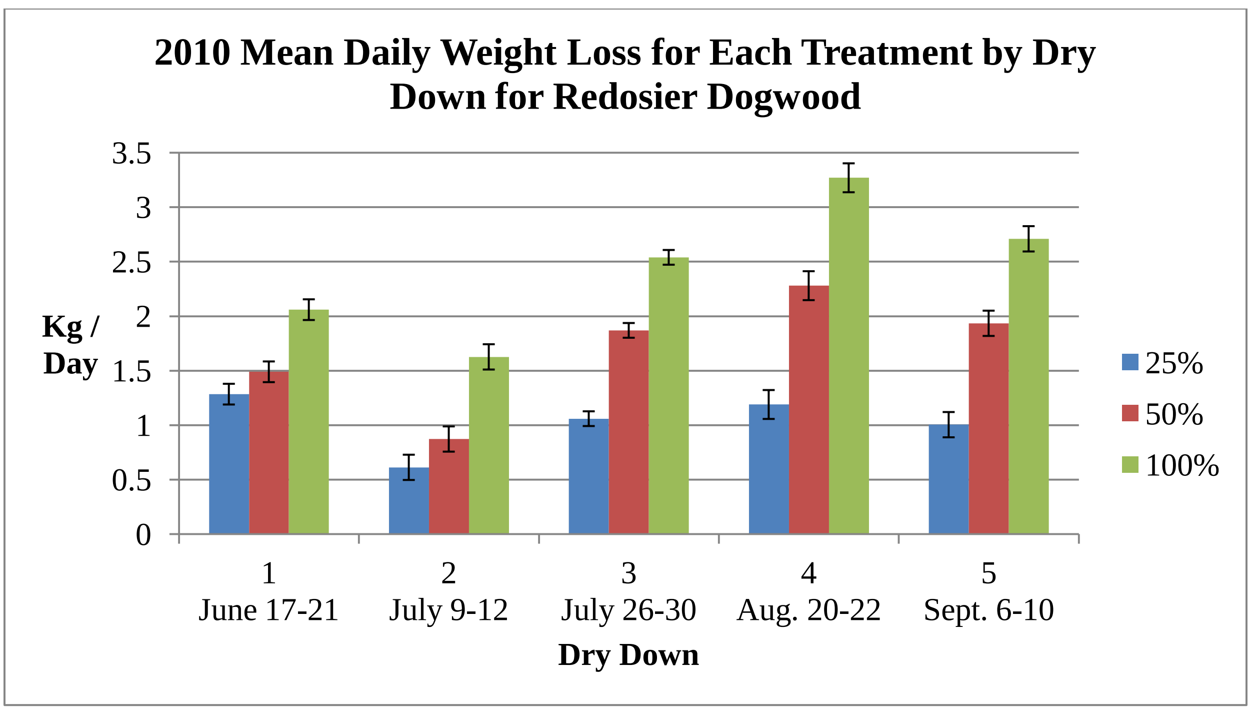

Figure 2.9b: Mean pot weight loss in 2010 for redosier dogwood ($p<0.05$)

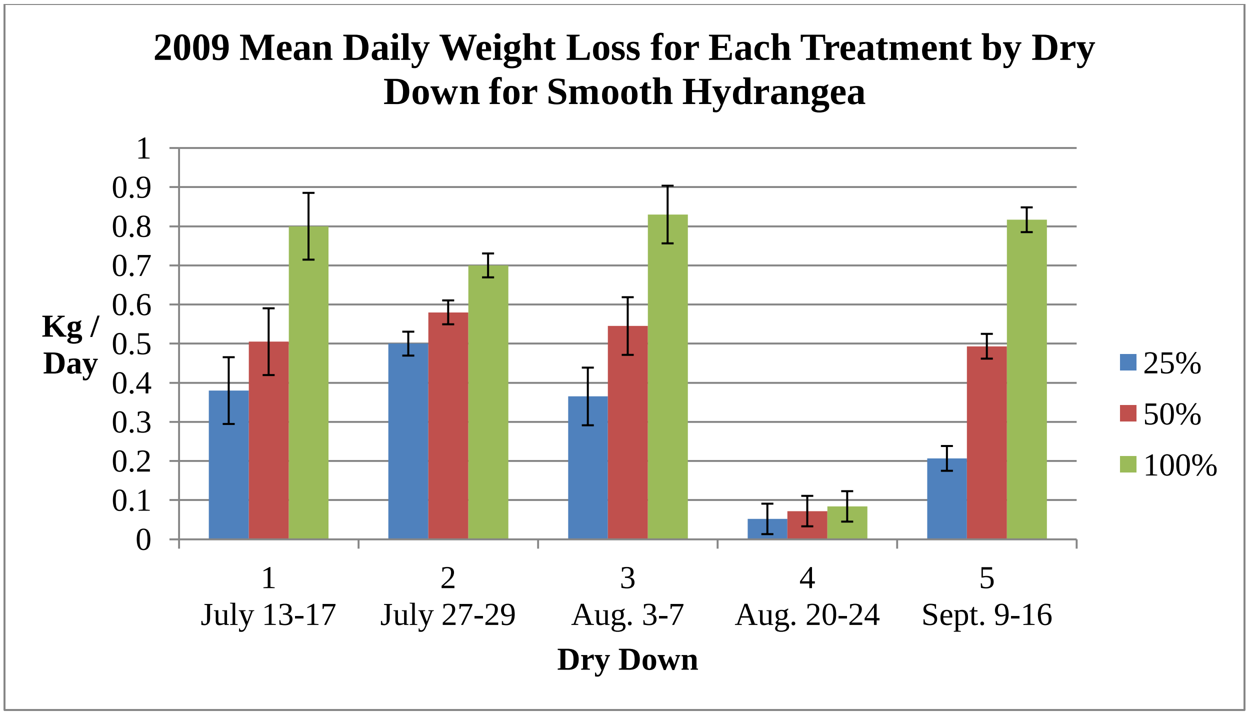

Figure 2.9c: Mean pot weight loss in 2009 for smooth hydrangea ($p<0.05$)

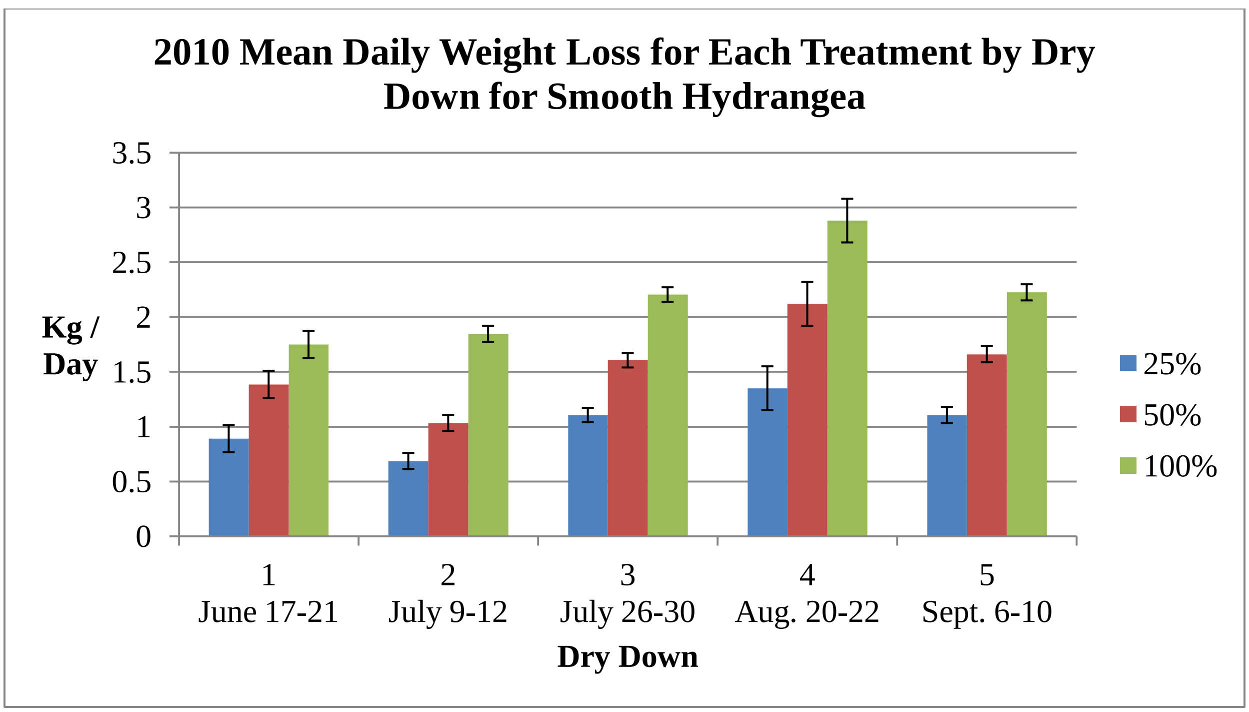

Figure 2.9d: Mean pot weight loss in 2010 for smooth hydrangea ($p<0.05$)

The predawn leaf water potential of each plant was measured during each dry down to monitor the increasing stress levels in each treatment as water became more limited in the pot. Results during 2010 were opposite from the results during 2009. It seems counterintuitive that the results would have changed from one year to the next, however both of the plants' morphology changed from one year to the next.

Figure 2.10a through Figure 2.10d show the mean predawn leaf water potential readings of the redosier dogwood and smooth hydrangea during each dry down conducted in 2009 and 2010. In general, the results for both species during 2009 are similar. During the last day of each dry down (Figure 2.10a and Figure 2.10c), the plants receiving 100% of ET_o had the least negative predawn leaf water potential readings (least stressed), and the plants receiving 25% ET_o had the most negative readings (most stressed). However, there are a few anomalies in the graphs. First, there is no data for dry down #2 as a result of inclement weather. During the evenings of both days during dry down #2, precipitation events occurred during the times that readings should have been collected. Further, since the precipitation exceeded the ET_o rates (Table 2.2), the dry down ceased early, as explained earlier. The second discrepancy is that during dry down #3, the 50% dogwood was the most stressed of all the treatments by the end of the dry down. This result was also affected by the aforementioned issue that had affected the dry down weights for the 50% dogwood with the malfunctioning drip line in one of the replications. Despite these two issues, in general it appeared that more water given to both species will increase water potential and thus reduce stress.

During 2010, the results had changed from 2009 so that they were opposite of what had occurred the year before. As Figure 2.10b depicts, in general by the end of each dry down the redosier dogwood receiving 100% of ET_o had the most negative predawn leaf water potential readings (most stressed) and the treatment receiving 25% of ET_o had the least negative readings (least stressed). The dogwoods receiving 50% of ET_o fluctuated in between being equally stressed with the 100% or the 25% treatment, depending upon the dry down. The hydrangea during dry downs #1 and #3 (Figure 2.10d) also followed a similar pattern as the dogwood, in that the 100% treatment was the most stressed and the 25% was the least stressed by the conclusion of the dry down. However, during dry downs #2, #4, and #5, the hydrangea did not follow a similar pattern as the dogwood because all treatments were generally equal to each other by the conclusion of the dry down. This result shows that during dry downs #2, #4, and #5, all treatments were equally stressed. The varying results among dry downs #2, #4, and #5 and dry downs #1 and #3 for hydrangea may be due to the environmental factors that caused a greater water demand on the hydrangeas during dry downs #1 and #3. As shown in Table 2.2, the cumulative ET_o rates during the time dry downs #1 and #3 were conducted was greatest when compared to the other dry down periods. This means that evaporative demand on all plants would have been greater during these two periods of time. Nonetheless, the hydrangea did not have reduced water potential readings when getting more water. These results appear counterintuitive until the height and width data is also considered when observed with the predawn leaf water potential data. At the conclusion of 2009, very few differences were present for height or width for the redosier dogwood or smooth hydrangea (Figure 2.5a and Figure 2.5c), and all the plants were essentially the same size. However, as Figure 2.5b and Figure 2.5d depicts, at the conclusion of the 2010 growing season, the size of both species generally increased as irrigation amounts increased. These size differences are important because larger plants have more leaf area and more leaf area equals more transpiration and more water demand (Irmak, 2009). Despite the plants being unequal in size during 2010, the data showed that the plants essentially grew to a size that they could support themselves with the available water. Since more water was available in the higher treatments, the plants used that water for more growth and in doing so the water demand also increased. In short, these two shrub species given more water will use that water to grow in size but the overall water need of the plant will also increase.

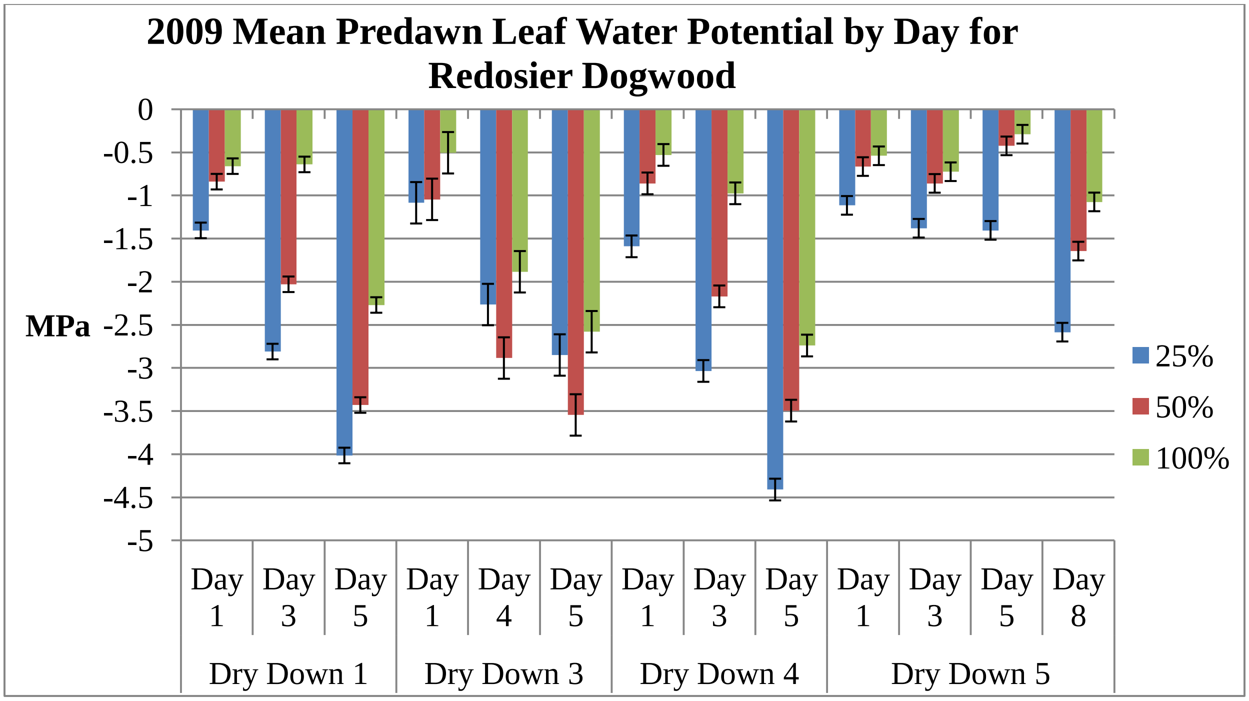

Figure 2.10a: Mean predawn leaf water potential readings for each 2009 dry down by day for redosier dogwood ($p<0.05$)

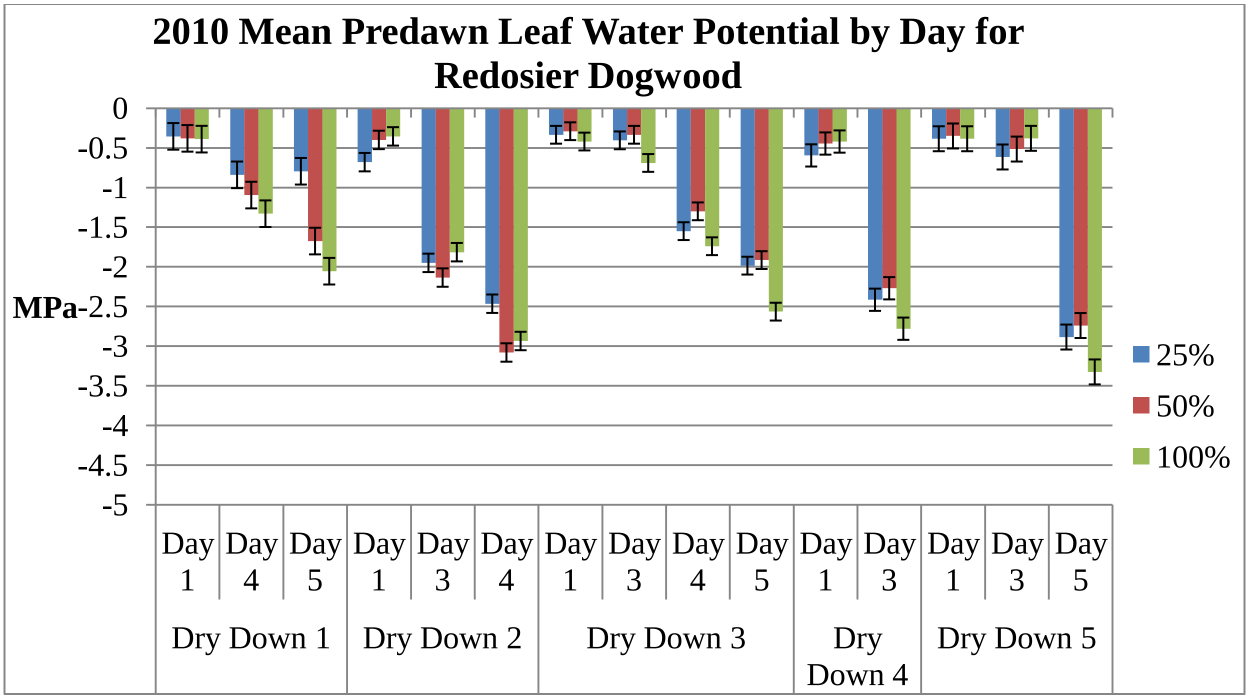

Figure 2.10b: Mean predawn leaf water potential readings for each 2010 dry down by day for redosier dogwood ($p<0.05$)

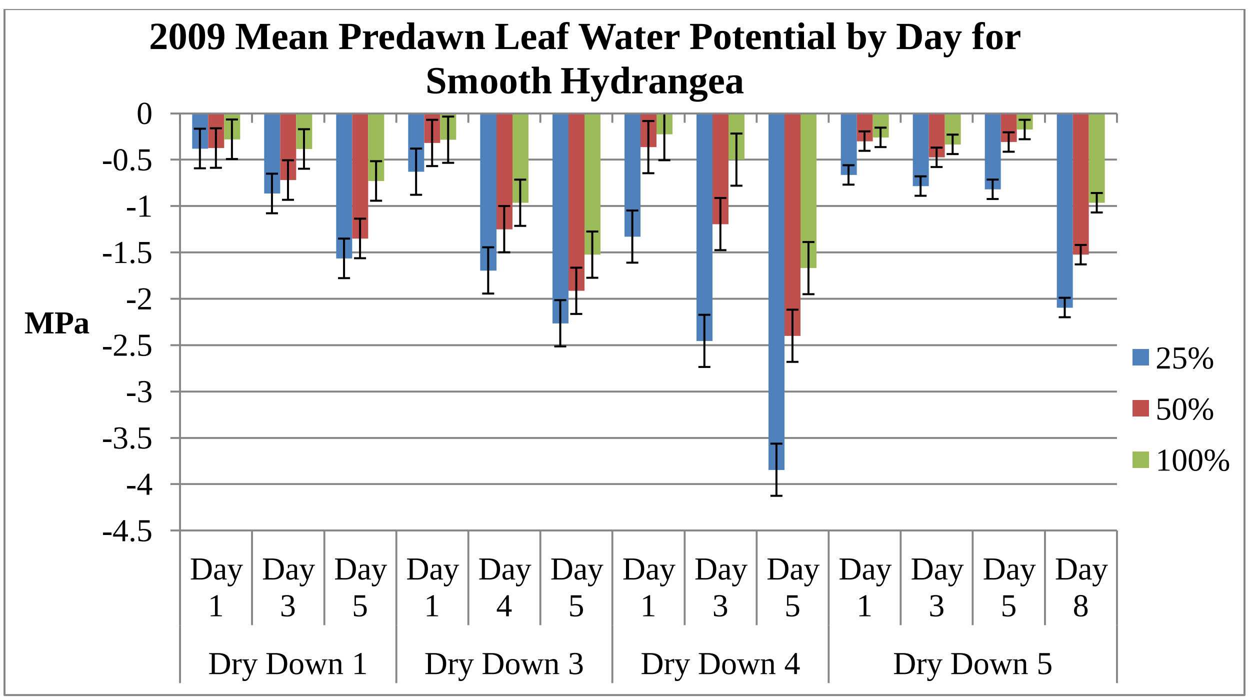

Figure 2.10c: Mean predawn leaf water potential readings for each 2009 dry down by day for smooth hydrangea ($p<0.05$)

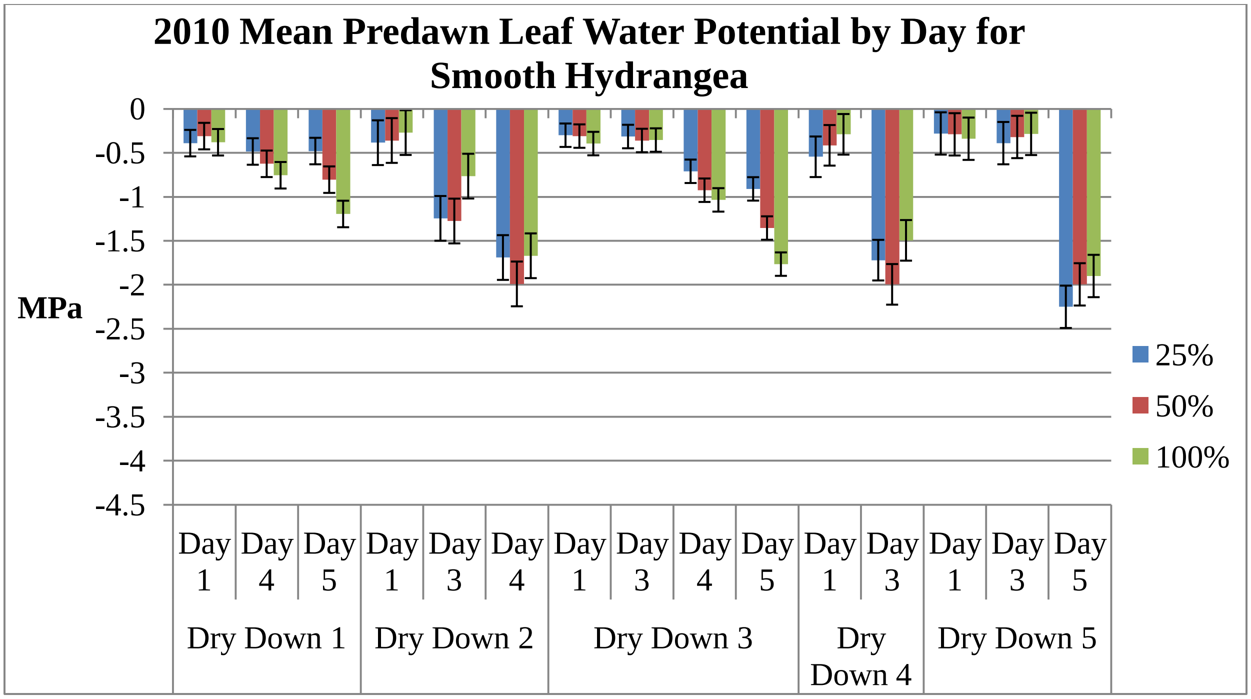

Figure 2.10d: Mean predawn leaf water potential readings for each 2010 dry down by day for smooth hydrangea ($p<0.05$)

As occurred with the field experiment, leaves were collected from each plant to determine the average area, fresh weight, and dry weight per leaf from both shrub species in each treatment. This data was collected to determine if watering treatments had any effect on the growth habits of the foliage for either species.

During 2009, the different watering treatments appear to have had an impact on the leaf characteristics on both the redosier dogwood and the smooth hydrangea. Further, the graphs for the leaf area (Figure 2.11a), leaf fresh weight (Figure 2.11b), and leaf dry weight (Figure 2.11c) essentially mirror each other in how the treatments affected the characteristics of the foliage for both species. The leaves on the dogwood increased in area and weight as irrigation treatments increased. The hydrangea leaves in the 50% and 100% were equal to each other but they were still larger in area and in biomass than those in the 25% treatment. As a result, it appears that when both species received more water, leaf area and leaf biomass also increased. However, this result changed in 2010.

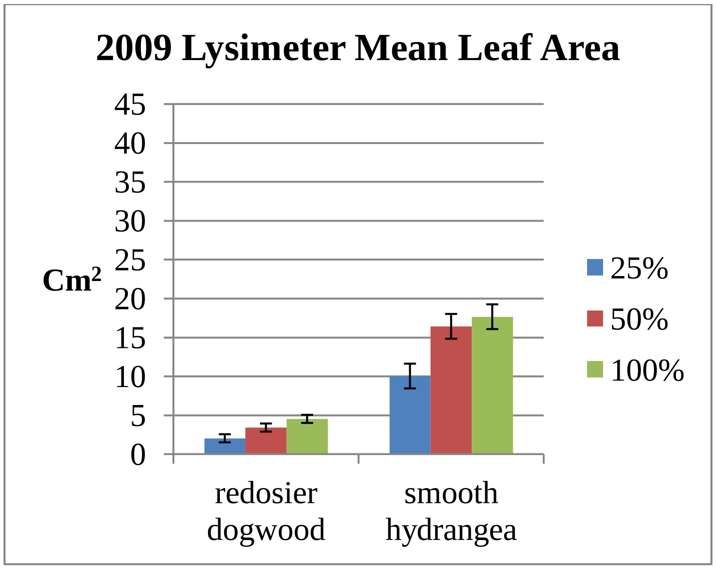

Figure 2.11a: 2009 Mean area per leaf of lysimeter shrubs (p<0.05)

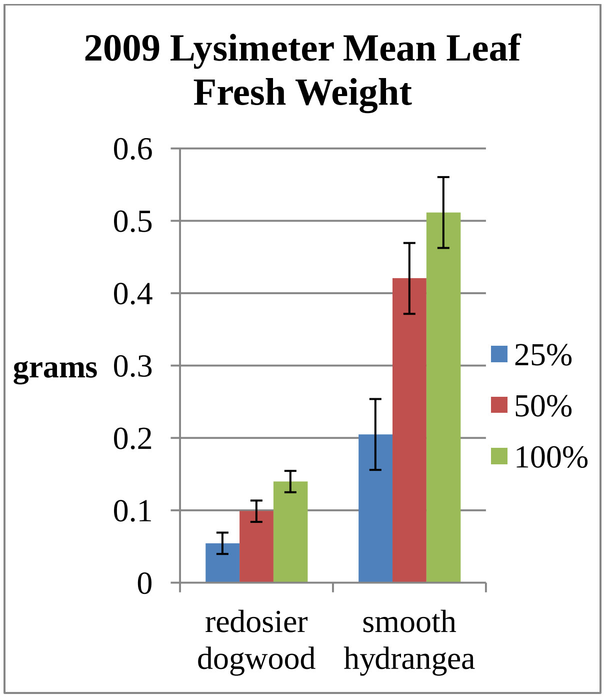

Figure 2.11b: 2009 Mean fresh weight per leaf of lysimeter shrubs (p<0.05)

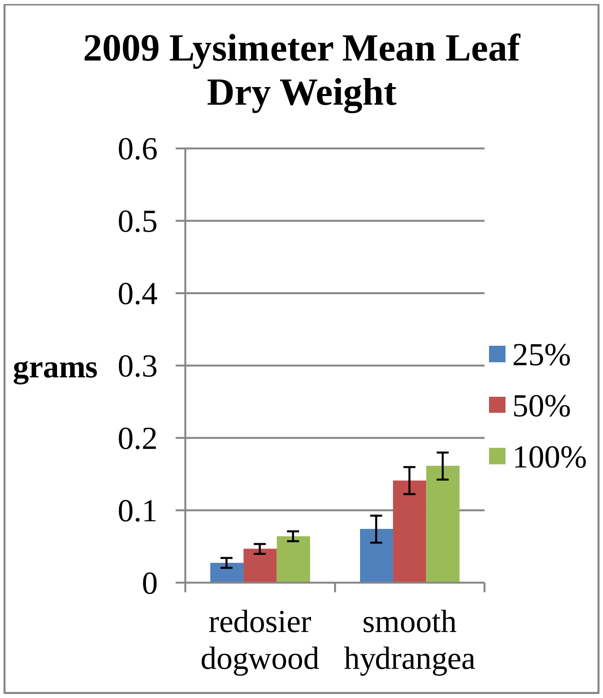

Figure 2.11c: 2009 Mean dry weight per leaf of lysimeter shrubs (p<0.05)

Leaf characteristics changed during 2010, especially in leaf fresh and dry weights. The leaf area for the redosier dogwood did not significantly differ for any particular treatment (Figure 2.12a). However, the area for the smooth hydrangea leaves did have some differences, which partially matched the results from 2009. During 2010 (and 2009), the hydrangea leaves in the 100% treatment were larger in area than the 25% treatment. However, the 50% treatment did not follow the same pattern during both years since during 2010 the hydrangea leaves from the 50% treatment were not larger than the 25% (as was the case in 2009). The leaf weights for the smooth hydrangea, both fresh and dry (Figure 2.12b and Figure 2.12c), showed no differences among treatments during 2010. The dogwood had one statistical difference when looking at the leaf weights. The dry weight of the leaves in the 25% treatment was greater than the weight of those in the 50% and 100% treatments. Other than this difference, no statistical differences were present for any treatment for the dogwood in the fresh or dry weight of the leaves.

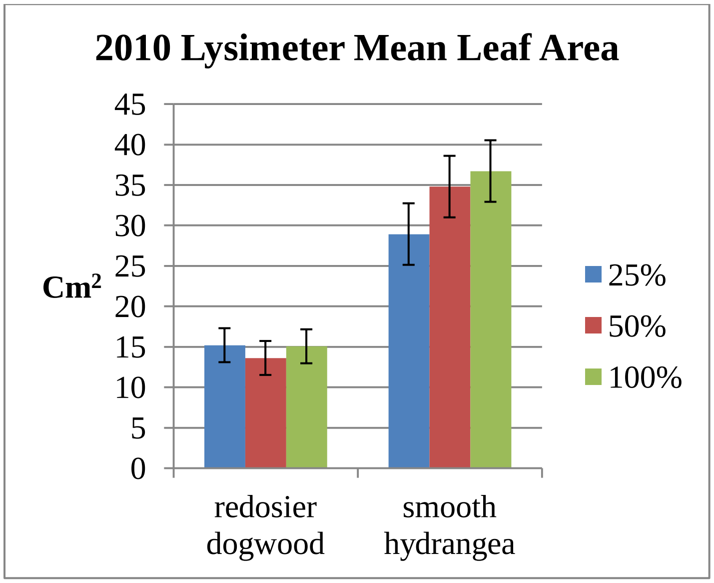

Figure 2.12a: 2010 Mean area per leaf of lysimeter shrubs ($p<0.05$)

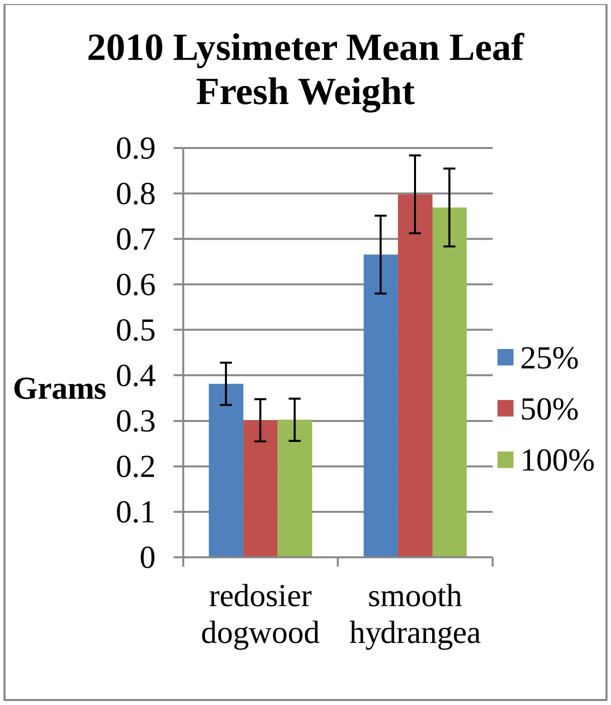

Figure 2.12b: 2010 Mean fresh weight per leaf of lysimeter shrubs ($p<0.05$)

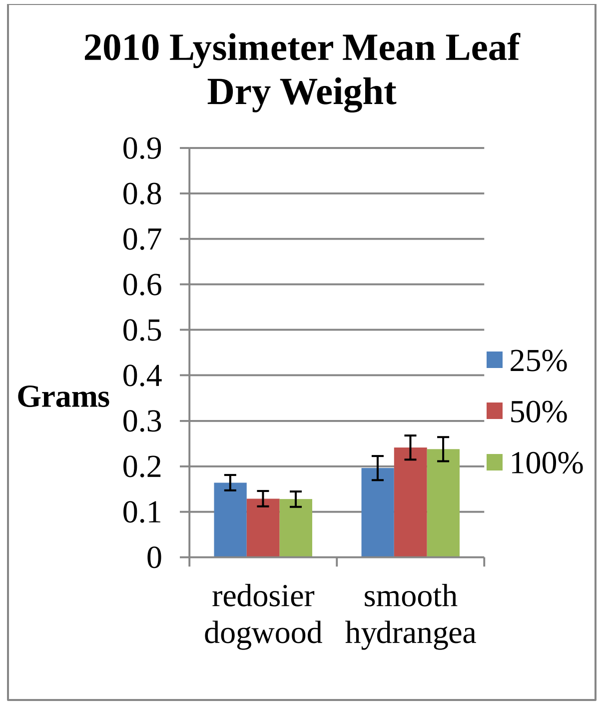

Figure 2.12c: 2010 Mean dry weight per leaf of lysimeter shrubs ($p<0.05$)

The results from 2009 suggested that changing the watering amounts changed the leaf characteristics of both species. When both shrubs received more water, larger leaves with more overall biomass resulted. However, the 2010 results did not support this conclusion since few differences occurred. The lack of differences can again be attributed to the size differences of the shrubs from 2009 to 2010. Figure 2.5a through Figure 2.5d show that the heights and widths of both shrub species had few differences during 2009, but differences were present during 2010. It is theorized that plants can better tolerate later episodes of drought stress when they have previously been exposed to drought stress (Kozlowski and Pallardy, 2002; Williams, Rosenqvist and Buchhave, 2000). The episodes of drought stress that occurred during 2009 may have affected the way in which the shrubs grew in each treatment so that the shrubs could tolerate drought stress during 2010. Both plant species automatically adjusted their growth characteristics to account for the water amounts that they received. The shrubs essentially grew to a size that they could support themselves with the available water. They developed leaves that were comparable to each other since the overall size of the shrubs differed but leaf area and biomass did not vary. It appears that the leaf characteristics may be affected by the watering practices for both species after one year. However, after both species of shrubs had repeated instances of receiving decreased water amounts, growth characteristics of the leaves may not be affected as the plants may adjust their growth rates in height and width to account for different moisture levels.

As occurred with the field component of the experiment, at the conclusion of the lysimeter component of the experiment, all of the plants were cut to the ground and collected to determine if watering treatments had any effect on shoot biomass that each species had grown in each treatment. Since this measuring technique was destructive, it was only done during 2010. The data is represented in Figure 2.13a for the mean shoot fresh weight and Figure 2.13b for the mean shoot dry weight. The results for the redosier dogwood and the smooth hydrangea are the same for both the fresh and dry weights of the collected shoots. As watering amounts increased, overall weights also increased. As a result, it appears that watering amount has a direct effect on the amount of shoot growth for redosier dogwood and smooth hydrangea. The more water these plants receive, the more biomass and water holding capacities will result in the shoots.

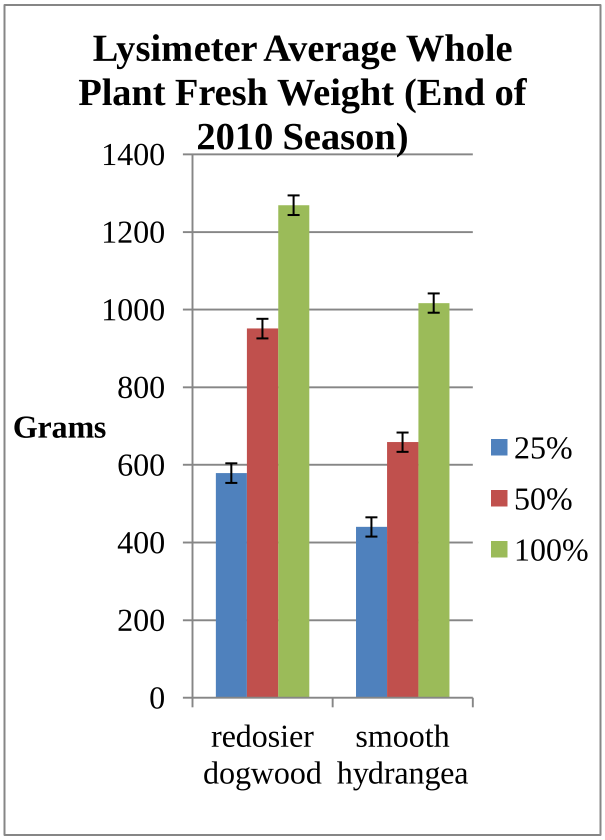

Figure 2.13a: Mean shoot fresh weight of lysimeter shrubs ($p<0.05$)

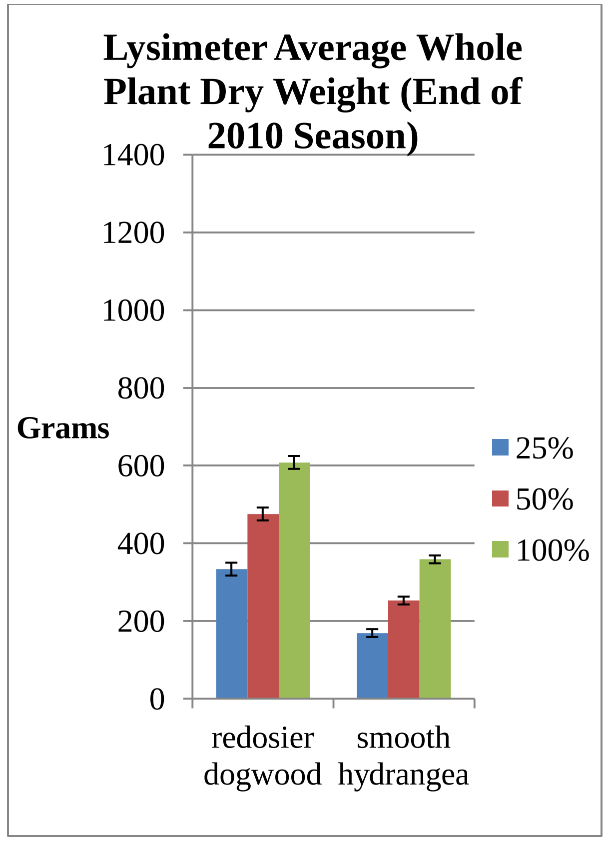

Figure 2.13b: Mean shoot dry weight of lysimeter shrubs ($p<0.05$)

The lysimeter component of the study tested two species of shrubs to determine if they can do well with decreased amounts of irrigation. In other studies, shrubs have been researched by conducting several dry down periods to monitor increasing levels of drought stress while actively growing in containers (García-Navarro, et al., 2004; Ounsworth, 2007; Zollinger, et al., 2006). Additionally, research has been done to determine plant responses when watered with different percentages of ET_o (Henson, et al., 2006; Pittenger and Shaw, 2004a.) This study monitored shrubs both actively growing in containers and going through dry down periods, while being watered based on varying percentages of ET_o. By researching shrubs grown in containers when watered with different percentages of ET_o a better idea was gained on how much water the plants used on a daily basis. It also shows how the plants used the water provided for growth when contained in a confined rooting area for an extended period of time.

The results from the Lysimeter component of the study had variations from 2009 to 2010 but both the dogwood and hydrangea responded similarly to each other during each year. During 2009, more water appears to have reduced physiological stress and increased visual ratings, but during 2010, the shrubs appear to have modified their growth habits to account for the varying water amounts provided through the three different treatments. The sizes of both shrubs had little differences during 2009, but in 2010, the plants increased in size as the treatment amounts increased. The plants grew to a size that they could support themselves with the available water (Smith and Klett, 2011). The overall size of the shrubs varied but the characteristics of the leaves remained relatively similar for each species among all three treatments. This further represents that both species grew to a point that they could support themselves with the available water supply since overall size became limited but foliage characteristics did not among the different treatments. By the end of the 2010 season, both species also had increased shoot biomass, visual ratings, and broke dormancy more quickly (as much as two to three weeks) as irrigation amounts increased. As a result, it appears that more water positively impacted both species. However, when comparing the season begin and end widths during 2010 with the dogwood (Figure 2.5d) and the season begin and end heights and widths with the hydrangea (Figure 2.5b and Figure 2.5d), all treatments increased in size by the end of the season. Growth still resulted on both species when watered with as little as 25% of ET_o. If more growth is needed faster, such as is often desired in nursery production, then watering applications should be greater than 25% of ET_o so more growth occurs for a larger plant in less time.

While providing more water to dogwood and hydrangea will result in larger plants, these larger plants will further require more water to maintain their larger size. Both the dogwood and hydrangea used more water on a daily basis as the water amounts increased (Figure 2.9a through Figure 2.9d, Appendix F). This caused the plants to use the stored water in the pots at a faster rate. Water was used at a faster rate in the 100% treatment than the 25% treatment. Therefore, the amount of time that the plants in the 100% treatment were able to survive without being watered was decreased since the water potential readings became more negative (more stressed) at a faster rate than the lower watered treatments. As a result, more vigilance would be required to insure that larger shrubs were hydrated in a nursery setting. Conversely, the shrubs that were watered with 25% of ET_o were able to last longer with less water. This result occurred because the shrubs adjusted their growth characteristics to account for the decreased irrigation. This growth adjustment could result in superior plants when it is eventually planted in the landscape, because a plant that has been subjected to drought stress is better able to tolerate repeated episodes of drought stress (Kozlowski and Pallardy, 2002; Williams, Rosenqvist and Buchhave, 2000). As a result, it could be advantageous to grow both of these plant species with 25% of ET_o to encourage growth characteristics that are better able to tolerate decreased watering amounts.

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APPENDIX A

Kentucky bluegrass 0% ET_o
(Sept. 1, 2010)

Kentucky bluegrass 25% ET_o
(Sept. 1, 2010)

Kentucky bluegrass 50% ET_o
(Sept. 1, 2010)

Kentucky bluegrass 100% ET_o
(Sept. 1, 2010)

APPENDIX A


redosier dogwood 0% ET_o
(Sept. 1, 2010)


redosier dogwood 25% ET_o
(Sept. 1, 2010)


redosier dogwood 50% ET_o
(Sept. 1, 2010)


redosier dogwood 100% ET_o
(Sept. 1, 2010)

APPENDIX A

smooth hydrangea 0% ET_o
(Sept. 1, 2010)

smooth hydrangea 25% ET_o
(Sept. 1, 2010)

smooth hydrangea 50% ET_o
(Sept. 1, 2010)

smooth hydrangea 100% ET_o
(Sept. 1, 2010)

APPENDIX A

Diablo® ninebark 0% ET_o
(Sept. 1, 2010)

Diablo® ninebark 25% ET_o
(Sept. 1, 2010)

Diablo® ninebark 50% ET_o
(Sept. 1, 2010)

Diablo® ninebark 100% ET_o
(Sept. 1, 2010)

APPENDIX A

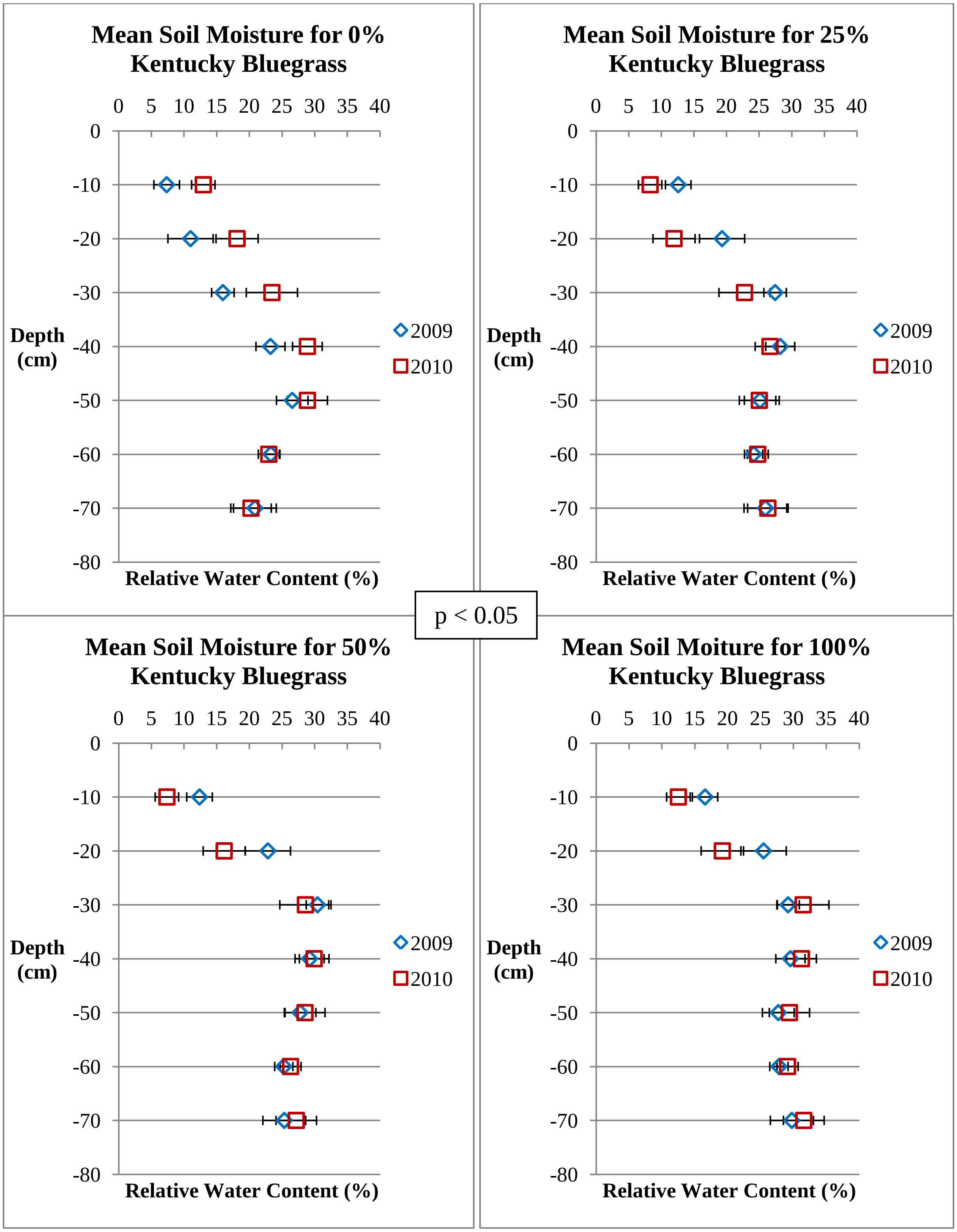

arctic blue willow 0% ET_o
(Sept. 1, 2010)


arctic blue willow 25% ET_o
(Sept. 1, 2010)


arctic blue willow 50% ET_o
(Sept. 1, 2010)

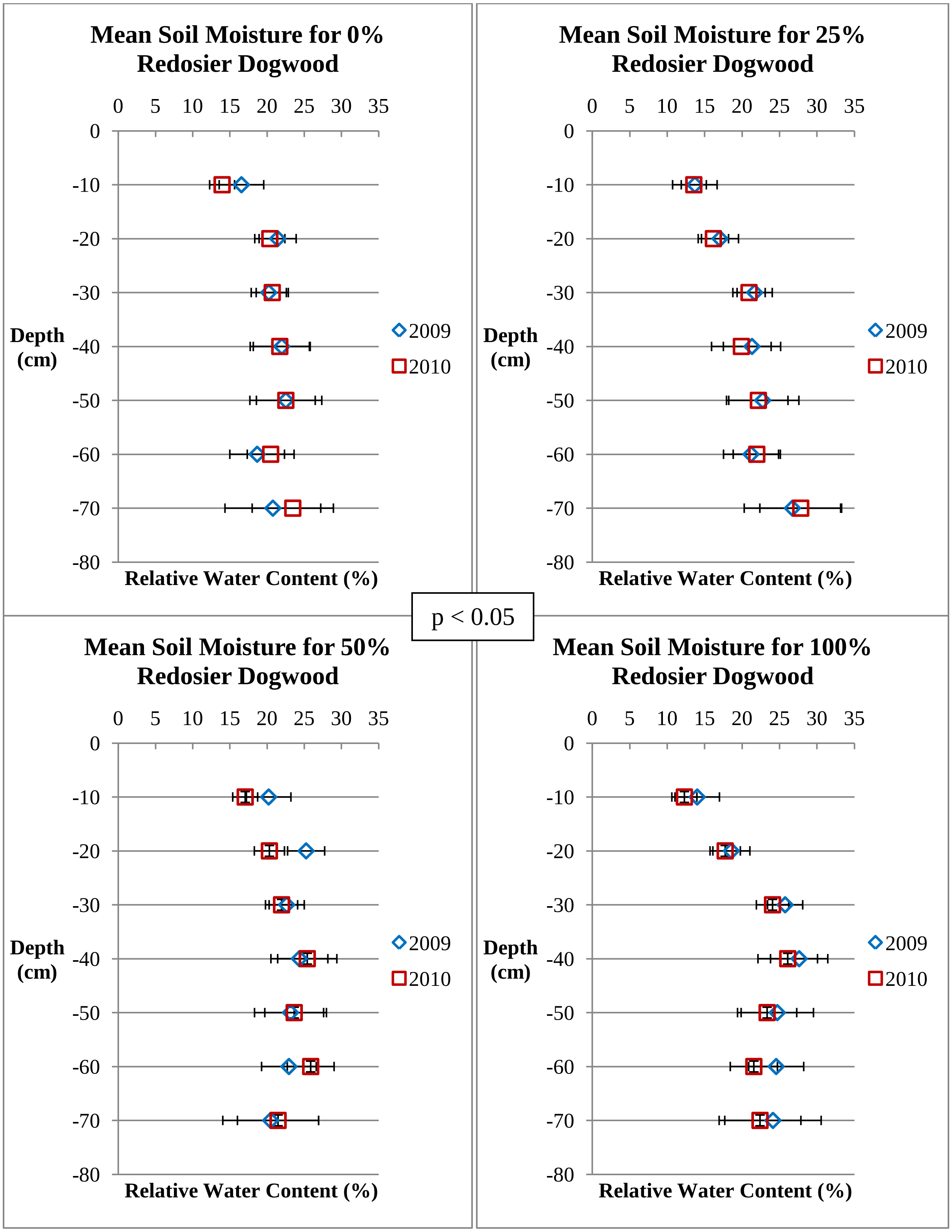

arctic blue willow 100% ET_o
(Sept. 1, 2010)

APPENDIX B

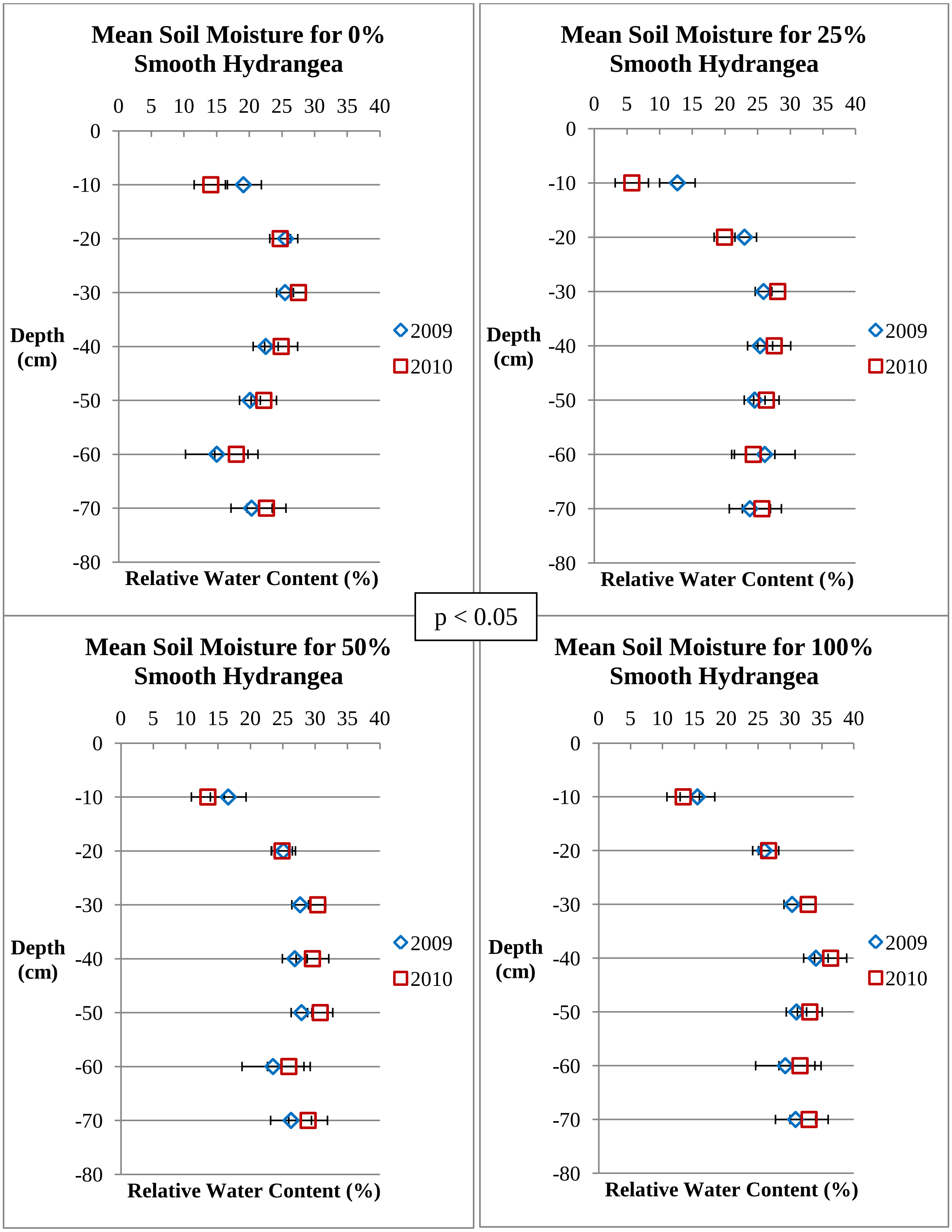


Mean Soil Moisture for 0% Kentucky Bluegrass
Mean Soil Moisture for 25% Kentucky Bluegrass
Mean Soil Moisture for 50% Kentucky Bluegrass
Mean Soil Moiture for 100% Kentucky Bluegrass
0 5 10 15 20 25 30 35 40
0 -10 -20 -30 -40 -50 -60 -70 -80
Depth (cm)
Relative Water Content (%)
2009
2010
p < 0.05

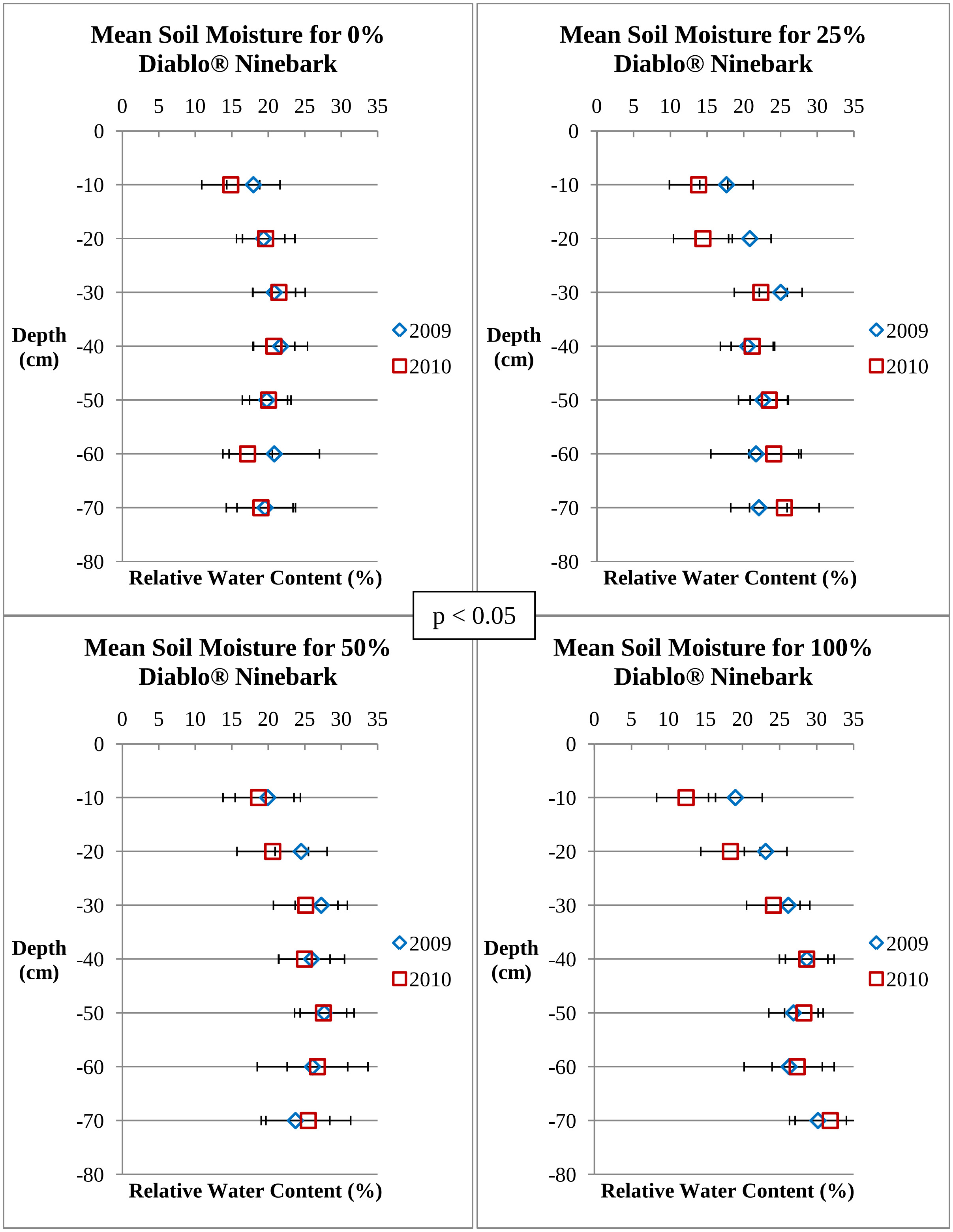
APPENDIX B


Mean Soil Moisture for 0% Redosier Dogwood
Mean Soil Moisture for 25% Redosier Dogwood
Mean Soil Moisture for 50% Redosier Dogwood
Mean Soil Moisture for 100% Redosier Dogwood
0 5 10 15 20 25 30 35
0 -10 -20 -30 -40 -50 -60 -70 -80
Depth (cm)
Relative Water Content (%)
2009
2010
p < 0.05

APPENDIX B

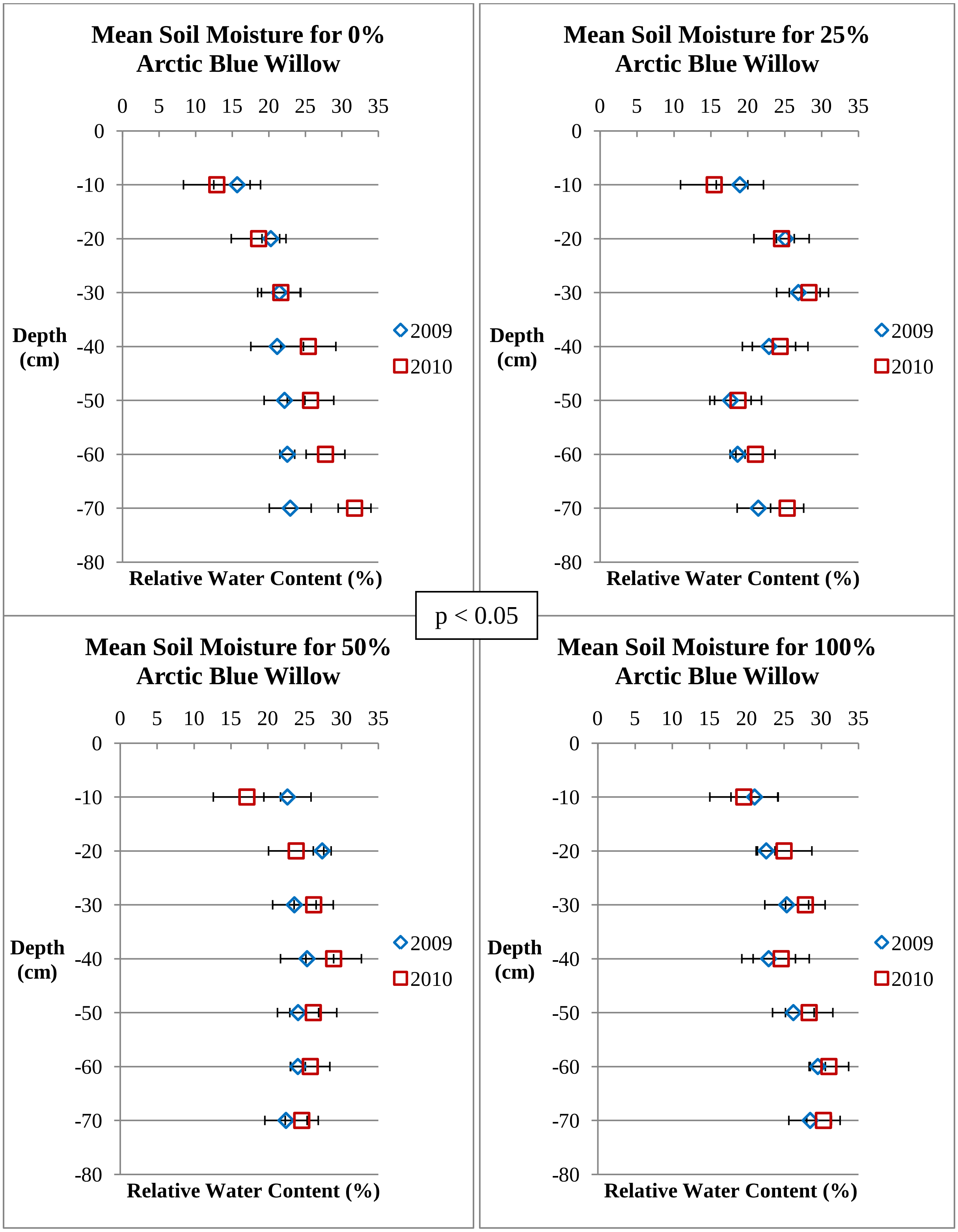

Mean Soil Moisture for 0% Smooth Hydrangea
Mean Soil Moisture for 25% Smooth Hydrangea
Mean Soil Moisture for 50% Smooth Hydrangea
Mean Soil Moisture for 100% Smooth Hydrangea
0 5 10 15 20 25 30 35 40
0
-10
-20
-30
-40
-50
-60
-70
-80
Depth (cm)
Relative Water Content (%)
2009
2010
p < 0.05

APPENDIX B



Mean Soil Moisture for 0% Diablo® Ninebark
Mean Soil Moisture for 25% Diablo® Ninebark
Mean Soil Moisture for 50% Diablo® Ninebark
Mean Soil Moisture for 100% Diablo® Ninebark
0 5 10 15 20 25 30 35
0 -10 -20 -30 -40 -50 -60 -70 -80
Depth (cm)
Relative Water Content (%)
2009
2010
p < 0.05

APPENDIX B

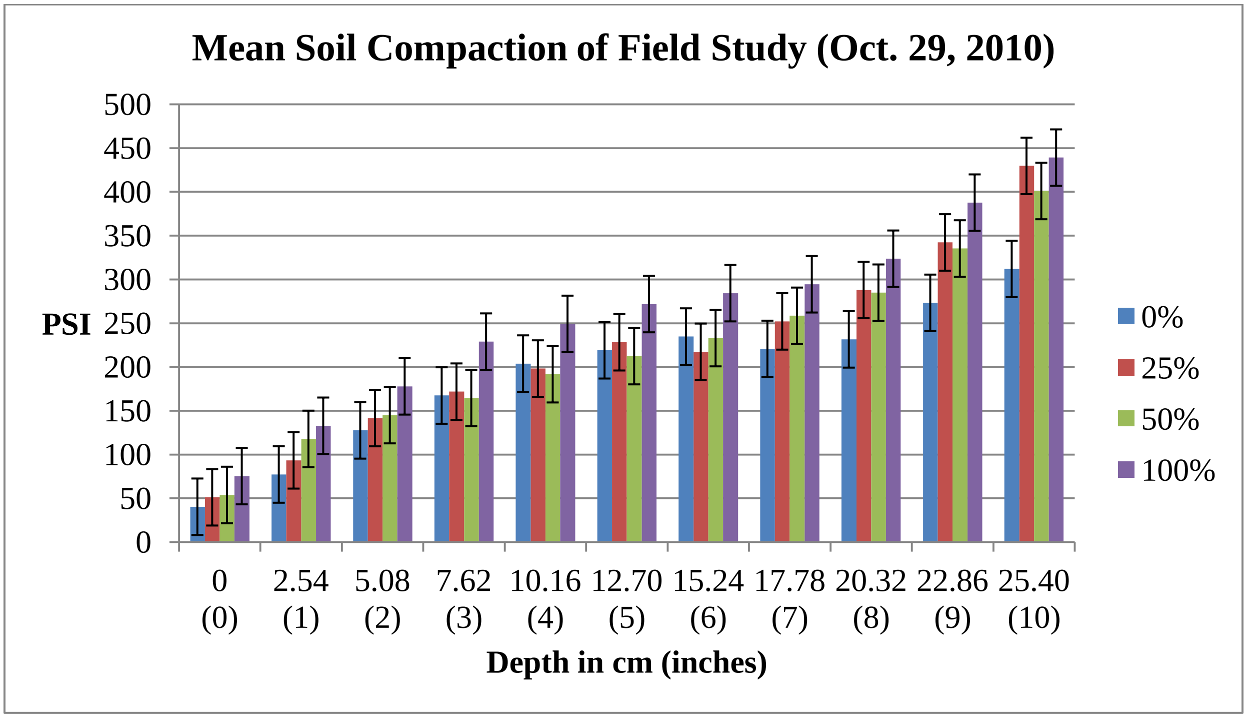

Mean Soil Moisture for 0% Arctic Blue Willow
Mean Soil Moisture for 25% Arctic Blue Willow
Mean Soil Moisture for 50% Arctic Blue Willow
Mean Soil Moisture for 100% Arctic Blue Willow
0 5 10 15 20 25 30 35
0 -10 -20 -30 -40 -50 -60 -70 -80
Depth (cm)
Relative Water Content (%)
2009
2010
$p < 0.05$

APPENDIX C

Soil Analysis												
Treatment Plot	pH	EC mmhos/ cm	Lime Estimate	%OM	NO_3-N ppm	P ppm	K ppm	Zn ppm	Fe ppm	Mn ppm	Cu ppm	Texture Estimate
0%	7.3	0.7	High	11.5	10.5	101	638	9.5	43.1	5.3	2.6	Loam
25%	7.2	0.5	High	8.8	5.3	100	296	13.3	55.5	6.1	4.8	Loam
50%	7.2	0.7	High	11.6	19.1	110	867	26.8	106	14.4	5.8	Loam
100%	7.2	0.7	High	10.4	8.3	103	707	12.7	41.3	6.4	3.9	Loam

Soil analysis from Colorado State University soil testing laboratory (May 2005)

APPENDIX D



Mean Soil Compaction of Field Study (Oct. 29, 2010)
PSI
500
450
400
350
300
250
200
150
100
50
0
0 (0)
2.54 (1)
5.08 (2)
7.62 (3)
10.16 (4)
12.70 (5)
15.24 (6)
17.78 (7)
20.32 (8)
22.86 (9)
25.40 (10)
Depth in cm (inches)
0%
25%
50%
100%

APPENDIX E

redosier dogwood 25% ET_o (Sept. 1, 2010)

redosier dogwood 50% ET_o (Sept. 1, 2010)

redosier dogwood 100% ET_o (Sept. 1, 2010)

APPENDIX E


smooth hydrangea 25% ET_o (Sept. 1, 2010)


smooth hydrangea 50% ET_o (Sept. 1, 2010)


smooth hydrangea 100% ET_o (Sept. 1, 2010)

APPENDIX F

2009 Mean Millimeters of Water Lost Per Day by Dry Down for Redosier Dogwood					
	1 July 13-17	2 July 27-29	3 Aug. 3-7	4 Aug 20-24	5 Sept. 9-16
25%	1.35	3.70	3.05	0.37	1.28
50%	2.31	4.63	2.97	0.40	3.06
100%	4.74	6.01	5.47	0.80	5.73

2010 Mean Millimeters of Water Lost Per Day by Dry Down for Redosier Dogwood					
	1 June 17-21	2 July 9-12	3 July 26-30	4 Aug 20-22	5 Sept. 6-10
25%	9.91	4.73	8.17	9.17	7.75
50%	11.49	6.73	14.42	17.58	14.92
100%	15.88	12.54	19.58	25.21	20.89

2009 Mean Millimeters of Water Lost Per Day by Dry Down for Smooth Hydrangea					
	1 July 13-17	2 July 27-29	3 Aug. 3-7	4 Aug 20-24	5 Sept. 9-16
25%	2.93	3.85	2.81	0.40	1.59
50%	3.89	4.47	4.20	0.56	3.80
100%	6.17	5.40	6.40	0.65	6.30

2010 Mean Millimeters of Water Lost Per Day by Dry Down for Smooth Hydrangea					
	1 June 17-21	2 July 9-12	3 July 26-30	4 Aug 20-22	5 Sept. 6-10
25%	6.86	5.29	8.52	10.41	8.52
50%	10.68	7.97	12.37	16.34	12.80
100%	13.49	14.24	17.00	22.20	17.15

APPENDIX G

```
import java.io.*;

/**
 * @author FRED SMITH
 */
public class LeafArea {
/**
 * @param args the command line arguments
 */
  public static void main(String[] args) {
    GV varClass = new GV();
    //Look for config file to setup vars, else use defaults
    File tmpFile = new File("C:\\leafarea.cfg");
    if (tmpFile.exists()) {
      ReadCfg.ReadCfg();
    } else {
      GV.setGV("redBgVal", 215);
      GV.setGV("blueBgVal", 215);
      GV.setGV("greenBgVal", 215);
      GV.setGV("dpi", 300);
      GV.setGV("minLeafPixels", 150);
      GV.setGV("minLeftBorder", 100);
      GV.setGV("minRightBorder", 100);
      GV.setGV("minTopBorder", 100);
      GV.setGV("minBottomBorder", 100);
      GV.setGV("units", "cm");
      GV.setGV("fFormat", "bmp");
      GV.setGV("fileChosen", "false");
      GV.setGV("pathChosen", "false");
      GV.setGV("verbose", "false");
      GV.setGV("debug", "false");
    }
    new Gui().setVisible(true);
  }
}

/**
 * Gui.java
 * Created on Sep 30, 2009, 8:06:58 PM
 */
import java.awt.Image;
import java.awt.image.BufferedImage;
import javax.swing.*;
import java.io.*;
import java.util.*;
import javax.imageio.*;
/**
 * @author FRED SMITH
 */
public class Gui extends javax.swing.JFrame {
/** Creates new form Gui */
  public Gui() {
    initComponents();
    setTitle("Leaf Area Ver. 1.0");
```

```
    textField1.setText("");
    textField2.setText("");
    jSpinner1.setValue(GV.getRedBgVal());
    jSpinner2.setValue(GV.getBlueBgVal());
    jSpinner3.setValue(GV.getGreenBgVal());
    jSpinner4.setValue(GV.getDpi());
    if (GV.getVerbose()) {
      jRadioButton4.doClick();
    } else {
      jRadioButton3.doClick();
    }
    if (GV.getUnits().equalsIgnoreCase("cm")) {
      jRadioButton2.doClick();
    } else {
      jRadioButton1.doClick();
    }
  }
  public static void updateLog(String str) {
    if (GV.getVerbose()) {
      textArea1.append(str + "\n");
    }
  }

  public static void debugLog(String str) {
    if (GV.getDebug()) {
      textArea1.append(str + "\n");
    }
  }

  /** This method is called from within the constructor to
   * initialize the form.
   * WARNING: Do NOT modify this code. The content of this method is
   * always regenerated by the Form Editor.
   */
   @SuppressWarnings("unchecked")
   // <editor-fold defaultstate="collapsed" desc="Generated Code">//GEN-
BEGIN:initComponents
  private void initComponents() {
    buttonGroup1 = new javax.swing.ButtonGroup();
    buttonGroup2 = new javax.swing.ButtonGroup();
    label1 = new java.awt.Label();
    label2 = new java.awt.Label();
    label3 = new java.awt.Label();
    textField1 = new java.awt.TextField();
    textField2 = new java.awt.TextField();
    label4 = new java.awt.Label();
    jRadioButton1 = new javax.swing.JRadioButton();
    jRadioButton2 = new javax.swing.JRadioButton();
    label6 = new java.awt.Label();
    label7 = new java.awt.Label();
    label8 = new java.awt.Label();
    button1 = new java.awt.Button();
    button2 = new java.awt.Button();
    button3 = new java.awt.Button();
    jSpinner1 = new javax.swing.JSpinner();
```

```
  jSpinner2 = new javax.swing.JSpinner();
  jSpinner3 = new javax.swing.JSpinner();
  jSpinner4 = new javax.swing.JSpinner();
  textArea1 = new java.awt.TextArea();
  jRadioButton3 = new javax.swing.JRadioButton();
  jRadioButton4 = new javax.swing.JRadioButton();
  jLabel2 = new javax.swing.JLabel();
  setDefaultCloseOperation(javax.swing.WindowConstants.EXIT_ON_CLOSE);

  label1.setAlignment(java.awt.Label.RIGHT);
  label1.setFont(new java.awt.Font("Dialog", 1, 12));
  label1.setText("Input Dir:");
  label2.setAlignment(java.awt.Label.RIGHT);
  label2.setFont(new java.awt.Font("Dialog", 1, 12));
  label2.setText("Output File:");

  label3.setAlignment(java.awt.Label.RIGHT);
  label3.setFont(new java.awt.Font("Dialog", 1, 12));
  label3.setText("DPI:");
  textField1.setName("inFile"); // NOI18N
  textField1.setText("textField1");
  textField1.addTextListener(new java.awt.event.TextListener() {
    public void textValueChanged(java.awt.event.TextEvent evt) {
      textField1TextValueChanged(evt);
    }
  });

textField2.setName("outFile"); // NOI18N
textField2.setText("textField2");
textField2.addTextListener(new java.awt.event.TextListener() {
  public void textValueChanged(java.awt.event.TextEvent evt) {
    textField2TextValueChanged(evt);
  }
});
textField2.addActionListener(new java.awt.event.ActionListener() {
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    textField2ActionPerformed(evt);
  }
});

label4.setAlignment(java.awt.Label.CENTER);
label4.setFont(new java.awt.Font("Dialog", 1, 12));
label4.setText("Units");

buttonGroup1.add(jRadioButton1);
jRadioButton1.setText("SQ.IN");
jRadioButton1.addActionListener(new java.awt.event.ActionListener() {
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    jRadioButton1ActionPerformed(evt);
  }
});

buttonGroup1.add(jRadioButton2);
jRadioButton2.setText("SQ.CM");
jRadioButton2.addActionListener(new java.awt.event.ActionListener() {
```

```
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    jRadioButton2ActionPerformed(evt);
  }
});

label6.setAlignment(java.awt.Label.RIGHT);
label6.setFont(new java.awt.Font("Dialog", 1, 12));
label6.setText("RED Bg:");

label7.setAlignment(java.awt.Label.RIGHT);
label7.setFont(new java.awt.Font("Dialog", 1, 12));
label7.setText("BLUE Bg:");

label8.setAlignment(java.awt.Label.RIGHT);
label8.setFont(new java.awt.Font("Dialog", 1, 12));
label8.setText("GREEN Bg:");

button1.setFont(new java.awt.Font("Dialog", 1, 12));
button1.setLabel("...");
button1.setName("inFileSearch"); // NOI18N
button1.addActionListener(new java.awt.event.ActionListener() {
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    button1ActionPerformed(evt);
  }
});

button2.setFont(new java.awt.Font("Dialog", 1, 12));
button2.setLabel("...");
button2.setName("outFileSearch"); // NOI18N
button2.addActionListener(new java.awt.event.ActionListener() {
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    button2ActionPerformed(evt);
  }
});

button3.setFont(new java.awt.Font("Dialog", 1, 12));
button3.setLabel("Start");
button3.setName("startButton"); // NOI18N
button3.addActionListener(new java.awt.event.ActionListener() {
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    button3ActionPerformed(evt);
   }
});

jSpinner4.addChangeListener(new javax.swing.event.ChangeListener() {
  public void stateChanged(javax.swing.event.ChangeEvent evt) {
    jSpinner4StateChanged(evt);
  }
});

buttonGroup2.add(jRadioButton3);
jRadioButton3.setText("Terse");
jRadioButton3.addActionListener(new java.awt.event.ActionListener() {
  public void actionPerformed(java.awt.event.ActionEvent evt) {
    jRadioButton3ActionPerformed(evt);
```

```
    }
  });

  buttonGroup2.add(jRadioButton4);
  jRadioButton4.setText("Verbose");
  jRadioButton4.addActionListener(new java.awt.event.ActionListener() {
    public void actionPerformed(java.awt.event.ActionEvent evt) {
      jRadioButton4ActionPerformed(evt);
    }
  });

  jLabel2.setFont(new java.awt.Font("Tahoma", 1, 11));
  jLabel2.setText("Logging");
  javax.swing.GroupLayout layout = new
javax.swing.GroupLayout(getContentPane());
  getContentPane().setLayout(layout);
  layout.setHorizontalGroup(
    layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADING)
    .addGroup(javax.swing.GroupLayout.Alignment.TRAILING,
layout.createSequentialGroup()
    .addGap(28, 28, 28)
    .addComponent(textArea1, javax.swing.GroupLayout.PREFERRED_SIZE, 682,
javax.swing.GroupLayout.PREFERRED_SIZE)
    .addGap(52, 52, 52))
    .addGroup(layout.createSequentialGroup()
    .addGap(327, 327, 327)
    .addComponent(button3, javax.swing.GroupLayout.PREFERRED_SIZE, 103,
javax.swing.GroupLayout.PREFERRED_SIZE)
    .addContainerGap(332, Short.MAX_VALUE))
    .addGroup(layout.createSequentialGroup()
    .addContainerGap()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG)
    .addGroup(layout.createSequentialGroup()
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED, 596,
javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(label3, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addGap(22, 22, 22)
    .addComponent(jSpinner4, javax.swing.GroupLayout.PREFERRED_SIZE, 56,
javax.swing.GroupLayout.PREFERRED_SIZE))
    .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG, false)
    .addComponent(label1, javax.swing.GroupLayout.DEFAULT_SIZE, 70,
Short.MAX_VALUE)
    .addComponent(label2, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
.addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED, 26,
Short.MAX_VALUE)
```

```
.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG, false)
    .addComponent(textField2, javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, Short.MAX_VALUE)
    .addComponent(textField1, javax.swing.GroupLayout.DEFAULT_SIZE, 232,
Short.MAX_VALUE))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG)
    .addComponent(button1, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(button2, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
    .addGap(40, 40, 40)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(jRadioButton4)
    .addComponent(jLabel2)
    .addComponent(jRadioButton3))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(label4, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(jRadioButton1, javax.swing.GroupLayout.PREFERRED_SIZE, 71,
javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(jRadioButton2))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG, false)
    .addComponent(label6, javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, Short.MAX_VALUE)
    .addComponent(label7, javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, Short.MAX_VALUE)
    .addComponent(label8, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
    .addGap(22, 22, 22)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G, false)
    .addComponent(jSpinner1, javax.swing.GroupLayout.DEFAULT_SIZE, 56,
Short.MAX_VALUE)
    .addComponent(jSpinner2)
    .addComponent(jSpinner3))))
    .addGap(52, 52, 52))
  );
  layout.setVerticalGroup(
    layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADING)
```

```
    .addGroup(javax.swing.GroupLayout.Alignment.TRAILING,
layout.createSequentialGroup()
    .addContainerGap(31, Short.MAX_VALUE)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(label6, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(jSpinner1, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(label7, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(jSpinner2, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(jSpinner3, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(label8, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE)))
    .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.TRAILI
NG)
    .addComponent(textField1, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(button1, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))
    .addGroup(layout.createSequentialGroup()
    .addGap(4, 4, 4)
    .addComponent(label1, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE)))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
```

```
.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(textField2, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(button2, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(label2, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE))))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addComponent(label3, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addComponent(jSpinner4, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE,
javax.swing.GroupLayout.PREFERRED_SIZE)))
    .addGroup(layout.createSequentialGroup()

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.LEADIN
G)
    .addGroup(layout.createSequentialGroup()
    .addComponent(label4, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addGap(23, 23, 23))
    .addGroup(javax.swing.GroupLayout.Alignment.TRAILING,
layout.createSequentialGroup()
    .addGap(4, 4, 4)
    .addComponent(jLabel2)
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.BASELI
NE)
    .addComponent(jRadioButton1)
    .addComponent(jRadioButton3, javax.swing.GroupLayout.PREFERRED_SIZE, 23,
javax.swing.GroupLayout.PREFERRED_SIZE))))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)

.addGroup(layout.createParallelGroup(javax.swing.GroupLayout.Alignment.BASELI
NE)
    .addComponent(jRadioButton2)
    .addComponent(jRadioButton4))))
    .addPreferredGap(javax.swing.LayoutStyle.ComponentPlacement.RELATED)
    .addComponent(button3, javax.swing.GroupLayout.PREFERRED_SIZE,
javax.swing.GroupLayout.DEFAULT_SIZE, javax.swing.GroupLayout.PREFERRED_SIZE)
    .addGap(27, 27, 27)
    .addComponent(textArea1, javax.swing.GroupLayout.PREFERRED_SIZE, 326,
javax.swing.GroupLayout.PREFERRED_SIZE)
    .addContainerGap())
  );
  pack();
}// </editor-fold>//GEN-END:initComponents
```

APPENDIX G

```
private void button3ActionPerformed(java.awt.event.ActionEvent evt) {//GEN-
FIRST:event_button3ActionPerformed
  ArrayList list = new ArrayList();
  Image image = null;
  BufferedImage bImage = null;
  InputStream leafIS = new BufferedInputStream(null);
  FileWriter fstream = null;
  BufferedWriter bwOut = null;

  if(GV.getPathChosen()) {
    System.out.println("in button3Action: got path chosen true");
    System.out.println("  getInFilePath: " + GV.getInFilePath());
    System.out.println("  getInFileName: " + GV.getInFileName());
    File infile = new File(GV.getInFilePath());
    if (infile.exists() & infile.isDirectory()) {
      System.out.println(" tested for file.exists and isDirectory true");
      //Build a list of jpg files in this directory to run though
      String files;
      File[] listOfFiles = infile.listFiles();
      for (int i = 0; i < listOfFiles.length; i++) {
        if (listOfFiles[i].isFile()) {
          files = listOfFiles[i].getName();
          if (files.endsWith(".jpg") || files.endsWith(".JPG")) {
            Gui.updateLog(files);
            list.add(files);
          }
        }
      }
    }
  }
  if(GV.getFileChosen()){
    System.out.println("in button3Action: got file chosen true");
    System.out.println("  getInFilePath: " + GV.getInFilePath());
    System.out.println("  getInFileName: " + GV.getInFileName());
    System.out.println("  getInAbsolutePath: " +
    GV.getInAbsolutePath());
    File infile = new File(GV.getInAbsolutePath());

    //Check to see if this is just a single file
    if (infile.isFile() & (infile.getName().endsWith(".jpg") ||
       infile.getName().endsWith(".JPG"))) {
      //Make a list with the single file
      list.add(infile.getName());
      //Extract the file path
      //int sep =
GV.getInFilePath().lastIndexOf(System.getProperty("file.separator"));
      //GV.setGV("inFilePath", (sep > 0) ? GV.getInFilePath().substring(0,
sep) : GV.getInFilePath());
    }
  }
  if (list.size() < 1) {
    textArea1.append("No jpg image files found.\n");
  } else {
    //Let's open up an output file if one is set
```

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```
    if (GV.getOutFileName().length() > 1) {
      try {
           fstream = new FileWriter(GV.getOutAbsolutePath());
           bwOut = new BufferedWriter(fstream);
      } catch (Exception ex) {
           Gui.textArea1.append("Exception when opening output file:" + ex);
      }
    }
    //Now cycle through the list of jpg files
    for (int i = 0; i < list.size(); i++) {
      System.out.println("inFilePath:" + GV.getInFilePath() + ", inFileName:
" + (String) list.get(i));
    // try {
           GV.setGV("inFileName", (String)list.get(i));
           //Convert the image to a bitmap file
           GV.setGV("inAbsolutePath", GV.getInFilePath() +
System.getProperty("file.separator") + GV.getInFileName());
           try {
               leafIS = new BufferedInputStream(new
FileInputStream(GV.getInAbsolutePath()));
               bImage = ImageIO.read(leafIS);
           } catch (IOException e) {
             textArea1.append("IOException reading file: " +
GV.getInAbsolutePath() + "\n");
             textArea1.append("Caught exception in Gui.java" + e.getMessage()
+ "\n");
           } finally {
               try {
                   leafIS.close();
               } catch (IOException ex) {
                   textArea1.append("IOException when closing InputStream
reading image\n");
                   //Logger.getLogger(Gui.class.getName()).log(Level.SEVERE,
null, ex);
               }
            }
            //write the BMP formated image
            try {
                GV.setGV("bmpFileName", GV.getInAbsolutePath());
                int index = GV.getBmpFileName().lastIndexOf('.');
                GV.setGV("bmpFileName", GV.getBmpFileName().substring(0,
index));
                GV.setGV("bmpFileName",
GV.getBmpFileName().concat("_tmp.bmp"));
                GV.setGV("bmpFile",  new File(GV.getBmpFileName()));
                ImageIO.write(bImage, GV.getOutFileFormat(),
GV.getBmpFile());
            } catch (IOException ex) {
                textArea1.append("IOException writing BMP file: " +
GV.getBmpFileName() + "\n");
                textArea1.append("Caught exception in main" + ex.getMessage()
+ "\n");
            }
            //Don't need the bufferedImage any more
```

```
            bImage.flush();
            System.gc();

            calcArea.calcArea(GV.getBmpFileName());
            String tmpArea = Double.toString(GV.getArea());
            int index = tmpArea.lastIndexOf(".");
            int size = tmpArea.substring(index).length();
            size = (size > 3) ? 4 : size;
            tmpArea = tmpArea.substring(0, index + size);
            textArea1.append("File: " + GV.getInFileName() + ",\tArea: " +
tmpArea + "\n");
            if (fstream != null) {
              try {
                   bwOut.append(GV.getInFileName() + "," + tmpArea + "\r\n");
              } catch (IOException e) {//Catch exception if any
                   Gui.textArea1.append("Error writing to output file: " +
e.getMessage());
              }
            }
            //Remove the bmp file since we are done
            GV.getBmpFile().delete();
            //Do some system cleanup
            System.gc();
          }
        }
        if (bwOut != null) {
            try {
                //Close the output file
                bwOut.close();
            } catch (IOException ex) {
                Gui.textArea1.append("Error closing output file: " +
ex.getMessage());
            }
        }
      }//GEN-LAST:event_button3ActionPerformed

private void jRadioButton2ActionPerformed(java.awt.event.ActionEvent evt)
{//GEN-FIRST:event_jRadioButton2ActionPerformed
    // TODO add your handling code here:
    // Set the units to CM
    GV.setGV("units", "cm");
}//GEN-LAST:event_jRadioButton2ActionPerformed

private void textField2ActionPerformed(java.awt.event.ActionEvent evt)
{//GEN-FIRST:event_textField2ActionPerformed
    GV.setGV("outAbsolutePath",  textField2.getText());
    int sep =
GV.getOutAbsolutePath().lastIndexOf(System.getProperty("file.separator"));
    GV.setGV("outFileName", (sep > 0) ? GV.getOutAbsolutePath().substring(sep
+ 1) : GV.getOutAbsolutePath());
    GV.setGV("outFilePath", (sep > 0) ? GV.getOutAbsolutePath().substring(0,
sep) : GV.getOutAbsolutePath());
}//GEN-LAST:event_textField2ActionPerformed
```

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```
private void textField2TextValueChanged(java.awt.event.TextEvent evt) {//GEN-
FIRST:event_textField2TextValueChanged
    GV.setGV("outAbsolutePath", textField2.getText());
    int sep =
GV.getOutAbsolutePath().lastIndexOf(System.getProperty("file.separator"));
    GV.setGV("outFileName", (sep > 0) ? GV.getOutAbsolutePath().substring(sep
+ 1) : GV.getOutAbsolutePath());
    GV.setGV("outFilePath", (sep > 0) ? GV.getOutAbsolutePath().substring(0,
sep) : GV.getOutAbsolutePath());
}//GEN-LAST:event_textField2TextValueChanged

private void button1ActionPerformed(java.awt.event.ActionEvent evt) {//GEN-
FIRST:event_button1ActionPerformed
    //Open a file chooser for the input file
    JFileChooser chooser = new JFileChooser("");
    chooser.setCurrentDirectory(GV.getLastDir());
    chooser.setFileSelectionMode(JFileChooser.FILES_AND_DIRECTORIES);
    int returnVal = chooser.showOpenDialog((java.awt.Component) null);
    if (returnVal == JFileChooser.APPROVE_OPTION) {
      File inFile = chooser.getSelectedFile();
      GV.setGV("lastDir", chooser.getCurrentDirectory());
      //GV.setGV("inFilePath", chooser.getCurrentDirectory());
      //GV.setGV("inFilePath", inFile.getPath());
      if(inFile.isFile()){
        System.out.println("in button1Action: tested for a file");
        GV.setGV("inFileName", inFile.getName());
        int sep =
inFile.getPath().lastIndexOf(System.getProperty("file.separator"));
        GV.setGV("inFilePath", inFile.getPath().substring(0, sep));
        GV.setGV("inAbsolutePath", GV.getInFilePath() +
        System.getProperty("file.separator") +
        GV.getInFileName());
        GV.setGV("fileChosen", "true");
        Gui.updateLog("inFileName: " + GV.getInFileName());
        GV.setGV("pathChosen", "false");
      }
      if(inFile.isDirectory()){
        System.out.println("in button1Action: tested for a directory");
        GV.setGV("inFileName", "");
        GV.setGV("inFilePath", inFile.getPath());
        GV.setGV("inAbsolutePath", GV.getInFilePath());
        GV.setGV("pathChosen", "true");
        Gui.updateLog("inFilePath: " + GV.getInFilePath());
        GV.setGV("fileChosen", "false");
      }
      textField1.setText(GV.getInAbsolutePath());
    }
  }//GEN-LAST:event_button1ActionPerformed

private void button2ActionPerformed(java.awt.event.ActionEvent evt) {//GEN-
FIRST:event_button2ActionPerformed
    // TODO add your handling code here:
    //Open a file chooser for the input file
```

```
    JFileChooser chooser = new JFileChooser("");
    chooser.setFileSelectionMode(JFileChooser.FILES_ONLY);
    int returnVal = chooser.showOpenDialog((java.awt.Component) null);
    if (returnVal == chooser.APPROVE_OPTION) {
      java.io.File outFile = chooser.getSelectedFile();
      GV.setGV("outFileName", outFile.getName());
      GV.setGV("outFilePath", outFile.getPath());
      textField2.setText(GV.getOutFilePath());
    }
}//GEN-LAST:event_button2ActionPerformed

private void textField1TextValueChanged(java.awt.event.TextEvent evt) {//GEN-
FIRST:event_textField1TextValueChanged
    // TODO add your handling code here:
}//GEN-LAST:event_textField1TextValueChanged

private void jRadioButton1ActionPerformed(java.awt.event.ActionEvent evt)
{//GEN-FIRST:event_jRadioButton1ActionPerformed
    // TODO add your handling code here:
    // Units set to square inches
    GV.setGV("units", "in");
}//GEN-LAST:event_jRadioButton1ActionPerformed

private void jSpinner4StateChanged(javax.swing.event.ChangeEvent evt) {//GEN-
FIRST:event_jSpinner4StateChanged
    // Value change in DPI
    GV.setGV("dpi", (Integer)jSpinner4.getValue());
}//GEN-LAST:event_jSpinner4StateChanged
private void jRadioButton3ActionPerformed(java.awt.event.ActionEvent evt)
{//GEN-FIRST:event_jRadioButton3ActionPerformed
    GV.setGV("verbose", "false");
}//GEN-LAST:event_jRadioButton3ActionPerformed

private void jRadioButton4ActionPerformed(java.awt.event.ActionEvent evt)
{//GEN-FIRST:event_jRadioButton4ActionPerformed
    GV.setGV("verbose", "true");
}//GEN-LAST:event_jRadioButton4ActionPerformed

/**
 * @param args the command line arguments
 */
// Variables declaration - do not modify//GEN-BEGIN:variables
private java.awt.Button button1;
private java.awt.Button button2;
private java.awt.Button button3;
private javax.swing.ButtonGroup buttonGroup1;
private javax.swing.ButtonGroup buttonGroup2;
private javax.swing.JLabel jLabel2;
public static javax.swing.JRadioButton jRadioButton1;
public static javax.swing.JRadioButton jRadioButton2;
public static javax.swing.JRadioButton jRadioButton3;
public static javax.swing.JRadioButton jRadioButton4;
private javax.swing.JSpinner jSpinner1;
private javax.swing.JSpinner jSpinner2;
```

```
private javax.swing.JSpinner jSpinner3;
private javax.swing.JSpinner jSpinner4;
private java.awt.Label label1;
private java.awt.Label label2;
private java.awt.Label label3;
private java.awt.Label label4;
private java.awt.Label label6;
private java.awt.Label label7;
private java.awt.Label label8;
public static java.awt.TextArea textArea1;
private java.awt.TextField textField1;
private java.awt.TextField textField2;
// End of variables declaration//GEN-END:variable
}


import java.io.File;

/**
 * GV.java
 * A place to put some global stuff
 * @author FRED SMITH
 */
public class GV {
  private static String inFileName = "";
  private static String inFilePath = "";
  private static String inAbsolutePath = "";
  private static String outFileName = "";
  private static String outFilePath = "";
  private static String outAbsolutePath = "";
  private static String bmpFileName = "";
  private static String fFormat = "bmp";
  private static String units = "cm";
  private static Integer redBgVal = 215;
  private static Integer blueBgVal = 215;
  private static Integer greenBgVal = 215;
  private static Integer dpi = 300;
  private static Integer minLeafPixels = 150;
  private static Integer minLeftBorder = 100;
  private static Integer minRightBorder = 100;
  private static Integer minTopBorder = 100;
  private static Integer minBottomBorder = 100;
  private static Boolean verbose = false;
  private static Boolean debug = false;
  private static Boolean useGrayScale = false;
  private static Boolean fileChosen = false;
  private static Boolean pathChosen = false;
  private static File lastDir = null;
  private static File bmpFile = null;
  private static double area = 0;
  private static double nonSymmetryCorrection = 1.0;
  private static final String rev = "1.0";
  private static final int SCALE_AREA_AVERAGING = 16;
  private static final int SCALE_DEFAULT = 1;
```

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```
  private static final int SCALE_FAST = 2;
  private static final int SCALE_REPLICATE = 8;
  private static final int SCALE_SMOOTH = 4;
  public static void setGV(String varName, String varValue){

  if(varName.contains("inFileName")) inFileName = varValue;
  else if (varName.contains("inFilePath")) inFilePath = varValue;
  else if (varName.contains("inFilePath")) inFilePath = varValue;
  else if (varName.contains("inAbsolutePath")) inAbsolutePath = varValue;
  else if (varName.contains("outFileName")) outFileName = varValue;
  else if (varName.contains("outFilePath")) outFilePath = varValue;
  else if (varName.contains("outAbsolutePath")) outAbsolutePath = varValue;
  else if (varName.contains("units")) units = varValue;
  else if (varName.contains("bmpFileName")) bmpFileName = varValue;
  else if (varName.contains("fFormat")) fFormat = varValue;
  else if(varName.contains("verbose")) verbose =
varValue.equalsIgnoreCase("true");
  else if (varName.contains("debug")) debug =
varValue.equalsIgnoreCase("true");
  else if(varName.contains("fileChosen")) fileChosen =
varValue.equalsIgnoreCase("true");
  else if (varName.contains("pathChosen")) pathChosen =
varValue.equalsIgnoreCase("true");
  else if (varName.contains("useGrayScale")) useGrayScale =
varValue.equalsIgnoreCase("true");
}

public static void setGV(String varName, Integer varValue){
  if(varName.contains("redBgVal")) redBgVal = varValue;
  else if (varName.contains("blueBgVal")) blueBgVal = varValue;
  else if (varName.contains("greenBgVal")) greenBgVal = varValue;
  else if (varName.contains("dpi")) dpi = varValue;
  else if (varName.contains("minLeafPixels")) minLeafPixels = varValue;
  else if (varName.contains("minLeftBorder")) minLeftBorder = varValue;
  else if (varName.contains("minRightBorder")) minRightBorder = varValue;
  else if (varName.contains("minTopBorder")) minTopBorder = varValue;
  else if (varName.contains("minBottomBorder")) minBottomBorder = varValue;
}
public static void setGV(String varName, File varValue){
  if(varName.contains("lastDir")) lastDir = varValue;
    else if (varName.contains("bmpFile")) bmpFile = varValue;
}
public static void setGV(String varName, Double varValue){
  if(varName.contains("area"))  area = varValue;
  else if(varName.contains("nonSymmetryCorrection"))
    nonSymmetryCorrection = varValue;
}
public static String getRev() {return rev;}
public static String getInFileName(){return inFileName;}
public static String getInFilePath(){return inFilePath;}
public static String getInAbsolutePath(){return inAbsolutePath;}
public static String getOutFileName(){return outFileName;}
public static String getOutFilePath(){return outFilePath;}
public static String getOutAbsolutePath(){return outAbsolutePath;}
```

```
public static String getUnits(){return units;}
public static String getBmpFileName(){return bmpFileName;}
public static String getOutFileFormat(){return fFormat;}
public static Integer getScaleAreaAvg() {return SCALE_AREA_AVERAGING;}
public static Integer getScaleDefault() {return SCALE_DEFAULT;}
public static Integer getScaleFast() {return SCALE_FAST;}
public static Integer getScaleReplicate() {return SCALE_REPLICATE;}
public static Integer getScaleSmooth() {return SCALE_SMOOTH;}
public static Integer getRedBgVal(){return redBgVal;}
public static Integer getBlueBgVal(){return blueBgVal;}
public static Integer getGreenBgVal(){return greenBgVal;}
public static Integer getDpi(){return dpi;}
public static Integer getMinLeafPixels(){return minLeafPixels;}
public static Integer getMinLeftBorder(){return minLeftBorder;}
public static Integer getMinRightBorder(){return minRightBorder;}
public static Integer getMinTopBorder(){return minTopBorder;}
public static Integer getMinBottomBorder(){return minBottomBorder;}
public static Boolean getVerbose(){return verbose;}
public static Boolean getDebug(){return debug;}
public static Boolean getUseGrayScale(){return useGrayScale;}
public static Boolean getFileChosen(){return fileChosen;}
public static Boolean getPathChosen(){return pathChosen;}
public static File getLastDir(){return lastDir;}
public static File getBmpFile(){return bmpFile;}
public static double getArea(){return area;}
public static double getNonSymmetryCorrection(){return
nonSymmetryCorrection;}
}


import java.io.*;

/**
 * calcArea.java
 * Calculate the area of a scan by counting non-white pixels
 * @author FRED SMITH
 */
public class calcArea {
  public static class Leaf {
    Integer startRow;
    Integer endRow;
    Integer startColumn;
    Integer endColumn;
    Integer leafNumber;
    double pixelCount;

    Leaf(Integer ID) {
        this.startRow = 0;
        this.endRow = 0;
        this.startColumn = 0;
        this.endColumn = 0;
        this.pixelCount = 0;
        this.leafNumber = ID;
    }
```

```
}

  public static void calcArea(String imageFile) {
    Integer maxAreas = 200;
    Leaf[] leaves = new Leaf[maxAreas];
    Integer redBg = GV.getRedBgVal();
    Integer greenBg = GV.getGreenBgVal();
    Integer blueBg = GV.getBlueBgVal();
    Integer dpi = GV.getDpi();
    double pixelCount = 0;
    double area = 0;
    Integer leafCount = 0;
    Integer rowMargin = 2;
    Integer colMargin = 10;
    boolean leafFound = false;
    Gui.updateLog("loading:" + imageFile);
    try {
        FileInputStream fs = new FileInputStream(imageFile);
        int bflen = 14;  // 14 byte BITMAPFILEHEADER
        byte bf[] = new byte[bflen];
        fs.read(bf, 0, bflen);
        int bilen = 40; // 40-byte BITMAPINFOHEADER
        byte bi[] = new byte[bilen];
        fs.read(bi, 0, bilen);
        // Interperet data.
        int nsize = (((int) bf[5] & 0xff) << 24) |
                    (((int) bf[4] & 0xff) << 16) |
                    (((int) bf[3] & 0xff) << 8) |
                      (int) bf[2] & 0xff;
        Gui.updateLog("File type is :" + (char) bf[0] + (char) bf[1]);
        Gui.updateLog("Size of file is :" + nsize);

        int nbisize = (((int) bi[3] & 0xff) << 24) |
                      (((int) bi[2] & 0xff) << 16) |
                      (((int) bi[1] & 0xff) << 8) |
                        (int) bi[0] & 0xff;
        Gui.updateLog("Size of bitmapinfoheader is :" + nbisize);

        int nwidth = (((int) bi[7] & 0xff) << 24) |
                     (((int) bi[6] & 0xff) << 16) |
                     (((int) bi[5] & 0xff) << 8) |
                       (int) bi[4] & 0xff;
        Gui.updateLog("Width is :" + nwidth);

        int nheight = (((int) bi[11] & 0xff) << 24) |
                      (((int) bi[10] & 0xff) << 16) |
                       (((int) bi[9] & 0xff) << 8) |
                         (int) bi[8] & 0xff;
        Gui.updateLog("Height is :" + nheight);

        int nplanes = (((int) bi[13] & 0xff) << 8) |
                        (int) bi[12] & 0xff;
        Gui.updateLog("Planes is :" + nplanes);
```

```
        int nbitcount = (((int) bi[15] & 0xff) << 8) |
                          (int) bi[14] & 0xff;
        Gui.updateLog("BitCount is :" + nbitcount);

        // Look for non-zero values to indicate compression
        int ncompression = (((int) bi[19]) << 24) |
                           (((int) bi[18]) << 16) |
                           (((int) bi[17]) << 8) |
                             (int) bi[16];
        Gui.updateLog("Compression is :" + ncompression);

        int nsizeimage = (((int) bi[23] & 0xff) << 24) |
                         (((int) bi[22] & 0xff) << 16) |
                         (((int) bi[21] & 0xff) << 8) |
                           (int) bi[20] & 0xff;
        Gui.updateLog("SizeImage is :" + nsizeimage);

        int nxpm = (((int) bi[27] & 0xff) << 24) |
                   (((int) bi[26] & 0xff) << 16) |
                   (((int) bi[25] & 0xff) << 8) |
                     (int) bi[24] & 0xff;
        Gui.updateLog("X-Pixels per meter is :" + nxpm);

        int nypm = (((int) bi[31] & 0xff) << 24) |
                   (((int) bi[30] & 0xff) << 16) |
                   (((int) bi[29] & 0xff) << 8) |
                     (int) bi[28] & 0xff;
        Gui.updateLog("Y-Pixels per meter is :" + nypm);
        int nclrused = (((int) bi[35] & 0xff) << 24) |
                       (((int) bi[34] & 0xff) << 16) |
                       (((int) bi[33] & 0xff) << 8) |
                         (int) bi[32] & 0xff;
        Gui.updateLog("Colors used are :" + nclrused);

        int nclrimp = (((int) bi[39] & 0xff) << 24) |
                      (((int) bi[38] & 0xff) << 16) |
                      (((int) bi[37] & 0xff) << 8) |
                        (int) bi[36] & 0xff;
        Gui.updateLog("Colors important are :" + nclrimp);

        if (nbitcount == 24) {   // No Palatte data for 24-bit format but
scan lines are
          // padded out to even 4-byte boundaries.
          int npad = (nsizeimage / nheight) - (nwidth * 3);
          //The images won't fit in memory so read a line at a time
          byte brgb[] = new byte[(nwidth * 3) + npad];
          int nindex = 0;
          int nrgb = 0;
          int ndata[] = new int[nwidth];
          float grayScale = 0;
          boolean pixelFound = false;

          if (GV.getUseGrayScale()) {
            Gui.updateLog("using grayscale values");
```

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```
            } else {
              Gui.updateLog("using RGB values");
            }
            //Read past the bottom border
            for (int i = 0; i < GV.getMinBottomBorder(); i++) {
              fs.read(brgb, 0, (nwidth * 3) + npad);
            }
            //Read the bitmap pixels inside the minBorder area
            for (int row = GV.getMinBottomBorder(); row < nheight -
GV.getMinTopBorder(); row++) {
              fs.read(brgb, 0, (nwidth * 3) + npad);
              //Set our starting point inside the left border
              nindex = GV.getMinLeftBorder() * 3;
              for (int col = GV.getMinLeftBorder(); col < nwidth -
GV.getMinRightBorder(); col++) {
                if (GV.getUseGrayScale()) {
                  //Convert to grayscale...values used are from
                  //
http://en.wikipedia.org/wiki/Grayscale#Converting_to_grayscale
                  grayScale = (float)(((int) (brgb[nindex + 2] & 0xff)) * 0.3
+
                             ((int) (brgb[nindex + 1] & 0xff)) * 0.59 +
                             ((int) (brgb[nindex + 0] & 0xff)) * 0.11);
                  //use the redBg for background limit when in grayscale mode
                  if (grayScale < redBg) {
                    pixelFound = true;
                  } else {
                    pixelFound = false;
                  }
                } else {
                  //Use RGB values for luminance determination
                  if (((int) (brgb[nindex + 2] & 0xff) < redBg) &
                      ((int) (brgb[nindex + 1] & 0xff) < greenBg) &
                      ((int) (brgb[nindex + 0] & 0xff) < blueBg)) {
                       pixelFound = true;
                  } else {
                      pixelFound = false;
                  }
                }
                if (pixelFound) {
                  // Is this for an existing leaf?
                  if (leafCount > 0) {
                     //Set up for do-while
                     leafFound = false;
                     int cnt = 0;
                     do {
                        int tmp_row_max = leaves[cnt].endRow + rowMargin;
                        int tmp_col_min = leaves[cnt].startColumn -
colMargin;
                        int tmp_col_max = leaves[cnt].endColumn + colMargin;
                        //Check to see if we are within the bounds of
leaf[cnt]
                        if ((row < tmp_row_max) & (col > tmp_col_min) & (col
< tmp_col_max)) {
```

```
                          //Found a pixel for an existing leaf
                          leaves[cnt].pixelCount++;
                          Gui.debugLog("R,G,B Color at line:" + row +
                                       ", pixel:" + col + " is:" +
                                    ((int) (brgb[nindex + 2]) & 0xff) +
                                        ", " + ((int) (brgb[nindex + 1]) &
0xff) +
                                        ", " + ((int) (brgb[nindex + 0]) &
0xff));
                          Gui.debugLog("PixelCnt[leaf]: " +
leaves[cnt].pixelCount);
                          leaves[cnt].endRow = (row > leaves[cnt].endRow) ?
row : leaves[cnt].endRow;
                          leaves[cnt].startColumn = (col <
leaves[cnt].startColumn) ? col : leaves[cnt].startColumn;
                          leaves[cnt].endColumn = (col >
leaves[cnt].endColumn) ? col : leaves[cnt].endColumn;
                          leafFound = true;
                        } else {
                          //Not in bounds of the current leaf,
                          // cycle through all leaves to see where to add
this pixel
                          cnt++;
                        }
                      } while ((leafFound == false) & (cnt < leafCount));
                        if (leafFound == false) {
                          //We didn't find a match with an existing leaf,
must be a new one
                          if (leafCount < maxAreas) {
                             Gui.updateLog("Starting with leaf #" +
leafCount);
                             leaves[leafCount] = new Leaf(leafCount);
                             leaves[leafCount].startRow = row;
                             leaves[leafCount].endRow = row;
                             leaves[leafCount].startColumn = col;
                             leaves[leafCount].endColumn = col;
                             leaves[leafCount].pixelCount++;
                             leaves[leafCount].leafNumber = leafCount;
                             leafCount++;
                           }
                         }
                       } else {
                         //This is the first leaf
                         Gui.updateLog("Starting with leaf #" + leafCount);
                         leaves[leafCount] = new Leaf(leafCount);
                         leaves[leafCount].startRow = row;
                         leaves[leafCount].endRow = row;
                         leaves[leafCount].startColumn = col;
                         leaves[leafCount].endColumn = col;
                         leaves[leafCount].pixelCount++;
                         leaves[leafCount].leafNumber = 0;
                         leafCount++;
                         //since this is the first leaf
                       }
```

```
                        //This generates way too much data, but leaving it in
just in case
                        //Gui.debugLog("R,G,B Color at line:" + row +
                        //    ", pixel:" + col + " is:" +
                        //    ((int) (brgb[nindex + 2]) & 0xff) +
                        //    ", " + ((int) (brgb[nindex + 1]) & 0xff) +
                        //    ", " + ((int) (brgb[nindex + 0]) & 0xff));
                      }
                      nindex += 3;
                    }
                }

                for (int z = 0; z < leafCount; z++) {
                    Gui.updateLog("Leaf[" + z + "] pixelCont = " +
leaves[z].pixelCount);
                    Gui.updateLog("\tRowMin:" + leaves[z].startRow +
                                   " RowMax:" + leaves[z].endRow +
                                   " ColMin:" + leaves[z].startColumn +
                                   " ColMax:" + leaves[z].endColumn);

                    if (leaves[z].pixelCount > GV.getMinLeafPixels()) {
                        pixelCount += leaves[z].pixelCount;
                    }
                }
                //In case the scanner has non-symmetrical pixels

                pixelCount = (int) (pixelCount *
GV.getNonSymmetryCorrection());
                Gui.updateLog("Total non-background pixel count is: " +
pixelCount);

                area = ((pixelCount / dpi) / dpi);
                if (GV.getUnits().equalsIgnoreCase("cm")) {
                    area = area * 2.54 * 2.54;
                }
                Gui.updateLog("The leaf area in " + GV.getUnits() + " is: " +
area + "\n");
                Gui.updateLog(" the number of leaves found is:" + leafCount);
            }
            fs.close();
        } catch (Exception e) {
            Gui.textArea1.append("Caught exception in loadbitmap! " +
e.getMessage() + "\n");
        } finally {
            System.gc();
        }
        GV.setGV("area", area);
    }
}


import java.io.*;
import java.util.logging.Level;
import java.util.logging.Logger;
```

APPENDIX G

```
/**
 * readCfg.java
 * @author FRED SMITH
 */
public class ReadCfg {
  static void ReadCfg() {
    String cfgLine = "";
    FileInputStream fstream = null;
    try {
      fstream = new FileInputStream("C:\\leafarea.cfg");
      DataInputStream in = new DataInputStream(fstream);
      BufferedReader br = new BufferedReader(new InputStreamReader(in));
      String strLine;
      Integer strSize = 0;
      //Read File Line By Line
      while ((strLine = br.readLine()) != null) {
        //remove leading whitespace
        cfgLine = strLine.replaceAll("\\s+", "");
        cfgLine = cfgLine.replaceAll(";", "");
        if (cfgLine.substring(0, 1).equals("#")) {
          //this is a comment line
          continue;
        } else //Let's look for cfg vars we care about
          if (cfgLine.contains("minLeftBorder")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("minLeftBorder",
Integer.parseInt(cfgLine.substring(index + 1)));
            continue;
          } else if (cfgLine.contains("minRightBorder")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("minRightBorder",
Integer.parseInt(cfgLine.substring(index + 1)));
            continue;
          } else if (cfgLine.contains("minTopBorder")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("minTopBorder", Integer.parseInt(cfgLine.substring(index
+ 1)));
            continue;
          } else if (cfgLine.contains("minBottomBorder")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("minBottomBorder",
Integer.parseInt(cfgLine.substring(index + 1)));
            continue;
          } else if (cfgLine.contains("redBgVal")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("redBgVal", Integer.parseInt(cfgLine.substring(index +
1)));
            continue;
          } else if (cfgLine.contains("blueBgVal")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("blueBgVal", Integer.parseInt(cfgLine.substring(index +
1)));
```

```
            continue;
          } else if (cfgLine.contains("greenBgVal")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("greenBgVal", Integer.parseInt(cfgLine.substring(index +
1)));
            continue;
          } else if (cfgLine.contains("dpi")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("dpi", Integer.parseInt(cfgLine.substring(index + 1)));
            continue;
          } else if (cfgLine.contains("minLeafPixels")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("minLeafPixels",
Integer.parseInt(cfgLine.substring(index + 1)));
            continue;
          } else if (cfgLine.contains("debug")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("debug", cfgLine.substring(index + 1));
            continue;
          } else if (cfgLine.contains("verbose")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("verbose", cfgLine.substring(index + 1));
            continue;
          } else if (cfgLine.contains("units")) {
            int index = cfgLine.lastIndexOf("=");

            GV.setGV("units", cfgLine.substring(index + 1));
            continue;
          } else if (cfgLine.contains("useGrayScale")) {
            int index = cfgLine.lastIndexOf("=");
            GV.setGV("useGrayScale", cfgLine.substring(index + 1));
          } else if (cfgLine.contains("nonSymmetryCorrection")) {
            int index = cfgLine.lastIndexOf("=");
             try {
                Double d = Double.valueOf(cfgLine.substring(index +
1)).doubleValue();
                GV.setGV("nonSymmetryCorrection", d);
             } catch (NumberFormatException nfe) {
                Logger.getLogger(ReadCfg.class.getName()).log(Level.SEVERE,
null, nfe);
             }
          }
        }
      } catch (IOException ex) {
      Logger.getLogger(ReadCfg.class.getName()).log(Level.SEVERE, null, ex);
    } finally {
      try {
         fstream.close();
      } catch (IOException ex) {
         Logger.getLogger(ReadCfg.class.getName()).log(Level.SEVERE, null,
ex);
      }
    }
  }
}
```