Responses of Four Common Shrub Species to Different Irrigation Regimes[1]

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Abstract

The impact of different irrigation regimes to *Cornus sericea* L. 'Isanti', *Hydrangea arborescens* L. 'Annabelle,' *Physocarpus opulifolius* (L.) Maxim. 'Monlo', and *Salix purpurea* L. 'Nana' were assessed. Irrigation treatments were based on percentages of evapotranspiration (ET_o). *Poa pratensis* L. was used as a control. The shrubs were tested by being field grown (FG) and in a lysimeter using a pot in pot system (LYS). The FG shrubs had four treatments (0, 25, 50, or 100%) and the LYS shrubs had three treatments (25, 50, or 100%). Data collection included height/width, predawn leaf water potential, leaf and shoot fresh/dry weights, turf IR temperatures, soil moisture, and osmolality. As watering amounts increased for the FG *Cornus*, *Physocarpus*, and *Salix*, various characteristics (water potential, size, osmolality) were also positively affected. However, these three species in the 0% treatment appeared acceptable for landscape use as well. The water potential data suggest that FG *Hydrangea* needs more than 100% to improve growth and performance. The LYS *Cornus* and LYS *Hydrangea* adjusted their growth habits based on water availability. The LYS shrubs used water on a daily basis faster as irrigation treatments increased. Increased water use affected LYS shrub growth and more water resulted in larger shrubs.

Index words: plant water use, water stress, evapotranspiration, ET, lysimeter, water potential, osmolality.

Species used in this study: redosier dogwood (*Cornus sericea* L. 'Isanti'); smooth hydrangea (*Hydrangea arborescens* L. 'Annabelle'); Diablo® ninebark (*Physocarpus opulifolius* (L.) Maxim. 'Monlo'); Kentucky bluegrass (*Poa pratensis* L.); arctic blue willow (*Salix purpurea* L. 'Nana').

Significance to the Nursery Industry

The results from this experiment indicate how four different shrub species responded to limited irrigation treatments, which aids in determining the relative water use for each of these species. Knowing the water use of shrub species is important in aiding the decision making process for those involved in planning future landscape plantings, as well as those responsible for making cultural changes for current plantings of these shrub species in existing landscapes. Knowing the effects of irrigation treatments when these shrub species are grown in containers will also benefit those involved in container nursery production.

Introduction

Reductions in the amount of water used for the maintenance of residential and commercial landscapes are important for preserving an already strained water supply and will continue to increase in importance as the human population increases. Selection of plant species that require less water is essential for water efficient landscapes. If more water demanding plants are placed in a landscape and water becomes scarce during prolonged periods of below normal precipitation (drought) the plants in the landscape may succumb to a lack of water. This is especially true if municipalities impose restrictions on landscape irrigation during a drought. As a result, plants with lower water requirements should be placed in the landscape not only to reduce irrigation, but to create landscapes that can better tolerate periods of drought.

Shrubs are important components of urban landscapes; however, little is known about the water needs of many of the popular shrub species distributed throughout local wholesale and retail nurseries. The majority of the data that is used to determine which category of water use ornamental plants fall into is opinionative or observational in nature. Little research has been done on ornamental landscape plants, and the water requirements of most landscape plants are not known (7, 16, 22). The main purpose of the research summarized in this paper was to evaluate the responses of four common shrub species when subjected to progressively decreased amounts of irrigation.

Materials and Methods

Four shrub species (*Cornus sericea*, *Hydrangea arborescens*, *Physocarpus opulifolius*, and *Salix purpurea*) and one cool season turfgrass species (*Poa pratensis*) were used in the FG study. The *Poa pratensis* (KBG) was used as the control. The KBG used was a mix containing the varieties Blue Velvet, Moonlight SLT, Rampart, and Orseo. The *Cornus* and *Hydrangea* were also trialed in the LYS study. Both studies were conducted at Colorado State University in Fort Collins, Colorado.

Best Management Practices (5) were practiced whenever possible while transplanting the shrubs. All of the shrubs used in the study arrived in #5 containers with the exception of the *Hydrangea* which arrived in #2 containers. In the FG study, the shrubs were spaced at least 1.83 m (6 ft) away from each other. The plants used for the LYS study were transplanted into larger #15 containers. The backfill used for all shrubs was 80% field soil and 20% Sun Gro Sunshine LC1 mix (Agawam, MA). All shrubs were allowed to establish

[1]Received for publication April 10, 2013; in revised form June 1, 2013. Funding was provided by Colorado Nursery Research & Education Foundation, Colorado Water Institute, Colorado WaterWise Council, Garden Centers of Colorado, and GreenCO Foundation. The plant material was donated by Alameda Wholesale Nursery Inc. (Englewood, CO), Arbor Valley Nursery (Brighton, CO), Fort Collins Wholesale Nursery (Fort Collins, CO), James Nursery Co. (Denver, CO), and Turf Master Sod Farm LLC (Fort Collins, CO).

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during 2008. During the establishment year all plants were irrigated with 100% ET_o.

On July 24, 2009, and May 8, 2010, each shrub (FG and LYS) was fertilized with 118 g (0.26 lbs) of Scotts 15-9-12 Osmocote Pro (Marysville, OH). The fertilizer was placed evenly around each plant. On August 6, 2009, the KBG was fertilized with Hi-Yield Ammonium Sulfate (21-0-0) (Bonham, TX). The KBG was again fertilized with Scotts Turf Builder Lawn Fertilizer (32-0-4) (Marysville, OH) on May 8, 2010. On both occasions the KBG was fertilized at a rate of 453 g (1 lb) of nitrogen per 92.90 m^2 (1000 ft^2) based upon recommended guidelines (12).

All shrubs were watered using drip irrigation. The FG study had four watering treatments based on the evapotranspiration of a short reference crop (ET_o) (0, 25, 50, and 100%) and the LYS study had three treatments (25, 50, and 100%). Treatments were applied during the 2009 and 2010 growing seasons. Five replications of each species were present in each treatment plot. The layout for both studies was a complete randomized design.

During 2009 and 2010 treatments for the shrubs were calculated once a week using the Irrigator's Equation; Equation. 1 (14).

Equation. 1: $$Area \times Depth = Flow\ Rate \times Time$$

Area was the area that was to be watered. Depth was the amount of water lost from the soil due to ET minus any precipitation. Flow Rate was the rate at which water was applied. Time was the amount of time for which the irrigation system was to run. Since Area, Depth, and Flow Rate were all known the equation was rearranged to solve for Time.

During 2009 the value used for Area was the estimated rooting area for the shrubs in both the FG and LYS studies. Unfortunately, it was unforeseen that this number would become insufficient for the LYS shrubs over time as they grew as even the shrubs receiving the 100% ET_o treatment remained wilted after watering events. As a result, watering times were multiplied by a factor of two for the shrubs in the LYS study for the remainder of the 2009 experimental period (August 15, 2009–September 29, 2009) to prevent plant loss.

During 2010, the number used for Area for Eq. 1 for the LYS shrubs 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 (week of May 24, 2010), the estimated rooting radius was used for Area for Eq. 1 because the plants were still initially leafing out. After the first week, the number used for the Area portion was based on estimated total leaf area per plant. Leaf area was estimated for both species of shrubs through collecting leaf samples, measuring each leaf's area, and multiplying the mean individual leaf area by the total estimated leaves present on each shrub. Leaf areas were estimated on June 3, 2010, and July 7, 2010, and the Area in Eq. 1 was modified after each date. Estimated rooting area was still used for Area for Eq. 1 for the FG shrubs during 2010.

The KBG was hand watered using a watering breaker with an attached flow meter. Time did not need to be determined for turf treatments. All that was needed was the volume of water to apply. Equation 2 was used to determine watering amounts for the KBG.

Equation 2: $$Volume = Area \times Depth$$

The Depth was determined by monitoring the ET_o and precipitation on a daily basis. Equation 3 (17) was used to more accurately determine the number to use in Eq. 1 and Eq. 2 for the calculation of Depth. Data collected from Northern Water's weather station number 228 located in central Fort Collins, CO, was used to collect the daily ET_o rates and precipitation amounts (15). This weather station was the nearest station to the site that not only collected all of the necessary data to determine ET_o, but also posted the calculated ET rates on their website on a regular basis. Northern Water calculates reference ET using the ASCE Standardized Reference Evapotranspiration Equation (9).

Equation 3: $$D_i = D_{i-1} + (ET - P_e)_i$$

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

The mean weekly amount of water applied per shrub and KBG plot replicate in each treatment during 2009 and 2010 are represented in Table 1.

Table 1. Mean liters (gallons) of water applied per week for each shrub and turf replicate in each treatment during 2009 and 2010.

			% ET_o applied			
Year		**Treatment period**	**0%**	**25%**	**50%**	**100%**
2009	FG shrubs	May 12–September 29[z]	0 (0)	0.64 (0.17)	1.29 (0.34)	2.61 (0.69)
	FG turf	May 12–September 29	0 (0)	9.05 (2.39)	18.06 (4.77)	36.11 (9.54)
	LYS shrubs	May12–August 14[z]	N/A	0.61 (0.16)	1.17 (0.31)	2.35 (0.62)
	LYS shrubs	August 15–September 29[x]	N/A	1.36 (0.36)	2.76 (0.73)	5.53 (1.46)
2010	FG shrubs	May 17–October 5[z]	0 (0)	2.38 (0.63)	4.66 (1.23)	9.39 (2.48)
	FG turf	May 17–October 5	0 (0)	12.30 (3.25)	24.61 (6.50)	49.21 (13.00)
	LYS shrubs	May 17–May 24[z]	N/A	1.02 (0.27)	2.04 (0.54)	4.13 (1.09)
	LYS shrubs	May 25–July 8[y]	N/A	3.82 (1.01)	7.61 (2.01)	15.26 (4.03)
	LYS shrubs	July 9–October 5[y]	N/A	9.77 (2.58)	19.53 (5.16)	39.10 (10.33)

[z]Watering amounts calculated using estimated rooting area.

[y]Watering amounts calculated using estimated leaf area.

[x]Watering amounts calculated using twice estimated rooting area.

Height and width measurements for each shrub were taken at the beginning and end of the experimental seasons during 2009 and 2010. Beginning heights and widths were measured on June 16 (LYS shrubs) and 17 (FG shrubs) in 2009 and May 28 in 2010. The ending heights and widths were measured on October 20 in 2009 and September 29 in 2010.

A pressure chamber (Model 1000) made by PMS Instrument Company (Albany, OR) was used to monitor the predawn water potential of the shrubs throughout the growing season for both studies. The predawn water potential readings of the FG shrubs in 2009 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 June through September and once in October, for a total of nine data sets.

At the end of the 2009 and 2010 experimental periods, leaf samples (10 leaves per shrub) were collected from each replicate of each shrub species in each treatment and mean leaf fresh weights were determined. Each leaf sample was weighed using an Ohaus Adventurer Pro AV114C scale (Ohaus Corporation, Pine Brook, NJ). The leaves were then placed in a drying oven set at 70C (158F) for at least 72 hours, and reweighed to collect dry weights.

At the end of the 2010 experimental season, each plant was cut to ground level and shoot fresh and dry weights were collected. Since this harvesting method was destructive, these data were only collected once at the end of the experiment. All above ground growth of each shrub was weighed immediately after harvest using an Ohaus Adventurer Pro model AV2101C scale (Ohaus Corporation, Pine Brook, NJ). After all the fresh weights were determined, the samples were placed in a drying oven set at 70C (158F) for at least seven days. The dry weight was measured immediately after removing the samples from the drying oven.

The stress of the KBG was monitored by measuring the surface infrared (IR) temperatures. An Omega OS534 Handheld IR Thermometer (Stamford, CT) was used to collect temperatures in degrees Celsius. The emissivity was set to 0.95. The thermometer was held so that the sensor was parallel to the ground at an approximate height of 55.8 cm (22 in). Measurements were collected within an hour of solar noon.

In 2010, the total dissolved solutes, or the osmolality, of the sap for the FG shrubs were determined (1) using leaves that were collected during predawn once a month during July through September in 2010. The leaves were placed in individually labeled syringes for each replication of each shrub species. The syringes were placed in a freezer set at –14.44C (6F) and remained in the freezer for at least seven days. After removing the syringes, the samples were allowed 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. Ten micro liters of extracted sap were then placed onto a solute-free paper disc, which was then placed in a vapor pressure osmometer (Model Vapro 5520, Wescor, Inc., Logan, UT).

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 in the unit (from sands, loams, and clay loams) was used. As a result, all data collected were relative and were expressed as percent relative water content. Access tubes for the Diviner probe were present in all FG treatment plots. All of the tested FG species (shrubs and turf) in each treatment had an access tube in three of the five replications. Data were collected before and after water treatments every other week.

During the course of the experiment the shrubs in the LYS study went through several dry down periods where the shrubs were water stressed over a period of time and monitored to determine the effects. The shrubs in the LYS study went through 10 dry down periods (5 during 2009 and 5 during 2010). After the irrigation treatments were applied at the beginning of each dry down period, the shrubs in all three treatments (25, 50 and 100% ET_o) were not irrigated until after the dry down had concluded. Dry downs were concluded when the predawn water potential readings fell in the range of –2.0 to –2.5 MPa. During each day of a dry down period (including the day of watering) all of the pots were weighed. The weight loss from the previous day was used to determine daily water use. 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 predawn leaf water potential of each LYS shrub was also measured during each dry down to monitor the increasing water stress levels day to day as water became more limited in the pots in each treatment.

Data analysis was conducted using SAS/STAT® with SAS® 9.2 (SAS Institute Inc., Cary, NC). 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 from 2009 to 2010 had some variations. Table 2 shows the mean high and low temperatures, total precipitation, and cumulative reference evapotranspiration (ET_o) rates during the 2009 and 2010 experimental periods. When comparing the weather for each experimental period over the two years, 2009 had cooler temperatures, lower cumulative ET_o rates, and more precipitation. Additionally, on June 7, 2009, hail up to 2 cm (0.79 in) in diameter fell uniformly in the research plots. All test plants incurred hail damage and data collection was delayed until after the plants had releafed. The damage had no effect on the overall outcome of the experiment due to the damage being uniform.

Average IR temperatures of the KBG for each of the four treatments decreased as the irrigation amounts increased during the 2009 and 2010 experimental seasons. The KBG receiving 100% of ET_o generally had the lowest temperature. This lower temperature indicated that the turf in the 100% ET_o treatment plot was the least stressed of the four treatments

Table 2. Weather data (May 1–September 30) in 2009 and 2010 (15).

	2009	2010
Mean high temp in C (F)	25.62 (78.12)	27.14 (80.86)
Mean low temp in C (F)	9.46 (49.03)	9.82 (49.67)
Precipitation in cm (in)	26.92 (10.60)	15.80 (6.22)
Total ET_o in cm (in)	64.69 (25.47)	69.44 (27.34)

because lower canopy temperatures equate to lower water stress (11). Since irrigation treatments were applied only once a week, watering events were infrequent and deep for the 100% ET_o treatment. This watering technique promoted root growth with the turf which aids in better health and drought tolerance (3, 6). The turf in the 25 and 50% ET_o treatment plots resulted in no significant differences, as indicated by similar IR temperatures during both years. The KBG in the 0% ET_o treatment plot had the highest temperatures.

Regardless of treatment, survival rates for all shrub species were excellent. With the exception of one FG *Hydrangea* replication in the 0% ET_o treatment, all shrubs in all treatments in both the FG and LYS studies had a 100% survival rate at the conclusion of 2010. Although the FG *Hydrangea* in the 0% ET_o treatment had a high survival rate, these shrubs were not visually acceptable for use as landscape plants. As a result, all these shrub species would most likely survive (but not necessarily thrive) during periods when water is extremely limited after being planted in the ground for 2 years.

Little differences occurred among treatments in regards to the height of the FG *Cornus*, however, treatments did affect the width. By the end of the 2009 season, the shrubs in the 100% ET_o treatment were wider than those receiving 0% ET_o. This effect continued through the end of 2010, so that the shrubs receiving 100% ET_o were wider than those that received 0, 25, and 50% ET_o (Fig. 1).

By the end of the 2010 growing season, the FG *Hydrangea* in the 100% ET_o were significantly larger in height and width (Fig. 1) than the other three treatments. FG *Hydrangea* in all of the watered treatments (25, 50, and 100% ET_o) were wider than those receiving 0% ET_o. FG *Hydrangea* in the 100% ET_o treatment exhibited significantly more growth by the end of 2010 when compared to the beginning of the season. As a result, irrigation amounts as little as 25% ET_o appears to increase the overall size of *Hydrangea arborescens* 'Annabelle', and those given 100% ET_o will be larger compared to those provided with lower amounts of irrigation.

The *Cornus* and *Hydrangea* in the LYS study showed no differences during 2009, but 2010 did have differences. Both species in the LYS 50 and 100% ET_o treatments were taller than those in the 25% ET_o treatment at the beginning and end of the season (Fig. 2).

Similar to the 2010 height, the 2010 widths of the LYS *Hydrangea* in the 50 and 100% ET_o treatments were wider than those in the 25% ET_o treatment at the beginning of the season. However, by the end of the 2010 season, widths increased as the irrigation amounts increased. It appears that while more water will affect the overall width of both species, growth still resulted during a season for both species regardless of watering amount.

Treatments resulted in few height differences with the FG *Physocarpus* for both years, however the widths of the plants were affected by treatments. The general trend was that width increased as watering amounts increased. However, statistically the shrubs that received 100% ET_o had greater width than those that received the 0% ET_o treatment. When comparing the season beginning height and width data with the season ending height and width for both years, sizes did

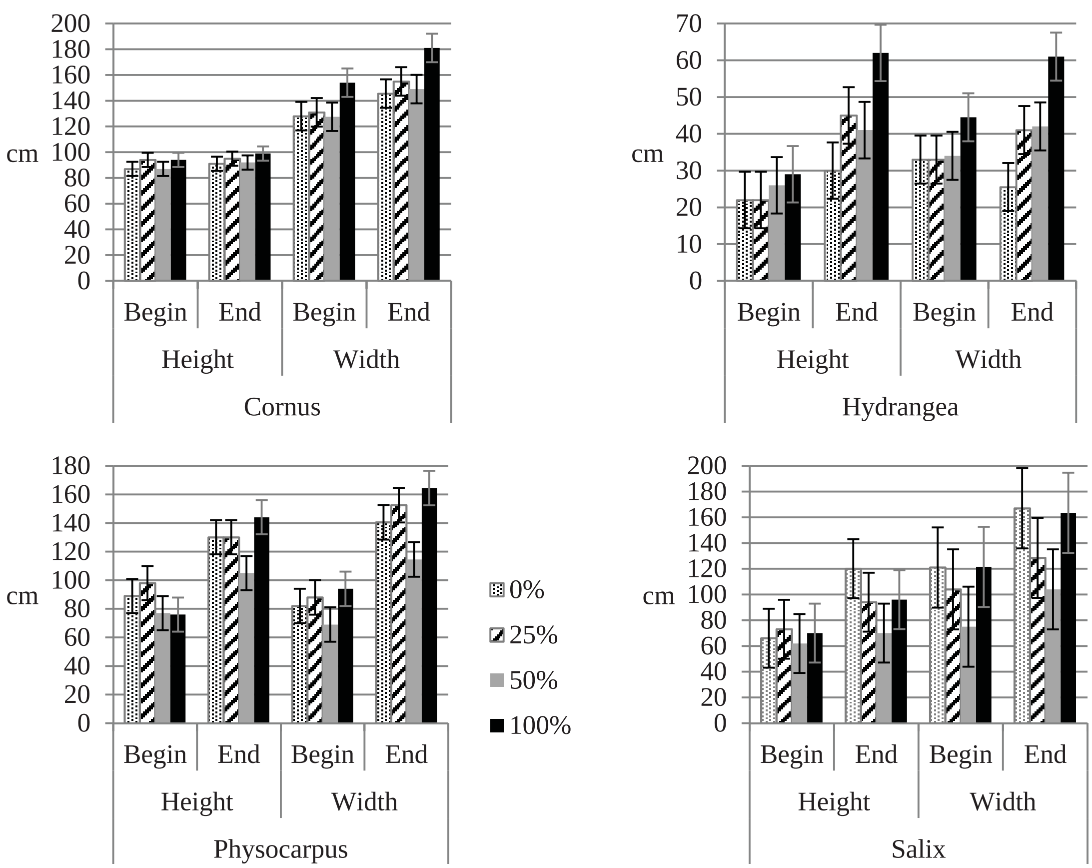

Fig. 1. Average heights and widths for each FG shrub in each treatment at the beginning and end of the 2010 experimental season. Significance is measured at $p < 0.05$.

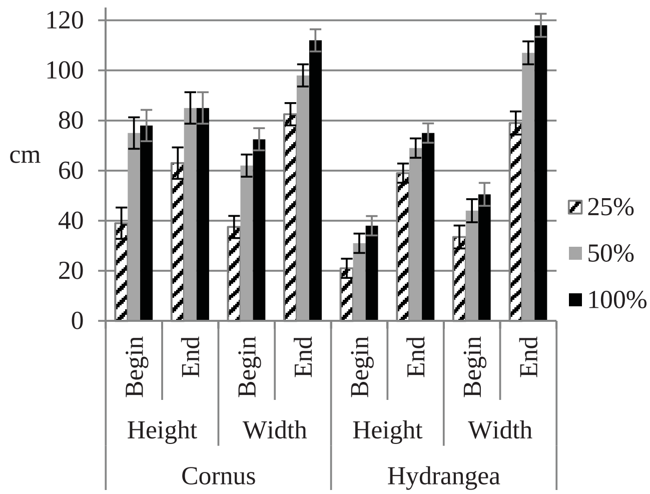

Fig. 2. Average heights and widths for both LYS shrubs in each treatment at the beginning and end of the 2010 experimental season. Significance is measured at $p < 0.05$.

increase for both years for all treatments. It appears that when given more water, *Physocarpus* will increase their overall size, but growth will still result regardless of watering amounts given during non-drought years

The growth of FG Salix was similar in both 2009 and 2010. There were no differences in the seasonal growth increment from the beginning and end of the season between any of the treatments. The data suggest that watering treatments up to 100% ET_o may have no effect on overall size, however, further testing is needed. It is possible that the size of FG *Salix* might be affected if they receive greater than 100% ET_o.

Depending upon the treatment, the LYS shrubs broke dormancy at different times in 2010. The shrubs in the 100% ET_o treatment broke dormancy earlier compared to shrubs that received 50% ET_o, and shrubs that received 50% ET_o broke dormancy more quickly than the shrubs that received 25% ET_o. The shrubs in the 100% ET_o treatment broke dormancy about 2–3 weeks earlier than the shrubs in the 25% ET_o treatment. During the winter of 2009–2010, all of the LYS *Cornus* replications in the 25% ET_o died back to the ground and broke dormancy in the Spring of 2010 by starting new growth from the base of the plant. This response suggests that the LYS *Cornus* that received 25% ET_o were water stressed at the end of 2009, since one symptom of water stress is twig dieback (18).

During 2009, few differences occurred with leaf water potential among treatments for any particular FG species; however, differences occurred during 2010 (Fig. 3). In 2010, the FG *Cornus*, *Physocarpus* and *Salix* that received 100% ET_o had less negative readings (less stressed) than their counterparts that received 0% ET_o. Additionally, the FG *Cornus* and FG *Salix* that received 100% ET_o had less negative readings than the shrubs in the 25 and 50% ET_o treatments. The FG *Physocarpus* that received the 100, 25, and 0% ET_o treatments had a general decreasing trend as water became more limited. As a result, it appears that the water potential becomes less negative if more water is provided to these three species.

The FG *Hydrangea* performed differently than the other FG shrubs in 2010. The FG *Hydrangea* had similar readings for the 0, 25, and 50% ET_o treatments, but surprisingly the most negative readings were in the 100% ET_o treatment. This result equates to the shrubs in the 0, 25, and 50% ET_o treatments being equally stressed, and the shrubs that received the 100% ET_o treatment being the most physiologically stressed. This counterintuitive result can be explained by the size differences during 2010. The FG *Hydrangea* in the 100% ET_o treatment plot were significantly larger in height and width at the end of the 2010 season (Fig. 1) and overall shoot fresh and dry weights (Fig. 4) compared to the other three treatment plots. The larger size resulted in an increase in transpiration, and thus greater water demand for the shrub (10). Since the larger *Hydrangea* shrubs were more water stressed, it is possible that *Hydrangea* could require more than 100% ET_o for optimal growth.

As the 2010 osmolality data show, solute concentrations generally increased as watering amounts decreased (Fig. 5). This trend was especially noted with the FG *Cornus*, *Hydrangea* and *Physocarpus*. The trend is not surprising since one of the responses to water stress is for a plant to undergo an osmotic adjustment (2).

The osmolality in the FG *Salix* was also affected by the treatments, but not to the extent as with the other species. The FG *Salix* did not result in a linear relationship as the other species. The FG *Salix* probably underwent some osmotic adjustment like the other three species since the shrubs in the 100% ET_o treatment plot were lower in solute concentrations than the FG *Salix* in the 0% ET_o treatment plot. However, since the FG *Salix* in the 0, 25 and 50% ET_o treatment plots had similar water potential readings (Fig. 3), the solute concentrations did not follow as pronounced a decreasing trend as water treatment amounts increased as observed in the other three species.

Table 3 displays the dates and corresponding weather conditions during two of the dry downs for the LYS shrubs in 2009 and 2010. 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, and dry downs conducted during cooler temperatures with some precipitation lasted longer.

The mean daily weight loss for two dry downs for 2009 and 2010 are displayed in Fig. 6. The results for the dry downs for both LYS shrubs indicate that as watering amounts increased, mean daily water use also increased. Thus if water is available in the soil, these shrubs will utilize that water. García-Navarro, et al. (2004) reported similar results where

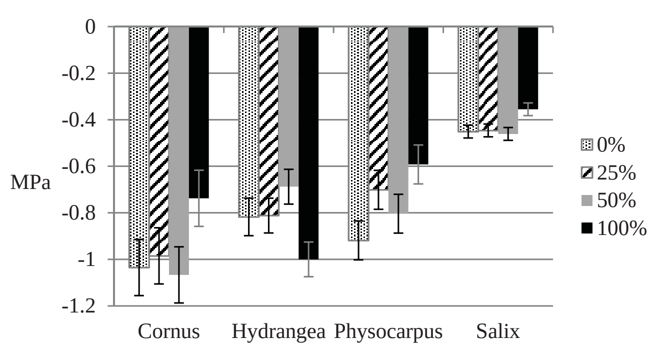

Fig. 3. Seasonal mean predawn leaf water potential for each FG shrub in each treatment during 2010. Significance is measured at $p < 0.05$.

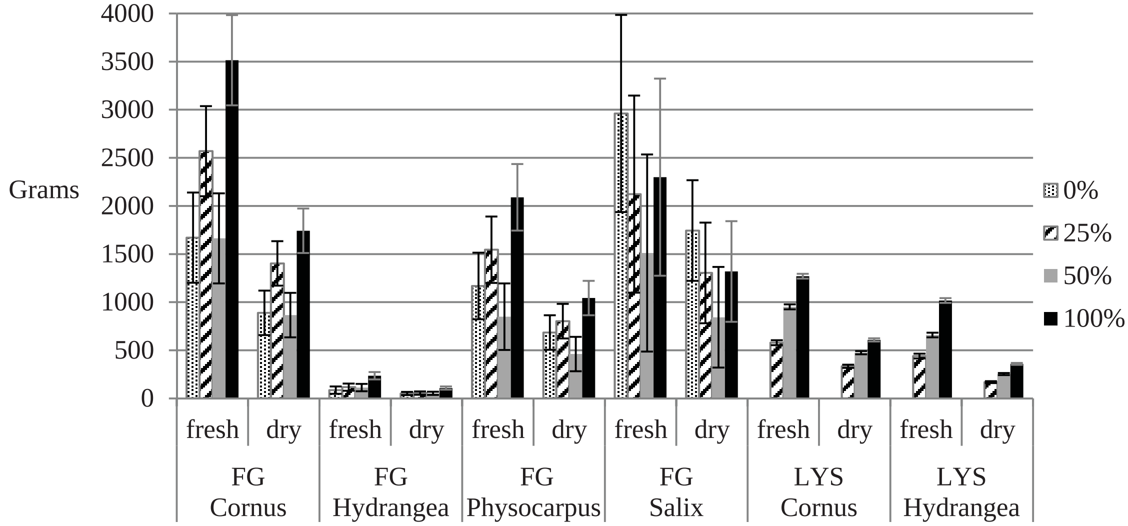

Fig. 4. **Mean fresh and dry shoot weights of each shrub species (FG and LYS) in each treatment during 2010. Significance is measured at $p < 0.05$.**

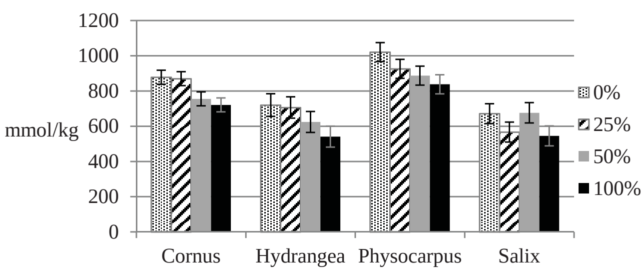

Fig. 5. **Seasonal mean osmolality for each FG shrub species in each treatment during 2010. Significance is measured at $p < 0.05$.**

shrubs in well-watered conditions averaged a greater daily water use than plants that received less water (4). In addition, the increase in water use from 2009 to 2010 is a result of the LYS shrubs having increased biomass and leaf area in 2010 when compared to 2009 (Fig. 7).

Fig. 8 displays the mean predawn leaf water potential readings of the LYS *Cornus* and *Hydrangea* during the same two dry downs conducted in 2009 and 2010 that were discussed earlier. During 2009, the predawn water potential results for both LYS species were similar. During the last day of each dry down, the LYS plants that received 100% ET_o had the least negative predawn leaf water potential readings (least stressed), and the plants that received 25% ET_o had the most negative readings (most stressed).

During 2010, the predawn water potential results had changed so that they were opposite of what had occurred in 2009. By the last day of each dry down in 2010 the LYS *Cornus* in the 100% ET_o treatment had the most negative predawn leaf water potential readings (most stressed) and the 25 and 50% ET_o treatments had the least negative readings (least stressed). By the last day of each dry down in 2010 the LYS *Hydrangea* also changed from 2009 so that the 100% ET_o either had more negative or equal readings as the 25% ET_o treatment by the end of the dry down. These results appear counterintuitive since more water should have made the water potential readings less negative, as occurred in 2009. However, the size differences of the plants can account for these varying results. At the conclusion of 2009, both LYS shrubs had little to no differences in size. However, at the conclusion of the 2010 growing season, the sizes of both species generally increased as irrigation amounts increased (Fig. 2). These size differences are important because larger plants have more leaf area and more leaf area equals more transpiration and more water demand (10).

Despite the LYS shrubs being unequal in size during 2010, the data shows that the plants essentially grew to a size that they could support themselves with the available water. Since more water was available to the shrubs in the higher irrigation 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 requirement of the plant will also increase.

Table 3. **Weather conditions during two of the LYS dry downs in 2009 and 2010 (15).**

Year	Dates of dry down	Mean high temp in C (F)	Mean low temp in C (F)	Precipitation in cm (in)	Cumulative ET_o in cm (in)
2009	July 13–17	30.87 (87.56)	12.92 (55.26)	0.00 (0.00)	2.97 (1.17)
	September 9–16	24.33 (75.80)	9.76 (49.56)	0.38 (0.15)	2.57 (1.01)
2010	July 26–30	32.29 (90.12)	15.73 (60.32)	0.41 (0.16)	2.36 (0.93)
	September 6–10	26.22 (79.20)	6.76 (44.16)	0.03 (0.01)	2.24 (0.88)

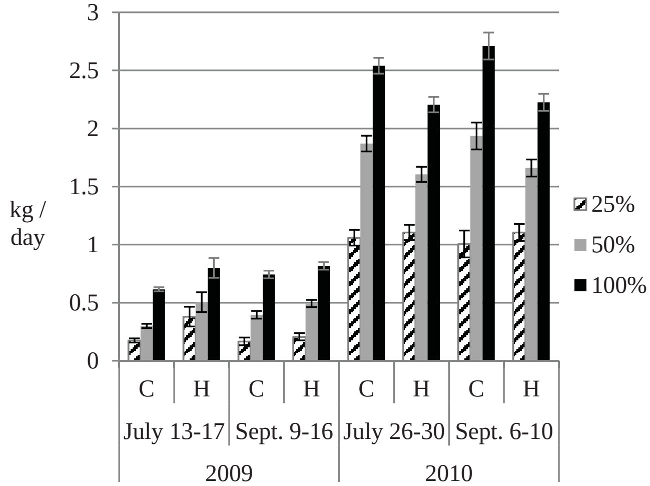

Fig. 6. Mean daily weight loss (due to evapotranspiration) during two dry downs in 2009 and 2010 for LYS *Cornus* (C) and LYS *Hydrangea* (H). Significance is measured at $p < 0.05$.

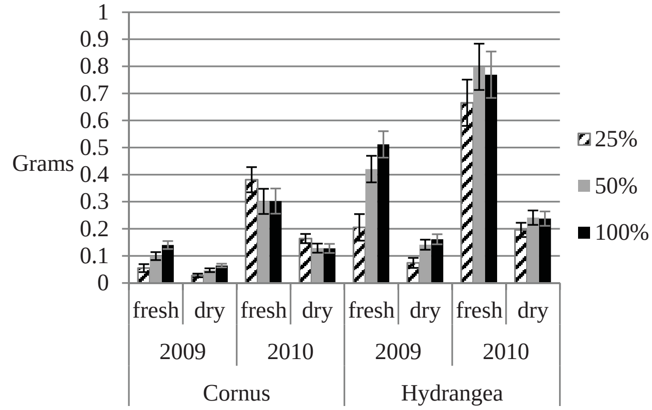

Fig. 7. Mean fresh and dry weights for an individual leaf for both LYS shrub species in each treatment during 2009 and 2010. Significance is measured at $p < 0.05$.

The soil moisture data suggested that the soil moisture around each species in each irrigation treatment plot was fairly similar during both seasons, indicating that the treatments were applied uniformly during both years. The KBG in all of the water treatments (25, 50, and 100% ET_o) resulted in the same general pattern where water content abruptly increased at the 30 cm (11.81 in) depth. Fig. 9 is representative of all three of the watered treatments. This result suggests that the turf did not access the water at depths beyond 30 cm (11.81 in). The turf in the 0% ET_o treatment (data not shown) did not follow the same trend as the watered treatments. The water content in the 0% ET_o treatment slowly increased as depth increased down to 50 cm (19.69 in). It is hypothesized that the majority of the 0% ET_o turf died and the turf that had remained had a very weak root system as was indicated by the increase in IR temperature measurements. These higher temperatures are further detrimental to the turf because higher temperatures can cause dieback of the root system of cool season grasses (3). As a consequence of the turf being mostly dead in the 0% ET_o treatment plot, little water would have been extracted from the soil.

The soil moisture readings for the FG *Cornus* and *Physocarpus* were fairly similar in the way each species responded to treatments. The soil moisture in the 0, 25, and 50% ET_o treatment plots appeared to have had no differences and the water content was fairly equal at all depths. The FG *Cornus* and *Physocarpus* in the 100% ET_o treatment matched the other treatments in water content once the depth exceeded 20

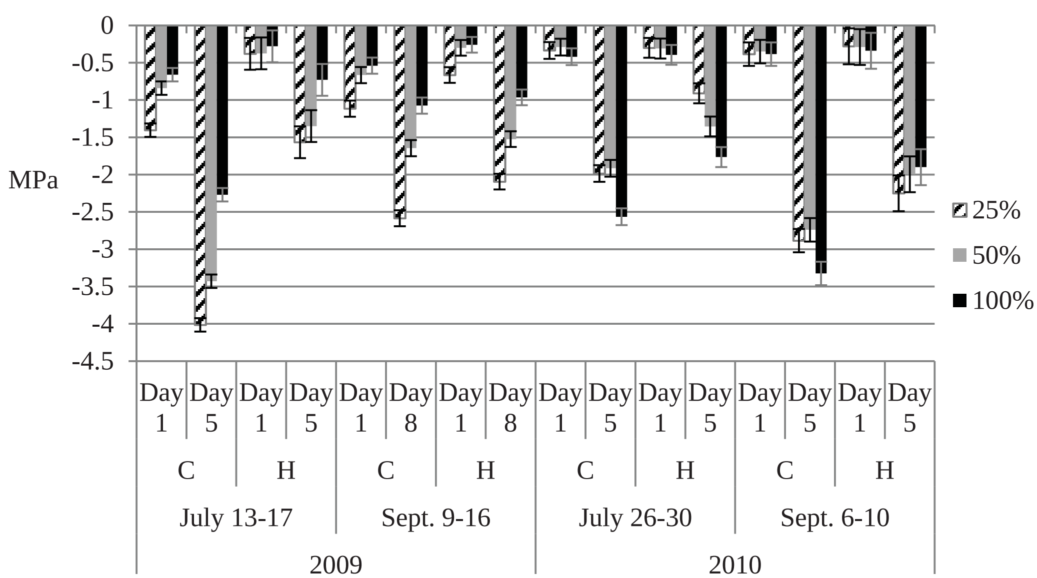

Fig. 8. Mean predawn leaf water potential readings for LYS *Cornus* (C) and LYS *Hydrangea* (H) during two dry downs in 2009 and 2010. The days represent the readings on the day the dry down was intiated (day 1) and the last day on which the dry down was terminated. Significance is measured at $p < 0.05$.

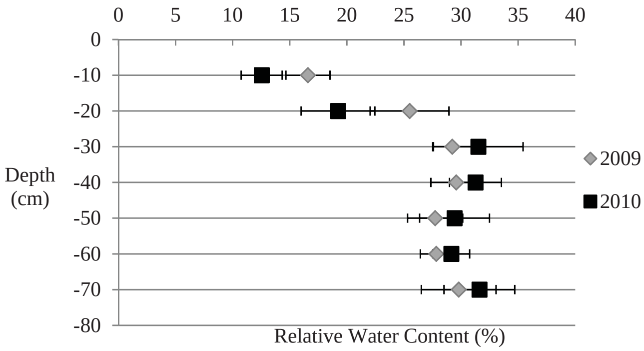

Fig. 9. Seasonal mean soil moisture content for the 100% ET_o KBG during 2009 and 2010. Significance is measured at $p < 0.05$.

cm (7.87 in). The 100% ET_o 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.

The soil moisture readings for the FG *Salix* revealed little variation in the 25, 50, or 100% ET_o treatment plots but moisture levels generally increased as depth increased in the 0% ET_o treatment plot.

The soil moisture readings for the FG *Hydrangea* were consistently lower in the top 10 cm (3.94 in) of the soil profile in all treatments. It appeared that the FG *Hydrangea* 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.

Fig. 10 displays the fresh and dry weight of leaf samples from 2009 and 2010. The FG *Cornus* had greater leaf dry weight in the 100% ET_o treatment during 2009 but even more in 2010 when fresh and dry. During 2009 as irrigation amounts increased, leaf weights generally increased for the FG *Cornus*. Despite the difference in the 50% ET_o treatment during 2009, the 100% ET_o treatment during 2010 was greater than the 0, 25, and 50% ET_o for both fresh and dry weights.

The FG *Physocarpus* receiving 100% ET_o was greater than the 0, 25, and 50% ET_o treatments in 2009, but during 2010, the 100% ET_o was only greater than the 25 and 50% ET_o treatments. Despite the 0% ET_o treatment falling outside the pattern in 2010, there was still a trend for both years that the FG *Physocarpus* were affected from watering treatments in which generally more water resulted in larger leaves.

Like the FG *Cornus*, the FG *Hydrangea* resulted in more significant differences in 2010 than 2009. The only significant leaf weight differences with the FG *Hydrangea* in 2009 were a slightly greater leaf fresh weight in the 100% ET_o treatment versus the 0% ET_o treatment. This result changed in 2010 whereby the 100% ET_o was significantly greater than all of the other treatments for both fresh and dry weight.

The FG *Salix* had little differences in leaf weight (data not shown). As a result, it appears that leaf weights were unaffected by watering treatments when irrigated up to 100% ET_o.

During 2009, the different watering treatments appear to have had an impact on the leaf characteristics on both of the LYS shrubs (Fig. 7). The leaves on the LYS *Cornus* increased in weight as irrigation treatments increased. The LYS *Hydrangea* leaves in the 50 and 100% ET_o were equal to each other but were still greater in weight than those in the 25% ET_o treatment. As a result, it appeared that when both species received more water, leaf weights also increased. However, this result changed in 2010.

The LYS leaf weights during 2010 had little differences. Other than the dry weight of the leaves for the 25% ET_o LYS *Cornus* being greater than the 50 and 100% ET_o treatments, no statistical differences were present for either LYS species in any treatment for the fresh or dry weight of the leaves.

The results from 2009 suggested that changing the watering amounts changed the leaf characteristics of both species. When both LYS shrub species received more water, leaves with more overall biomass resulted. However, the 2010 results did not support this conclusion since few differences occurred. The lack of differences can be attributed to the size differences of the shrubs from 2009 to 2010. During 2009 both shrub species had few differences in height or width, but differences were present during 2010 (Fig. 2). It is theorized that plants can better tolerate more drought stress when they have previously been exposed to drought stress (13, 21). 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 better tolerate drought stress during 2010. Both LYS shrub species adjusted

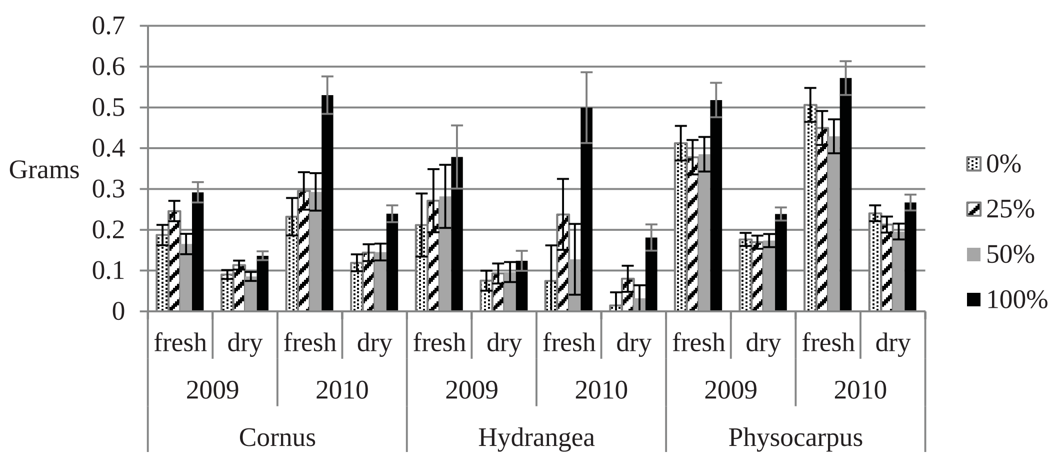

Fig. 10. Mean fresh and dry weights for an individual leaf for three of the FG shrub species in each treatment. Significance is measured at $p < 0.05$.

their growth characteristics to account for the water amounts that they received. The LYS shrubs essentially grew to a size that they could support themselves with the available water. Then, the shrubs developed leaves that were comparable to each other since the overall size of the shrubs differed but leaf weights did not.

Overall shoot biomass was affected by watering treatments for most of the trialed shrubs (Fig. 4). FG *Cornus* and *Physocarpus* had similar results. The fresh and dry weights in the 100% ET_o treatment were greater than the 0% ET_o treatment. The FG *Hydrangea* had the greatest fresh and dry weights in the 100% ET_o treatment when compared to the 0, 25 and 50% ET_o treatments. There was no statistical difference among treatments for the fresh or dry weight for the FG *Salix*. However, this study only tested 0 to 100% ET_o and further research is needed with the *Salix* to determine if different results are yielded when tested beyond 100% ET_o. The results for both of the LYS shrubs were the same, which was as watering amounts increased for the LYS *Cornus* and LYS *Hydrangea* overall shoot fresh and dry weights also increased. As a result, it appears that increasing watering amounts had a positive correlation on all tested shrubs in both studies with the exception of the FG *Salix*.

'Many commonly grown landscape plants are capable of maintaining aesthetic and functional value when irrigated at substantially less than 100% ET_o' (8). This research confirmed this statement with three of the four species tested (*Cornus*, *Physocarpus*, and *Salix*) after these shrubs have been growing for two years during non-drought years (19).

FG *Cornus* does well in the landscape after two years of establishment, regardless of the water amounts it received. The FG *Cornus* in all of the watered treatments (25, 50 and 100% ET_o) were similar visually. However, the FG *Cornus* in the 0% treatment was also quite acceptable visually for landscape use. Overall shoot biomass and leaf weights increased when receiving 100% ET_o. Shrub size appears to be impacted only if established FG *Cornus* receive 100% ET_o. Water potential was generally greater when the FG *Cornus* were watered with 100% ET_o. The osmolality was lower when the FG *Cornus* received at least 50% ET_o. These results suggest that the FG *Cornus* is less stressed physiologically when receiving at least 50% ET_o.

Hydrangea required the most water of the four species tested in the field study. The overall size, plant biomass with corresponding leaf area, and leaf weights were the greatest in the 100% ET_o treatment. Since the FG *Hydrangea* increased its growth when watered at 100% ET_o and osmolality decreased, it appeared that more water was beneficial in maintaining this plant. However, the water potential was most negative (most stressed) with the 100% ET_o, therefore, greater than 100% ET_o may be needed to maintain this shrub when they increase in size.

Despite the *Hydrangea*'s apparent high water needs, they were able to survive short drought periods. The FG *Hydrangea* had a 100% survivability rate in the 25, 50 and 100% ET_o treatments and an 80% survivability rate in the 0% ET_o treatment. It appears that established plantings of *Hydrangea* 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 inherent large leaf size and smaller root system and this can be problematic because larger leaf areas lead to increased transpiration rates (10). As a result of the leaves in the lower water treatments (0, 25, 50% ET_o) being smaller at the conclusion of the experiment (Fig. 10), the plants appeared to have adjusted their growth characteristics to account for having less available water. This mechanism of having decreased leaf area was a response to drought stress (2, 20). This is further influenced by the possible shallow root system. If *Hydrangea* has more shallow root systems, this would also help explain why *Hydrangea* has an increased water demand in the upper soil levels, since the plant would not be able to access water from deeper levels in the soil profile.

The FG *Physocarpus* resulted in good growth after two years of establishment, regardless of the water amounts it received. The FG *Physocarpus* had greater plant biomass in the 100% ET_o when compared to the 0% ET_o treatment. However, all treatments still increased in size when comparing the beginning to the ending season heights and widths. It appears the *Physocarpus* will still grow regardless of water amount received once the plant is established. The osmolality was lower and the water potential was greater (less stressed) in the 100% ET_o than the 0% ET_o, as well. As a result, more water appears to reduce physiological stress once irrigation treatments reach 100% ET_o.

The FG *Salix* appeared to do well in the landscape after two years of growth, regardless of the amount of water it received. The FG *Salix* did not have significant differences in height, width, 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 (2). While some osmotic adjustment appears to have occurred (Fig. 5), it appeared to be limited when compared to the other three FG species. However, osmolality fluctuated with treatments and water potential was less negative in the 100% ET_o treatment than the 0% ET_o treatment. As a result, the plant performed better physiologically when it received 100% ET_o. However, all plants in all treatments not only survived, but also were acceptable for landscape use.

The results from the Lysimeter study had variations from 2009 to 2010 but both the LYS *Cornus* and LYS *Hydrangea* responded similarly to each other during each year. During 2009, more water appeared to have reduced physiological stress and increased visual appeal, but during 2010, the shrubs modified their growth habits to account for the varying water amounts provided. 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 (19). The overall size of the shrubs varied but the characteristics of the leaves remained relatively similar for each species among all three irrigation treatments. In 2010 both species also had increased shoot biomass 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 beginning and ending season widths during 2010 with the LYS *Cornus* and the beginning and ending season heights and widths with the LYS *Hydrangea* (Fig. 2), all treatments increased in size by the end of the season. Growth still resulted on both species when watered with as little as 25% ET_o. If more growth is needed, then watering applications should be greater than 25% ET_o that more growth occurs for a larger plant in less time. However, the amount of time that the plants in the 100% ET_o 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 containerized shrubs were hydrated in a nursery or landscape setting. Conversely, the shrubs that were watered with 25% ET_o were able to survive 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 (13, 21). As a result, it could be advantageous to grow *Cornus* and *Hydrangea* with 25% ET_o while in containers to encourage growth characteristics that are better able to tolerate decreased watering amounts for when they are eventually planted in the ground.

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