WATER USE AND DROUGHT RESISTANCE OF TURFGRASS AND ORNAMENTAL LANDSCAPE PLANT SPECIES

by

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B.S., California Polytechnic State University, San Luis Obispo, 2001
M.S., California Polytechnic State University, San Luis Obispo, 2008

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Horticulture, Forestry, and Recreation Resources

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Abstract

In 2005, turfgrass was estimated to cover approximately 20 million ha of urbanized land. That area is increasing with rapid urbanization, stressing the importance of water conservation in the lawn and landscape industry. Turfgrasses have been identified for replacement by presumably more water-efficient ornamental plant species to conserve water. However, research comparing drought resistance and evapotranspiration (ET) of turfgrasses with ornamental landscape plants is limited. Two studies were conducted to evaluate water use and performance under drought stress of several ornamental and turfgrass species. An online course was developed to educate students about critical water issues related to irrigation in urbanizing watersheds.

In a field study, ET was measured using lysimeters and plant water status was evaluated under deficit irrigation (100%, 60%, and 20% ET) in *Festuca arundinacea* Schreb., *Buchloe dactyloides* (Nutt.) Engelm. 'Sharps Improved', and *Ajuga reptans* L. 'Bronze Beauty'. Evapotranspiration was similar between *A. reptans* and *F. arundinacea*, and was 32 and 35% greater than ET of *B. dactyloides*.

In a greenhouse study, the performance of one turfgrass (*Poa pratensis* L. 'Apollo') and eight landscape species (*Achillea millifolium* L.*, Ajuga reptans* L. 'Bronze Beauty'*, Liriope muscari* Decne.*, Pachysandra terminalis* Siebold and Zucc.*, Sedum album* L.*, Thymus serpyllum* L.*, Vinca major* L.*,* and *Vinca minor* L.) was evaluated during a severe dry down and subsequent recovery. *S. album*, *L. muscari*, and *P. terminalis* performed the best, requiring 86 to 254 d to decline to a quality rating of one (1-9 scale: 1=dead/dormant, 9=best quality). The remaining species required 52 to 63 d. The only species to recover were *P. pratensis* [46% pot cover (PC) after 60 days], *S. album* (38% PC), and *V. major* (35% PC).

A survey was developed to measure student learning as it relates to the level of *sense* and *meaning* present in the content of a new online course entitled "Water Issues in the Lawn and Landscape." Survey results were compared with student learning as measured through a post-test. Post-test scores declined as the difference between sense and meaning increased ($r = -0.82$; $P=0.03$), indicating student learning is higher when both sense and meaning are present.

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To my family: My wife, Cynthia, for going through this journey alongside me, I couldn't have done it without you – we did it!; my son, Dawson, thank you for making every day so much fun. You continue to amaze me and I am elated to be with you in Vermont, spending every day with you again; to my parents, Don and Judy, thank you for your continued support and encouragement through everything I have attempted in life; to my parents-in-law, Gary and Patti, thanks for trusting me with your daughter and supporting our many adventures; and to my grandmother, Ruby, thank you for always being there to listen.

Dedication

To my wife and best friend, Cynthia, and to my wonderful son, Dawson, you two were the motivation that kept me going while we were separated during the time I wrote the majority of my dissertation.

Chapter 1 - Evapotranspiration and Performance among Turfgrass and Ornamental Landscape Species in Response to Irrigation Deficit

Abstract

Water conservation is an increasingly important issue in the lawn and landscape industry. Turfgrasses have been singled out for replacement with presumably more water efficient plant species to conserve water despite limited research on comparative water use between popular turfgrasses and other landscape species. In this study, I evaluated water use and performance among two turfgrass and one ornamental species under irrigation deficits. Evapotranspiration (ET) was measured using lysimeters and plant water status was evaluated under deficit irrigation (100%, 60%, and 20% ET) in *Festuca arundinacea* Schreb., *Buchloe dactyloides* (Nutt.) Engelm. 'Sharps Improved', and *Ajuga reptans* L. 'Bronze Beauty'. The study was conducted for 99 d in the summer of 2010 and 85 d in the summer of 2011 under a rainout shelter near Manhattan, KS, USA. Water use rates were similar between *A. reptans* (4.0/5.0 mm d^{-1}) and *F. arundinacea* (4.4/5.0 mm d^{-1}), which were both higher than the ET of *B. dactyloides* (2.7/3.4 mm d^{-1}) (2010/2011). Results indicate *B. dactyloides* to be a good choice for landscapes where water is limited because of its lower water use and ability to maintain plant quality above minimal acceptability for more than ten weeks when receiving 20% ET replacement. *A. reptans* and *F. arundinacea* may be less appealing choices for landscapes where extended periods of drought are possible given their high ET rates and plant quality ratings which were most affected by the deficit irrigation treatments.

Introduction

Competition for water resources is intensifying as the world's population grows. In 2005, turfgrass was estimated to cover up to 20 million ha of urbanized land, and that area is increasing with rapid urbanization (Alig et al., 2004; Milesi et al., 2005). In the U.S., outdoor water use of residential and commercial clientele (e.g., for irrigation of lawn and landscape plants) can be as great as 50-70% of the overall municipal water use (Endter-Wada et al., 2008). Consequently, water conservation is an increasingly important issue in the lawn and landscape industry.

Turfgrasses have been singled out for replacement with what are presumed to be more water-efficient plant species to reduce the amount of turf and save water. For example, in 2006 the United States Environmental Protection Agency (EPA) created a voluntary program called WaterSense to promote water efficiency (WaterSense, 2008). The program outlined criteria that builders must follow in order to market a home as WaterSense approved. At the inception of WaterSense in 2006, the outdoor water efficiency component of the program required a reduction in the area of turfgrass in the landscape for the home to qualify for the WaterSense label.

Although it is often recommended to replace turfgrass with ornamental vegetation to conserve water, research is limited on the comparative water use between popular turfgrass species and other landscape plants (Devitt and Morris, 2008; Horst et al., 1997). In a greenhouse study, water use was measured in four turfgrass species (*Festuca arundinacea*, *Poa pratensis*, *Buchloe dactyloides*, and *Zoysia japonica*) and two ornamental species (*Ajuga reptans* and *Vinca minor*) using lysimeters (Horst et al., 1997). They found similar evapotranspiration (ET) rates between *Ajuga reptans* and *Festuca arundinacea*, which were also the highest water users, during the first year of their study. They also reported lower ET rates in *Buchloe dactyloides* and

Zoysia japonica than in *Vinca minor*, indicating some turfgrass species use less water than selected ornamentals. To our knowledge, no field studies have been conducted to compare water use between turfgrass and ornamental species.

Substantial research has been conducted to compare ET among turfgrass species (Aronson et al., 1987a; Aronson et al., 1987b; Biran et al., 1981; Kim and Beard, 1988; Qian et al., 1996; Tovey et al., 1969) as well among cultivars within a number of turfgrass species (Beard et al., 1992; Bowman et al., 1998; Bowman and Macaulay, 1991; Kopec et al., 1988; Shearman, 1986). Some turfgrass species have been identified as generally low or high water users in comparison with other species. For instance, tall fescue is considered to be a high water user and is known for its excellent wear, heat, and drought resistance (Christians, 2004; Turgeon, 2005). Buffalograss is considered a low water user and adapts very well to heavy soils and arid conditions (Christians, 2004; Turgeon, 2005).

Field research is needed to compare water use and drought performance between landscape ornamentals and turfgrasses. Therefore, the objectives of this study were to conduct a field study to: 1) Compare ET among two turfgrass species and two ornamental groundcover species under well-watered conditions and 2) Evaluate visual quality and plant water status of the same turfgrass and groundcover species under deficit irrigation. However, one of the ornamental species evaluated, *Vinca minor,* was not included in the final analysis because a severe fungus infestation (*Phoma exigua*) damaged *Vinca minor* plots during both studies.

Materials and Methods

Preparation and maintenance of field plots

Field plots were established in June 2009 at the Rocky Ford Turfgrass Research Center near Manhattan, Kansas (Rocky Ford; lat. 39°13’53” N, long. 96°34’51” W). There were two treatment factors, including: 1) species [two turfgrass species (*Buchloe dactyloides* ‘Sharps Improved’ and *Festuca arundinacea*) and two ornamental groundcover species (*Ajuga reptans* ‘Bronze Beauty’ and *Vinca minor*)]; and 2) irrigation (100%, 60%, and 20% ET replacement). Plots were established in a randomized complete block design with three replicates of each treatment combination, for a total of 36 plots. Plots measured 2 m by 2 m and were separated by 0.5 m borders covered with *F. arundinacea* turfgrass. The soil was a Chase silt loam (fine, smectitic, mesic, Aquertic, Argiudolls). Both species of turfgrass were sodded into plots from established swards at the Rocky Ford Turfgrass Research Center. The ornamental species were established by washing potting soil from the roots of several plants grown in nursery containers (11.4 cm diam. by 9.5 cm deep), purchased from a local garden center, and planted (30 cm apart) in the plots. Establishment of the ornamental species required three additional plantings, throughout the 2009 summer, from nursery containers to obtain full cover. All plots were well-established by spring 2010, when the first study began. Data collection for this study occurred from 28 June to 4 Oct. 2010, and from 20 June to 12 Sept. 2011.

Plots were maintained well-watered until the beginning of deficit irrigation treatments each year. *F. arundinacea* was fertilized at a rate of 49 kg N ha^{-1} (46N-0P-0K) in Sept. and Oct. of 2009 and 2010. Additional fertilizations of 49 kg N ha^{-1} were applied to all plots in Apr. 2010 and 2011. Turfgrass plots were mowed once weekly at 9 cm and ornamentals were kept trimmed to the outside edge of the plots.

Fungicide applications of flutolanil (N-[3-(1-methylethoxy) phenyl]-2-(trifluoromethyl) benzamide were applied at a rate of 11.2 kg ai. ha^{-1} on 19 July 2010, 16 Aug. 2010, 13 Sept. 2010, 30 June 2011, 21 July 2011, and 18 Aug. 2011 to all *A. reptans* and *V. minor* plots to prevent root rot (*Rhizoctonia solani*).

Herbicide applications of carfentrazone-ethyl (0.03 kg a.i. ha^{-1}) + d,4-D, 2-ethyl hexyl ester (1.29 kg a.i. ha^{-1}) + mecoprop-p acid (0.27 kg a.i. ha^{-1}) + dicamba acid (0.08 kg a.i. ha^{-1}) were applied to turfgrass plots for control of broadleaf weeds on 28 Apr. 2010, and 12 May 2011. Dithiopyr [S,S'-dimethyl 2-(difluoro-methyl)-4-(2-methylpropyl)-(trifluoromethyl)-3,5-pyridinedicarbothioate) was applied to all turfgrass plots at a rate of 0.58 kg a.i. ha^{-1} for control of annual grassy weeds on the same dates.

A rainout shelter similar to those described by Fay et al. (2000) was constructed in the spring of 2010 over the existing plots. The rainout shelter was a commercial greenhouse design (Thermolator; Agra Tech, Pittsburg, CA), measuring 10.67 m wide x 29.26 m long, with an eave height of 1.07 m, and a ridge height of 4.27 m. There was a 0.59 m buffer strip along each side of the shelter (space between the edge of the structure and the plots) and a 3.63 m buffer area on each end of the shelter. Rain gutters were installed along the eaves of the structure to capture runoff from the cover during a rain event and move the water away from the plots.

Preparation and maintenance of lysimeters

Lysimeters were used to measure ET among species under well-watered conditions and to determine irrigation requirements (i.e., ET replacement) for the field plots. Accordingly, lysimeters were placed in 100% ET plots, from which water amounts for each irrigation treatment (100%, 60%, and 20% ET replacement) were calculated. Lysimeters (25 cm diam. by 20 cm deep) identical to those described by Bremer (2003) were filled with a sand and topsoil

[Chase silt loam (fine, smectitic, mesic, Aquertic, Argiudolls)] mixture (1:1, v:v) with bulk densities ranging from 1.40 to 1.65 g cm^{-3}. Turf was established in the lysimeters with sod from the same swards that provided the turf plots. The ornamental species were established by washing potting soil from the roots of three plants grown in nursery containers (11.4 cm diam. by 9.5 cm deep), purchased from a local garden center, and transplanted to the lysimeters. Three lysimeters of each species were established, or one lysimeter in each 100% ET plot.

Lysimeters were planted on 25 Sept. 2009, for the 2010 study and on 30 Sept. 2010 for the 2011 study. Lysimeters were maintained in the greenhouse where day/night air temperature averaged 25°C / 23°C and supplemental light was provided 12-h d^{-1}. Lysimeters were kept well-watered and fertilized at the same rate and application time as the field plots. Turfgrass lysimeters were mowed once weekly at 9 cm. All plant material was trimmed to the outside edge of the lysimeter to keep the area of vegetation cover consistent among species.

Insecticide applications for controlling aphids, white fly, and scale during the establishment of the lysimeters in the greenhouse included dinotefuran {N-methyl-N’-nitro-N”-[(tetrahydro-3-furanyl)methyl]guanidine} at 0.22 kg a.i. ha^{-1} on 27 Oct. 2009; imidacloprid {1-[(6-Chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine} at 0.0139 kg a.i. ha^{-1} and spinosad [mixture of (spinosyn A, R=H) and (spinosyn D, R=CH_3)] at 0.2 kg a.i. ha^{-1} on 12 Jan. 2010; and buprofezin (2-tert-butylimino-3-isopropyl-5-phenylperhydro-1,3,5-thiadiazin-4-one) at 0.4 kg a.i. ha^{-1} on 9 Mar. 2010.

Lysimeters were moved to the field approximately 30 d prior to the beginning of each study to allow plants to acclimate to field conditions. Lysimeters were installed at randomly assigned locations within each of the 100% ET field plots. Placement of the lysimeters was kept at a minimum distance of 0.5 m from the edge of each plot. Plastic sleeves (29 cm diam. by 20 cm deep) were installed in the holes containing the lysimeters to prevent the sides from collapsing. In 2011 the study ended two weeks earlier than planned due to a loss of water availability for irrigation at the site resulting from a faulty pump.

Evapotranspiration in well-watered plots

Evapotranspiration was measured two times per week around 1000 CST. Measurements were obtained gravimetrically by manually weighing the lysimeters using an electronic balance (Sartorius, GMBH GOTTINGEN, Germany) (Bremer, 2003). One day prior to the beginning of the study each year, lysimeters were irrigated and allowed to drain until free drainage ceased. The bases were then sealed and the lysimeters weighed, and this weight was assumed to represent field capacity in the soil of each respective lysimeter. After three or four days, the lysimeters were weighed again and the water loss was attributed to ET. Each lysimeter was irrigated according to their respective ET loss to replenish the soil profile. For each species, proportionate amounts of water were applied to plots according to their assigned irrigation treatment (100%, 60%, and 20% ET replacement). Water was applied by hand through a fan spray nozzle that was attached to a hose, and an inline water meter (Model 03N31, GPI, Wichita, KS) ensured accuracy.

Canopy characteristics

Plant visual quality was rated two times per week around 1000 CST during both studies. Quality was evaluated using a scale of 1 to 9 (1=dead/dormant, 6=minimally acceptable, and 9=highest quality) depending on plant density, uniformity, and color. This scale is the standard for evaluating turfgrass in the National Turfgrass Evaluation Program (NTEP; Morris, 2000) and was adapted to the ornamentals for consistency across species.

Leaf water potential (Ψ_{leaf}) and electrolyte leakage (EL) were measured every two weeks around 1100 CST during both studies. Measurements of EL and Ψ_{leaf} included random sampling from each plot of three living leaves near the top of the plant canopy of ornamental species and 10 to 15 living leaves from each turfgrass plot. Leaves were placed in a Ziploc bag and quickly transported to the lab, where Ψ_{leaf} and EL samples were prepared within one hour of being harvested from the plots. The Ψ_{leaf} was measured with a water potential meter (WP4-T PotentiaMeter, Decagon Devices, Pullman, WA).

The technique used to determine EL was similar to the method of Blum and Ebercon (1981) and Marcum (1998) with modifications. Leaf samples were taken from each plot and placed in a test tube filled with 50 ml of deionized water. To maintain consistency in the length of cut leaf edges within each species, EL samples were prepared in the following manner: one 2-cm segment was cut out of three leaves taken from the *B. dactyloides* and *F. arundinacea* samples, exposing six cut ends of equal size within each turfgrass species; and three leaf disc samples were taken from three leaves of the *V. minor* and *A. reptans* samples using an eight mm diameter cork borer. Test tubes were shaken on a Titer Plate Shaker (Lab Line Instruments, Melrose Park, IL) for 24 h to dissolve electrolytes that had leaked from cells, presumably due to membrane damage caused by drought stress. An initial measurement of conductivity (C_1) was then measured with an Oakton Conductivity Meter (Model CON510 Series, OAKTON Instruments, Vernon Hills, IL). Thereafter, the test tubes were placed in a 90-100°C water bath for 1 h (Model MSB-1122A-1 Magni-Whirl Temp Water Bath, Blue M Electric, Blue Island, IL) to destroy all cell membranes. Test tubes were shaken for 24 h to extract the remaining electrolytes from the cells and a second conductivity measurement was taken (C_2). The calculation $(C_1/C_2)*100$ was used to determine the percentage of electrolytes that leaked due to drought stress.

Stomatal conductance (g_s) was measured every two weeks using a steady state diffusion porometer (Model SC-1 Leaf Porometer, Decagon Devices, Pullman, WA). Measurements were taken at 1300 CST on clear days to ensure that stomatal apertures would be near maximum for plants in all irrigation treatments. One living leaf of each ornamental species and of *F. arundinacea* was randomly selected near the top of the canopy, and four or five *B. dactyloides* leaves growing close to one another (enough to cover the measurement chamber orifice) were selected for measurements; one measurement was taken per plot.

Ancillary measurements

During both studies, volumetric soil water content (θ_v) was measured at 0-20 cm two times per week using time domain reflectometry (TDR). Because the TDR instrument used in 2010 (Model 6050X1, Soilmoisture, Santa Barbara, CA) malfunctioned between studies, a different TDR instrument was used in 2011 (TDR 300, item # 6430FS, Spectrum Technologies, Plainfield, IL).

To evaluate possible microclimate effects of the rainout shelter, air temperature (T_{air}) and relative humidity (RH) were monitored inside and outside of the rainout shelter during both studies. The T_{air} and RH were automatically logged every hour using a shaded, ventilated sensor (HOBO Pro v2, Onset Computer Corp., Bourne, MA) placed at 15 cm above the ground, which was slightly above the plant canopies. The PAR was measured at approximately 1300 CST on 15 July 2010 using a ceptometer (LP-80, Decagon Devices, Pullman, WA). Three PAR measurements (one over each block) from inside the rainout shelter were averaged and compared with PAR measured outside the rainout shelter. No PAR measurements were taken in 2011 because of a technical problem with the ceptometer. New plastic covering was installed at the beginning of each study, however, so it is likely that PAR intercepted by the plastic was similar between studies.

Vapor pressure deficit (VPD) was slightly higher inside than outside of the rainout shelter in both years. In 2010, daytime VPD inside and outside the shelter averaged 1.53 kPa and 1.37 kPa, respectively, and in 2011 daytime VPD inside and outside the shelter averaged 1.89 kPa and 1.74 kPa, respectively. Photosynthetically active radiation was reduced 16% by the plastic covering on the rainout shelter.

Plant materials from lysimeters were destructively harvested at the conclusion of each study to determine green leaf area index (LAI), aboveground green biomass, and leaf water content (LWC). All green leaf tissue was harvested and LAI was determined by a digital image analyzer (WinRHIZO Model 2002a, Regent Instruments, Quebec, Canada). Leaf samples were weighed to determine fresh weight (FW), then dried for 24 h at 60°C and weighed to determine dry weight (DW). The calculation (FW-DW)/(FW) x 100 was used to determine LWC.

Data analysis

Means of ET, measured from lysimeters in well-watered (100% ET) plots, as well as green LAI, aboveground green biomass, and LWC measured from the same lysimeters at the end of each study, were compared among species. Means of ET were tested for differences among species in the first week ET was measured, by two-week averages thereafter, and averaged over each entire study.

Means of θ_v, visual plant quality, EL, Ψ_{leaf}, and g_s were compared among species within each irrigation treatment, and among irrigation treatments within each species. Means were tested for differences on the first day measurements were taken (initial), by two-week averages thereafter, and averaged over each entire study.

All data were analyzed using the general linear model (GLM) procedure in SAS (SAS Institute, Cary, NC). Means were separated using Fisher's protected least significant difference (LSD) at P=0.05. The model for ET, green LAI, aboveground biomass, and LWC from well-watered plots (lysimeters) included only the factor of species, while the model for θ_v, visual plant quality, EL, Ψ_{leaf}, and g_s included the two factors of species and irrigation. Linear regression analysis between ET and green LAI was performed using the linear regression procedure in SigmaPlot 11.0 (Systat Software, Chicago, IL).

Results and Discussion

There was significant interaction between the two studies; therefore, data from each study are presented separately.

Evapotranspiration, green leaf area and aboveground biomass, and leaf water content in well-watered plots

Evapotranspiration of *B. dactyloides* was consistently lower than the other species, averaging 32 to 40% less across both studies (Fig. 1.1; Table 1.1). Bi-weekly averages of *B. dactyloides* ET ranged from 23 to 47% lower than *A. reptans* and *F. arundinacea* ET in both studies. Other research has also reported lower water use in *B. dactyloides* than in *F. arundinacea*. Qian et al. (1996) reported ET of *B. dactyloides* (5.1 mm d^{-1}) to be about 32% lower than *F. arundinacea* (6.75 mm d^{-1}). Kim and Beard (1988) reported similar results, with ET of *B. dactyloides* (4.8 mm d^{-1}) being 27% lower than *F. arundinacea* 'Kentucky 31' (6.1 mm d^{-1}). In a greenhouse study, Horst et al. (1997) reported water use of *B. dactyloides* to be 33%

lower than both *A. reptans* and *F. arundinacea.* They reported similar ET between *A. reptans* and *F. arundinacea* during the first year of their experiment. In the present study, which is the first field study to compare ET between these species, average water use was also similar between *A. reptans* and *F. arundinacea* in both years (Table 1.1), and in all bi-weekly averages of both studies except weeks 12 and 14 in 2010 (Fig. 1.1). Evapotranspiration of *A. reptans* and *B. dactyloides* was higher in 2011 than 2010 (Table 1.1). This is most likely because of a higher VPD in 2011 (1.89 kPa) than in 2010 (1.53 kPa).

Greater ET in *A. reptans* and *F. arundinacea* may be attributed to their green LAI, which was 1.6 to 2.6 times greater than in *B. dactyloides* in both studies (Table 1.1). In addition, g_s was greater in *A. reptans* in both years and *F. arundinacea* in 2010 than in *B. dactyloides* (Table 1.2), which likely contributed to greater ET rates in *A. reptans* and *F. arundinacea*. Green LAI was positively correlated with ET in all three species in 2010 (r^2=0.61) and 2011 (r^2=0.68), illustrating the effects of green, transpiring leaf area on ET rates (Fig. 1.2). Bremer (2003) also reported a positive correlation between LAI and ET of turfgrass grown in lysimeters.

Green LAI, aboveground green biomass, and LWC of *B. dactyloides* were consistently lower than the other two species in both studies with the exception of aboveground green biomass in 2010 being similar to *A. reptans* (Table 1.1). The lower LWC of *B. dactyloides* may relate to its greater drought resistance. Other research that has reported lower leaf relative water content is related to a plant's ability to withstand drought. A study evaluating drought performance of tropical tree seedlings reported a positive correlation (r^2=0.51) between species that performed well in a drought and species with lower leaf relative water content under well-watered conditions (Kursar et al., 2009).

Effects of irrigation deficit on visual plant quality and soil moisture content

Throughout both studies, visual quality in 100% ET plots never declined below a rating of eight among species (Fig. 1.3 A and B). All three species maintained quality ratings at or above minimal acceptability (rating of six or higher) in both 100% and 60% ET treatments (Fig. 1.3 A-D). This indicates *A. reptans*, *B. dactyloidies*, and *F. arundinacea* can be irrigated at 60% of their ET replacement requirements and still maintain an acceptable level of quality.

Near the end of each study, the quality of *B. dactyloides* was greater than the other two species in 20% ET (Fig. 1.3 E and F). Quality ratings of *A. reptans* and *F. arundinacea* generally declined faster than *B. dactyloides* in the irrigation-deficit treatments, particularly in 20% ET (Fig. 1.3 E and F). These data indicate *B. dactyloides* maintains quality better during drought.

Quality ratings of all three species in 20% ET plots declined faster in 2011 than 2010 (Fig. 1.3 E and F). For example, by week six visual quality remained high (near or above eight) in 2010 but had dropped to slightly greater than acceptable (six) in 2011. Additionally, the quality ratings at the completion of each study were 23 to 27% lower in 2011 than in 2010 for each species. Higher VPD in 2011 (1.89 kPa) than in 2010 (1.53 kPa) probably contributed to a faster dry down, loss of quality, and lower quality late in 2011.

A. reptans consistently had lower θ_v in 2010 indicating it used more water in the 0-20 cm soil profile than the other two species. Throughout 2010, the θ_v of *B. dactyloides* and *F. arundinacea* generally remained similar to one another among all three ET treatments (Fig. 1.4 A, C, and E). In 2011, however, θ_v was lower in both *A. reptans* and *B. dactyloides* than *F. arundinacea* (Fig. 1.4 D and F), suggesting *A. reptans* and *B. dactyloides* used more water in the 0-20 cm soil profile than *F. arundinacea*. *F. arundinacea* generally has an extensive, deep root system (Beard, 1973; Qian et al., 1997); this combined with the deep soils at the Rocky Ford

Turfgrass Research Center (Bremer et al., 2006; Su et al., 2008) probably allowed it to mine water from deeper in the soil profile.

Some *B. dactyloides* cultivars have deep roots (Engelke et al., 1991; Marcum et al., 1995; Richardson and Mancino, 1997) with root length densities at 30-60 cm depths similar to *F. arundinacea* (Qian et al., 1997). The *B. dactyloides* cultivar used in the present study, however, (Sharps Improved) had 94% of its total root count and 84% of its total root weight in the 0-20 cm soil profile in a previous greenhouse study (Marcum et al., 1995). In another field study, 44% of the total root weight of *B. dactyloides* 'Sharps Improved' was in the 0-30 cm soil profile (Richardson and Mancino, 1997). It is likely the roots of *B. dactyloides* were more developed at 0-20 cm by the second year of the study, allowing them to extract more water at that depth than during the previous year.

Electrolyte leakage

Deficit irrigation treatments did not affect EL among species with the exception of *A. reptans* at 20% ET (Fig. 1.5). On DOT 85 in 2010 and on the last three measurement days of 2011 (DOT 57, 71, and 85), EL in *A. reptans* was as much as 50% higher in 20% ET than in other irrigation treatments. This suggests a greater injury to cell membranes of *A. reptans* among species under severe drought although the quality of *A. reptans* remained similar to *F. arundinacea* at the end of the 2011 study (Fig. 1.3). Su et al. (2007) reported no significant effects of drought stress on EL among three cool-season turfgrass species grown at optimal temperatures. However, heat stress and heat and drought stress combined has reportedly increased EL of a number of turfgrass species (Du et al., 2009; Liu et al., 2007; Su et al., 2007, 2009).

On DOT 99 in 2010, EL increased abruptly in all species and irrigation treatments, which was likely the result of a freeze at the canopy level (Fig. 1.5). The T_{air} at 15 cm inside the rainout shelter dropped to 0.8°C on DOT 98 and 99. It is likely that the temperature at ground level dropped below freezing as it radiated heat into the atmosphere in the predawn hours (Campbell and Norman, 1998). Indeed, canopy temperature on turfgrass within 50 m of plots in this study, measured with infrared thermometers, revealed temperatures less than -4°C on both nights. The greatest increase in EL in 100% and 60% ET treatments was in *B. dactyloides*, indicating a greater sensitivity to freezing stress than the other species. In 20% ET, EL increased in *A. reptans* as much as in *B. dactyloides* on DOT 99, 2010, indicating a greater susceptibility to freezing damage in *A. reptans* when under drought stress.

Interestingly, EL was consistently greater in *B. dactyloides* than in *F. arundinacea* and *A. reptans* in 60 and 100% ET plots (Fig. 1.5 and Table 1.3); EL in 60 and 100% ET plots was also greater in *A. reptans* than in *F. arundinacea*. Because this pattern was evident under well-watered conditions, it probably represents normal differences in EL among species and is not indicative of tissue damage (Dr. C.B. Rajashekar, personal communication).

Leaf water potential

In 2011, the season-long average of Ψ_{leaf} was lower in 20% ET than 100% ET plots in all three species; a similar pattern was observed in *B. dactyloides* in 2010 (Table 1.4). With the exception of *A. reptans* in 2010, Ψ_{leaf} was 34 to 90% lower in the 20% ET than the 100% ET treatment by DOT 85 (Fig. 1.6). This illustrates the effects of increasing drought intensity on Ψ_{leaf} as the season progressed. VanDerZanden and Cameron (1996) reported drought stress lowered Ψ_{leaf} of 11 native *Fragaria chiloensis* varieties selected for use as ornamental groundcovers by as much as 86%. Qian and Fry (1997) also reported a decline of 70 to 86% of Ψ_{leaf} in four turfgrass species experiencing severe drought.

In well-watered plots, average seasonal Ψ_{leaf} was lower in *A. reptans* than in *F. arundinacea* in both years (Table 1.4). Similarly, Ψ_{leaf} was lower in *B. dactyloides* than *F. arundinacea* in 2011. These differences in Ψ_{leaf} among species in 100% ET plots were likely caused by natural differences among species. Qian and Fry (1997) found similar differences in Ψ_{leaf} among *F. arundinacea* and three warm-season turfgrass species under well-watered conditions. They reported the mean Ψ_{leaf} of the warm-season species (*B. dactyloides* included) to be 44% lower than *F. arundinacea*.

In irrigation deficit treatments, average seasonal Ψ_{leaf} was consistently lower in *A. reptans* and *B. dactyloides* than in *F. arundinacea* (Table 1.4). It is possible that in addition to natural differences, the deep roots of *F. arundinacea* (Beard, 1973; Su et al., 2008; Qian et al., 1997) may have allowed it to draw water from deeper in the profile and off-set the effects of drought in the irrigation deficit treatments. As discussed earlier, relatively shallower roots of the *B. dactyloides* cultivar in this study (Marcum et al., 1995; Richardson and Mancino, 1997) may have limited access to water deeper in the profile and contributed to its lower Ψ_{leaf} than *F. arundinacea* in the irrigation deficit treatments in this study. These findings indicate Ψ_{leaf} of *A. reptans* and *B. dactyloides* are more affected by drought stress than *F. arundinacea*, with the greatest impact of the drought on Ψ_{leaf} of *A. reptans*, although plant visual quality ratings do not reflect this (Fig. 1.3).

Stomatal conductance

There were no water deficit effects on g_s in *F. arundinacea* in either study (Table 1.2). The typically extensive, deep root system of *F. arundinacea* (Beard, 1973; Qian et al., 1997) combined with deep soils at the research site (Bremer et al., 2006; Su et al., 2008) probably allowed *F. arundinacea* to draw water from deeper in the soil profile than the other species. In 2010, season-long g_s in *B. dactyloides* was 25% less under 20% ET irrigation than 100% ET irrigation. However, there was no deficit irrigation effect on season-long g_s in *B. dactyloides* in 2011. It is possible that the root system in *B. dactyloides* had developed more by the second year of the study, allowing the plants to mine more water from the soil profile. A deep root system probably helped to maintain high g_s in *F. arundinacea* in both years, and *B. dactyloides* in 2011, even under water deficit.

The average, season-long g_s of *A. reptans* was 39% to 52% less in 60% and 20% ET than in 100% ET plots (Table 1.2). This indicates the g_s of *A. reptans* was more sensitive to drought than the other two species in the study. Soil moisture in the 0-20 cm profile was generally depleted more in *A. reptans* than *F. arundinacea* in both years and *B. dactyloides* in 2010 (Fig. 1.4). Drier soils may result in stomatal closure, presumably via signal hormones such as ABA that increase in roots of water-deficit plants (Kramer and Boyer, 1995). Other ornamental species have exhibited similar reductions in g_s when water is limited. For example, in *Callistemon laevis*, g_s was approximately 63% lower under water deficit (40% ET) than in well-watered plants, averaged over a 16 week period (Alvarez et al., 2011). The g_s of ornamental lily (*Lilium spp.* 'Sorbonne') receiving no irrigation for 20 days was 93% lower than g_s of well-watered plants on day 20 of the study (Zhang et al., 2011).

Conclusions

In order to reduce water inputs in residential and commercial landscapes, the recommendation should not necessarily be to replace turfgrass with ornamental landscape species. Results indicate *B. dactyloides* is a good choice for landscapes where water is limited because of its lower water use rate and its ability to maintain plant quality above minimal acceptability for more than ten weeks when receiving 20% ET replacement. *A. reptans* may be a less appealing choice for landscapes where water conservation is of concern given its high ET rate, plant quality ratings which were deleteriously affected by irrigation-deficit treatments, and lower plant water status during drought. Water use of *F. arundinacea* was also high and plant quality was reduced by water deficit treatments. However, physiological responses to irrigation-deficit treatments were least affected in *F. arundinacea* among species, likely because of the deep root system of *F. arundinacea* and the deep soils at the Rocky Ford Turfgrass Research Center (Bremer et al., 2006; Su et al., 2008). This indicates good drought resistance in *F. arundinacea* where soils are deep.

Due to a fungus infestation (*Phoma exigua*) that damaged all *Vinca minor* plots during both of these studies, we were not able to accomplish our original goal of evaluating another non-turf landscape plant in this study. Research continues to be limited on the comparative water use between popular turfgrass species and other landscape plants; therefore more field research is needed to evaluate the water use and drought resistance in other landscape plants.

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Figures

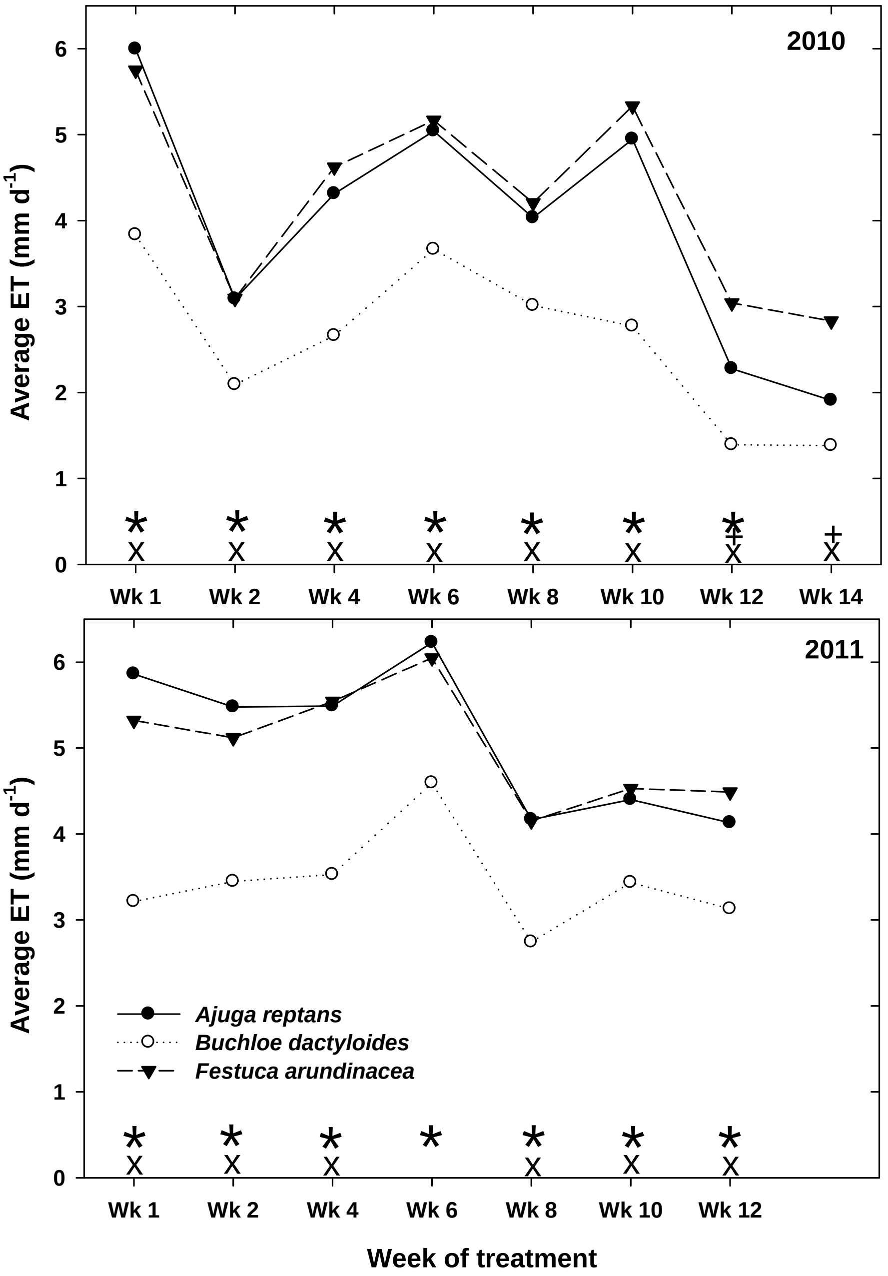

Figure 1.1 Average evapotranspiration (ET) among species for both studies. Data collection occurred from 28 June to 4 Oct. 2010, and from 20 June to 12 Sept. 2011. Symbols along the abscissa of each graph indicate significant differences (P=0.05) between: *A. reptans* and *B. dactyloides* (*); *B. dactyloides* and *F. arundinacea* (x); and *F. arundinacea* and *A. reptans* (+); on the first week of measurement and bi-weekly thereafter.

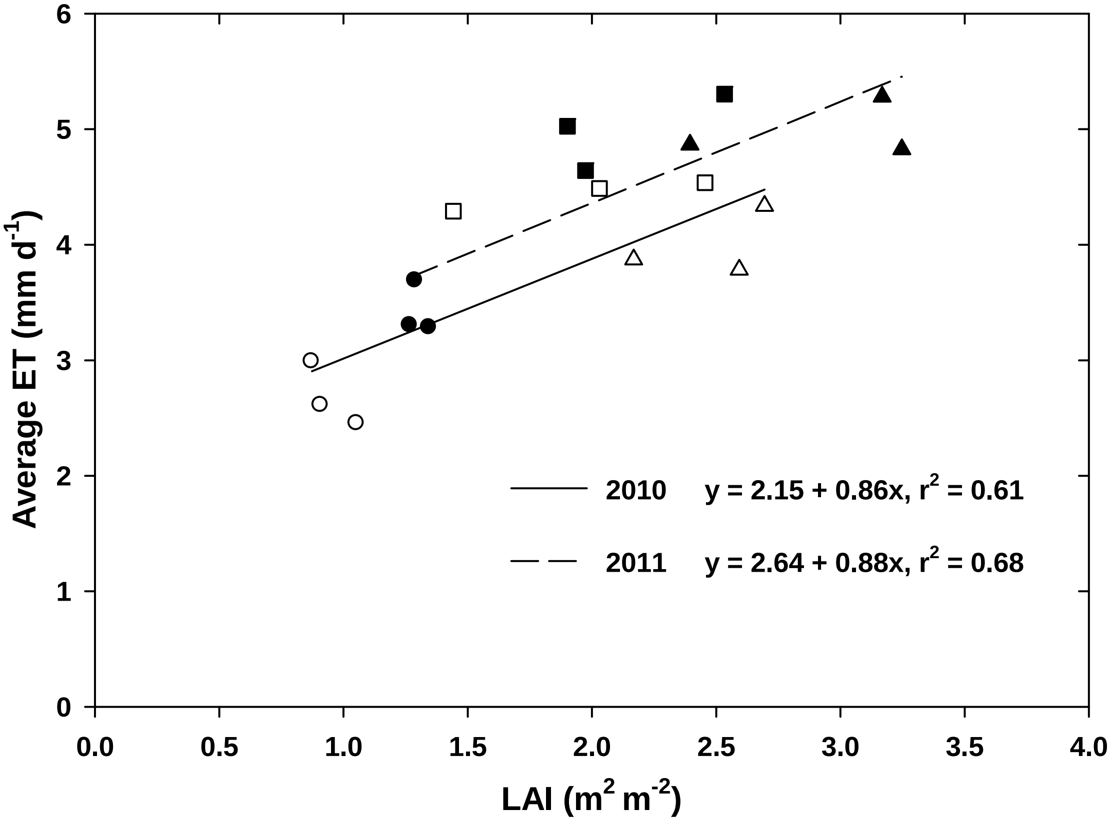

Figure 1.2 Regression models in each year between average evapotranspiration (ET) and green leaf area index (LAI), with all species pooled. Open symbols represent 2010 data and closed symbols represent 2011 data. Triangles, circles, and squares represent *Ajuga reptans*, *Buchloe dactyloides*, and *Festuca arundinacea*, respectively.

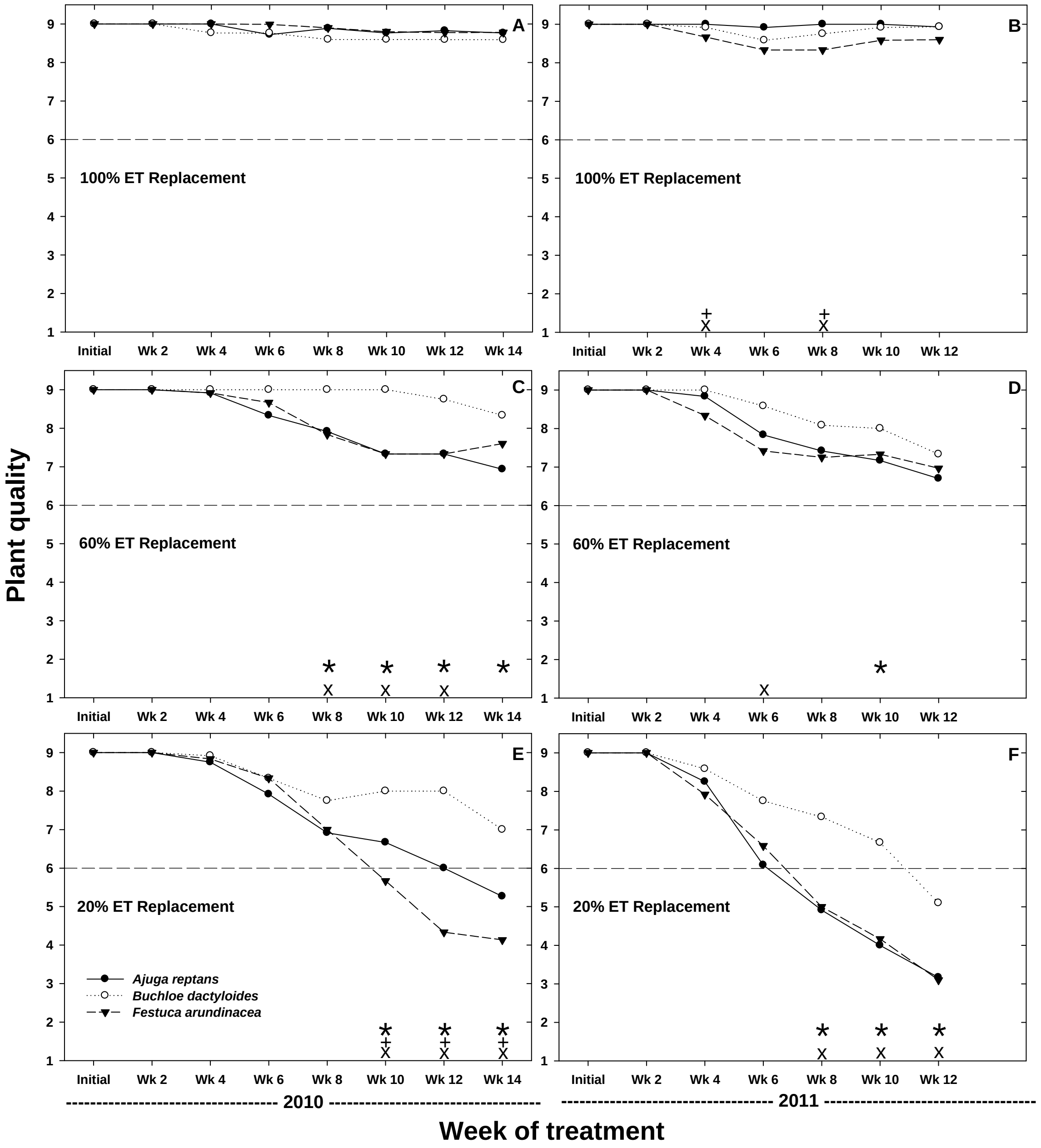

Figure 1.3 Effects on visual plant quality of: 100% ET in 2010 (A) and 2011 (B), 60% ET in 2010 (C) and 2011 (D), and 20% ET in 2010 (E) and 2011 (F). Data collection occurred from 28 June to 4 Oct. 2010, and from 20 June to 12 Sept. 2011. Horizontal dashed line indicates minimal acceptability (quality of six). Symbols along the abscissa of each graph indicate significant differences (P=0.05) between: *A. reptans* and *B. dactyloides* (*); *B. dactyloides* and *F. arundinacea* (x); and *F. arundinacea* and *A. reptans* (+); on the initial measurement and bi-weekly averages.

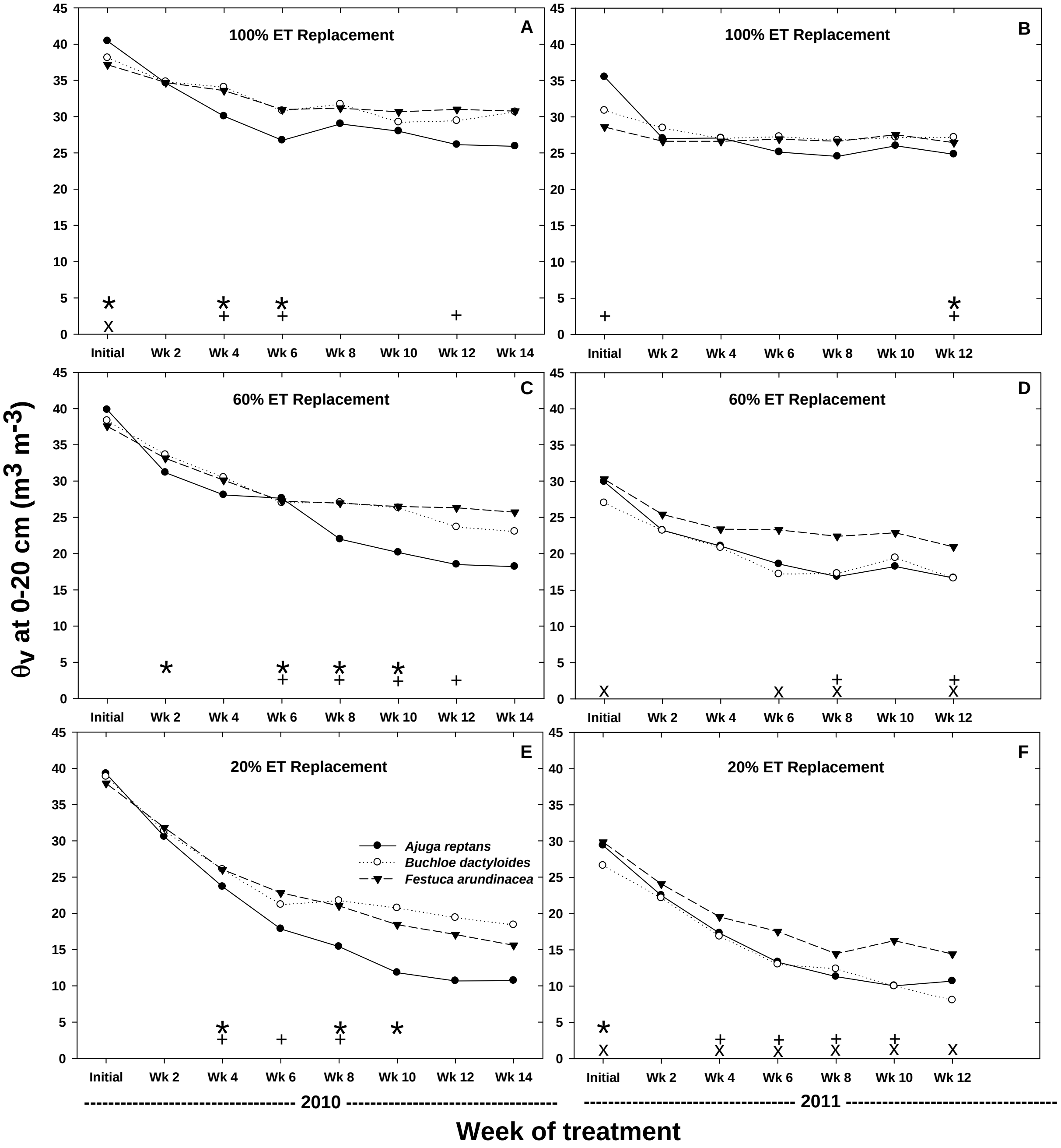

Figure 1.4 Effects on volumetric soil water content (θ_v) of: 100% ET in 2010 (A) and 2011 (B), 60% ET in 2010 (C) and 2011 (D), and 200% ET in 2010 (E) and 2011 (F). Data collection occurred from 28 June to 4 Oct. 2010, and from 20 June to 12 Sept. 2011. Symbols along the abscissa of each graph indicate significant differences (P=0.05) between: *A. reptans* and *B. dactyloides* (*); *B. dactyloides* and *F. arundinacea* (x); and *F. arundinacea* and *A. reptans* (+); on the initial measurement and bi-weekly averages.

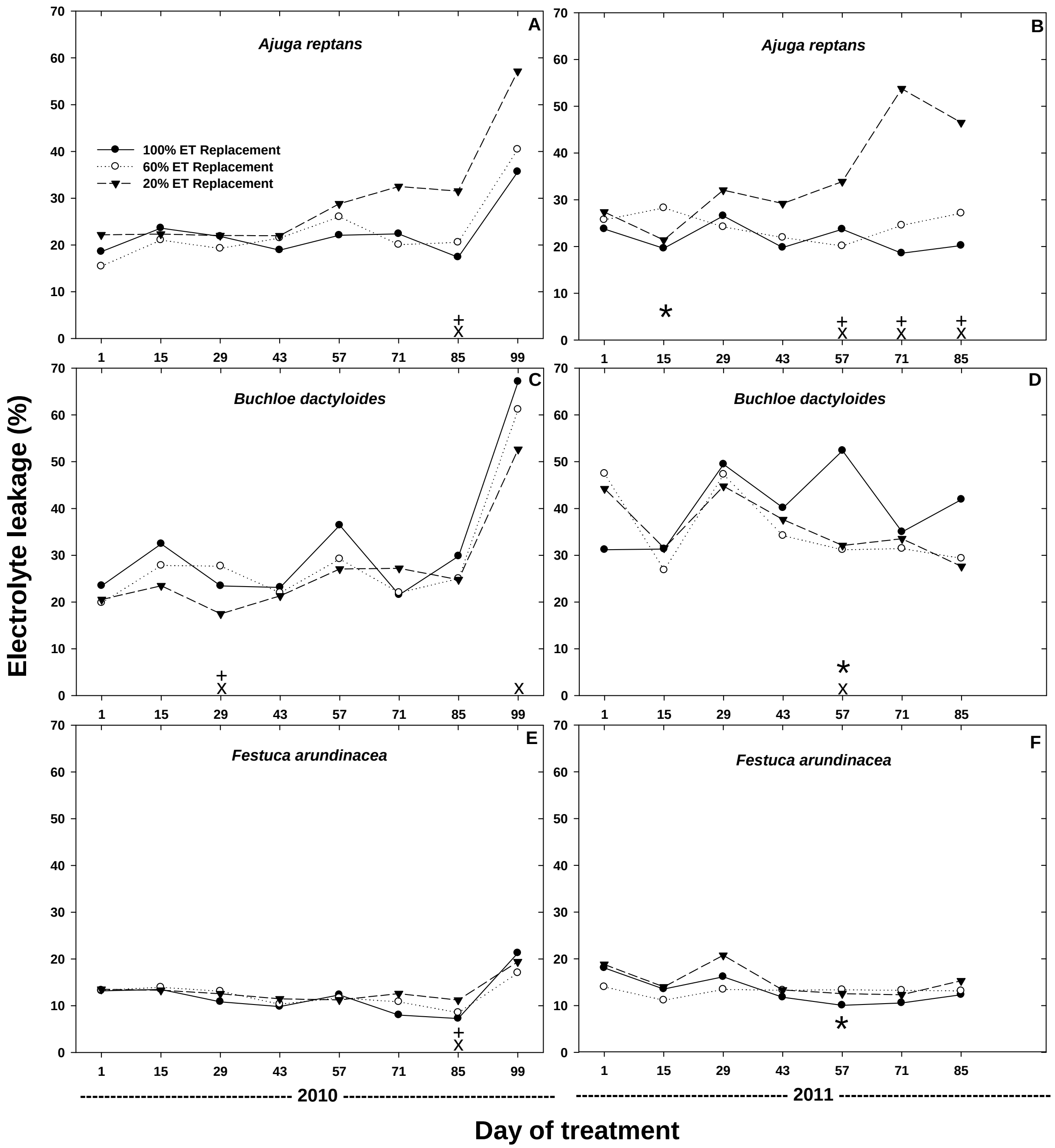

Figure 1.5 Effects on electrolyte leakage of: *A. reptans* in 2010 (A) and 2011 (B), *B. dactyloides* in 2010 (C) and 2011 (D), and *F. arundinacea* in 2010 (E) and 2011 (F). Data collection occurred from 28 June to 4 Oct. 2010, and from 20 June to 12 Sept. 2011. Symbols along the abscissa of each graph indicate significant differences (P=0.05) between: 100% ET and 60% ET (*); 20% ET and 100% ET (x); and 60% ET and 20% ET (+); on the initial measurement and bi-weekly averages.

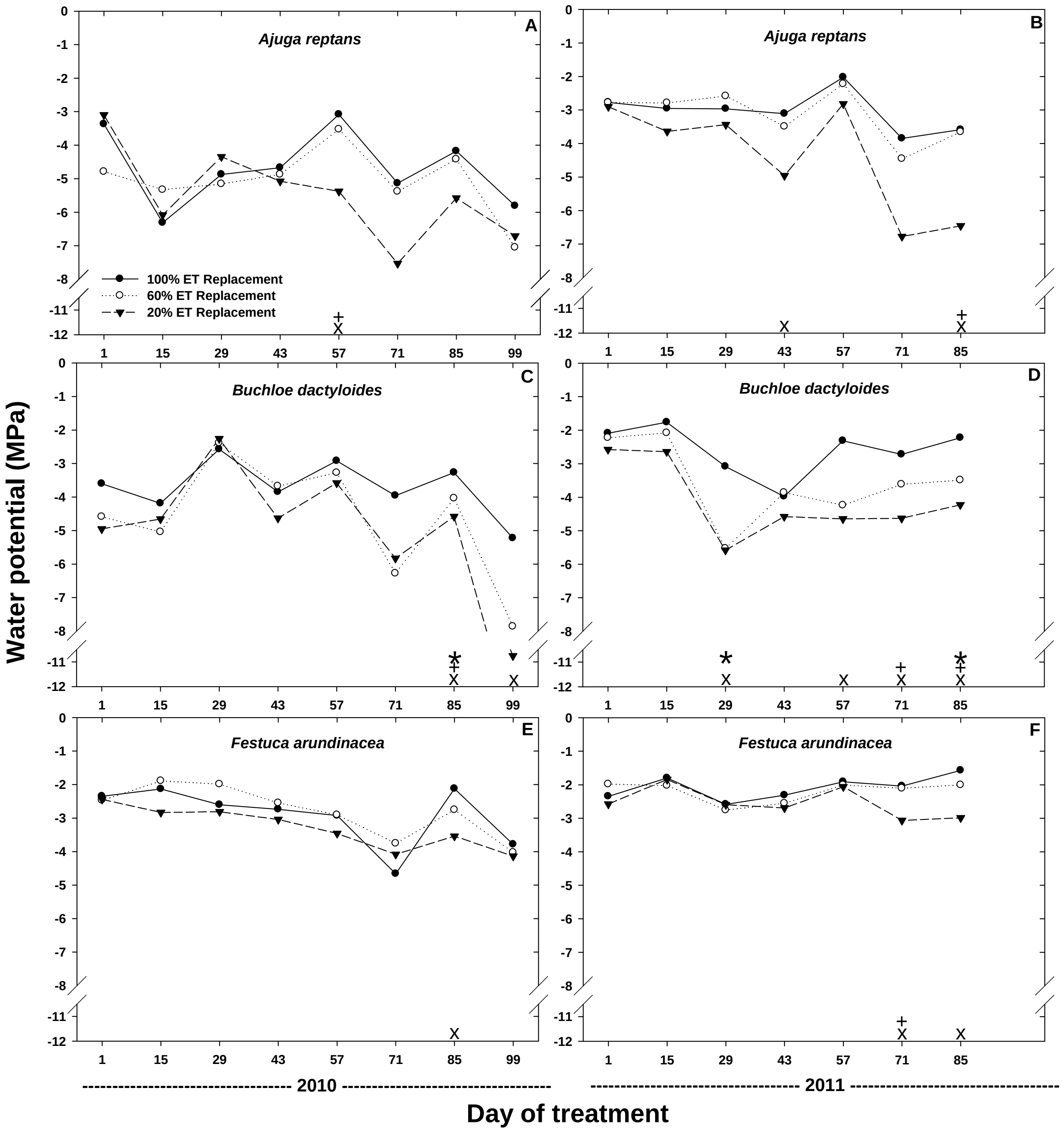

Figure 1.6 Effects on leaf water potential (Ψ_{leaf}) of: *A. reptans* in 2010 (A) and 2011 (B), *B. dactyloides* in 2010 (C) and 2011 (D), and *F. arundinacea* in 2010 (E) and 2011 (F). Data collection occurred from 28 June to 4 Oct. 2010, and from 20 June to 12 Sept. 2011. Symbols along the abscissa of each graph indicate significant differences (P=0.05) between: 100% ET and 60% ET (*); 20% ET and 100% ET (x); and 60% ET and 20% ET (+); on the initial measurement and bi-weekly averages.

Tables

Table 1.1 Average evapotranspiration (ET), green leaf area index (LAI), aboveground green biomoss, and leaf water content (LWC) of the lysimeters in well-watered plots in 2010 and 2011.

Species	ET^z mm d^{-1}		Green LAI		Green Biomass (g m^{-2})		LWC (%)	
	2010	2011	2010	2011	2010	2011	2010	2011
Ajuga reptans	4.00 $A^y b^x$	5.00 Aa	2.49 Aa	2.94 Aa	7.88 ABb	19.48 Ba	80.1 Aa	68.1 Ab
Buchloe dactyloides	2.68 Bb	3.42 Ba	0.95 Bb	1.30 Ca	4.51 Bb	15.21 Ca	47.7 Ba	35.6 Ca
Festuca arundinacea	4.44 Aa	4.99 Aa	1.98 Aa	2.14 Ba	8.66 Ab	23.94 Aa	66.1 Aa	56.1 Bb

[z] Averaged from 28 measurements in 2010 and 24 measurements in 2011.

[y] Within a column, means followed by the same upper-case letter are not statistically different according to LSD (*P*=0.05).

[x] Within a row, within each category, means followed by the same lower-case letter are not statistically different according to LSD (*P*=0.05).

Table 1.2 Average, season-long stomatal conductance (g_s) among species within each irrigation treatment for 2010 and 2011.

Species	g_s (mmol $m^{-2}s^{-1}$)[z]					
	2010[y]			2011		
	100% ET	60% ET	20% ET	100% ET	60% ET	20% ET
Ajuga reptans	475.3 A[x]a[w]	261.6 ABb	227.3 Ab	448.5 Aa	274.0 Ab	253.6 Ab
Buchloe dactyloides	201.5 Ba	164.7 Bab	151.6 Ab	186.9 Ba	175.4 Aa	163.3 Ba
Festuca arundinacea	360.9 Aa	309.1 Aa	292.5 Aa	257.3 Ba	229.0 Aa	264.5 Aa

[z] Averaged from eight measurements in 2010 and seven measurements in 2011.

[y] 2010 means do not include data from day of treatment (DOT) 99 because of freezing temperatures on DOT 98 and 99.

[x] Within a column, means followed by the same upper-case letter are not statistically different according to LSD (*P*=0.05).

[w] Within a row, within each year, means followed by the same lower-case letter are not statistically different according to LSD (*P*=0.05).

Table 1.3 Average, season-long electrolyte leakage (EL) among species within each irrigation treatment for 2010 and 2011.

Species	EL (%)[z]					
	2010[y]			2011		
	100% ET	60% ET	20% ET	100% ET	60% ET	20% ET
Ajuga reptans	20.66 B[x]a[w]	20.54 Ba	25.88 Aa	21.73 Bb	24.54 Bb	34.78 Aa
Buchloe dactyloides	27.17 Aa	24.72 Aa	23.11 Aa	40.18 Aa	35.37 Ab	35.90 Aab
Festuca arundinacea	10.69 Ca	11.66 Ca	12.26 Ba	13.21 Ca	13.85 Ca	15.30 Ba

[z] Averaged from eight measurements in 2010 and seven measurements in 2011.

[y] 2010 means do not include data from day of treatment (DOT) 99 because of freezing temperatures on DOT 98 and 99.

[x] Within a column, means followed by the same upper-case letter are not statistically different according to LSD (*P*=0.05).

[w] Within a row, within each year, means followed by the same lower-case letter are not statistically different according to LSD (*P*=0.05).

Table 1.4 Average, season-long leaf water potential (Ψ_{leaf}) among each species within each irrigation treatment for 2010 and 2011.

Species	Ψ_{leaf} (MPa)[z]					
	2010[y]			2011		
	100% ET	60% ET	20% ET	100% ET	60% ET	20% ET
Ajuga reptans	-4.52 B[x]a[w]	-4.78 Ba	-5.30 Ca	-3.02 Ca	-3.14 Ba	-4.43 Bb
Buchloe dactyloides	-3.48 ABa	-4.18 Bab	-4.36 Bb	-2.60 Ba	-3.58 Bb	-4.13 Bb
Festuca arundinacea	-2.79 Aab	-2.62 Aa	-3.17 Ab	-2.08 Aa	-2.21 Aab	-2.55 Ab

[z] Averaged from eight measurements in 2010 and seven measurements in 2011.

[y] 2010 means do not include data from day of treatment (DOT) 99 because of freezing temperatures on DOT 98 and 99.

[x] Within a column, means followed by the same upper-case letter are not statistically different according to LSD (*P*=0.05).

[w] Within a row, within each year, means followed by the same lower-case letter are not statistically different according to LSD (*P*=0.05).

Chapter 2 - Responses of Turfgrass and Ornamental Landscape Species to Prolonged Drought Stress

Abstract

With the depletion of water resources it is not uncommon for municipalities to restrict irrigation of urban landscapes, causing plants to experience drought stress. Few data are available on the drought resistance of non-turfgrass landscape species. This study evaluated the performance of one turfgrass (*Poa pratensis* L. 'Apollo') and eight landscape species (*Achillea millifolium* L.*, Ajuga reptans* L. 'Bronze Beauty'*, Liriope muscari* Decne.*, Pachysandra terminalis* Siebold and Zucc.*, Sedum album* L.*, Thymus serpyllum* L.*, Vinca major* L., and *Vinca minor* L.) during a severe dry down and subsequent recovery. This greenhouse study was conducted in the spring/summer and again in the fall of 2010. *S. album* performed the best, averaging 254 d to decline to a quality rating of one (1-9 scale, 1=dead/dormant and 9=best quality). *L. muscari* and *P. terminalis* also performed well, averaging 86 d. *V. minor* and *V. major* declined faster than the previous species, averaging 63 d to a rating of one. *A. millifolium*, *A. reptans*, *P. pratensis*, and *T. serpyllum* performed the worst, averaging 52 d to decline to a quality rating of one. Thereafter, irrigation was resumed, and after 60 d the only species to recover were *P. pratensis* [46% pot cover (PC)], *S. album* (38% PC), and *V. major* (35% PC) in the spring/summer study; no species recovered during the fall study. Results indicate *S. album*, *L. muscari*, and *P. terminalis* would be the most successful of the species evaluated in landscapes where severe drought may occur. In landscapes with intermittent or less severe droughts, *V. minor* and *V. major* may also be good selections, as well as *P. pratensis* if periods of dormancy are acceptable to homeowners.

Introduction

Water resources continue to be depleted as the world's population grows. American families can use up to 400 gallons of water per day, and more than 50% may be used outdoors (Smith and Brown, 2003). Alig et al. (2004) predicted urbanization to increase by as much as 80% between 2004 and 2025, indicating more land will be used for residential and commercial landscapes. This, along with already limited water supplies, illustrates a need for conserving water in the lawn and landscape. Selection of drought tolerant species for use in the landscape may be one solution.

It is not uncommon for water municipalities to impart water restrictions on residential landscapes, which can cause plants to experience drought stress. Including plants in the landscape that have the ability to maintain their quality longer or experience dormancy during drought, and recover afterwards, would be beneficial in areas with water restrictions. A number of studies have evaluated drought resistance of turfgrass species in the greenhouse or growth chamber (Huang and Gao, 1999; Jiang and Huang, 2001; Liu et al., 2007; Qian and Fry, 1997) or in the field (Hook et al., 1992; Karcher et al., 2008; Merewitz et al., 2010; Richardson et al., 2008; Steinke et al., 2010). Few studies, however, have assessed drought resistance of ornamental landscape species or directly compared drought resistance between turf and non-turf groundcovers (Devitt and Morris, 2008; Staats and Klett, 1995).

Previous research has indicated succulents, such as those in the *Sedum* genera, have performed well on green roofs, where moisture is typically a limiting factor (Bousselot et al., 2010 and 2011; Kircher, 2004; Monterusso et al., 2005). One reason *Sedum* is well suited for possible drought situations such as on green roofs is that *Sedum* has the ability to switch from using a C_3 photosynthetic pathway to a Crassulacean Acid Metabolism (CAM) photosynthetic pathway when growing in an environment where water is limiting (Phillips and Burrell, 1993; Sayed et al., 1994). This minimizes water loss during the day, when temperatures and evaporation are highest.

Among cool-season grasses, *Poa pratensis* is the most commonly used in the United States for residential and commercial lawns, parks, and golf courses (Christians, 2004; Lyman et al., 2007; Turgeon, 2005). One advantage of *P. pratensis* is its ability to survive during extended drought through dormancy (Christians, 2004; Goldsby et al., 2011). Studies have examined drought resistance of *P. pratensis* by initiating severe dry downs and evaluating plant responses (Keeley and Koski, 2001; Liu et al., 2007; Merewitz et al., 2010; Richardson et al., 2008 and 2009). Richardson et al. (2009) found wide variation in responses to drought among *P. pratensis* cultivars and suggested selection of better-performing cultivars could result in water conservation.

Turfgrasses are often singled out for replacement by presumably more water-efficient plant species in order to save water. For example, in 2006 the United States Environmental Protection Agency (EPA) created a voluntary program called WaterSense to promote water efficiency (WaterSense, 2008). This program lists criteria for builders to follow to have a home labeled a WaterSense home. At the inception of WaterSense in 2006, the outdoor water efficiency component of the program required a reduction in the area of turfgrass in the landscape for the home to qualify for the WaterSense label. Research is needed, however, to either validate or refute claims that turfgrass uses more water or is less drought resistant than ornamentals.

Therefore, the objectives of this study were to: 1) Evaluate visual quality and water status of one turfgrass and eight non-turf ornamental landscape species during a severe dry down, and 2) Evaluate visual quality of the same species during recovery from the severe dry down.

Materials and Methods

Preparation and maintenance of plants in nursery containers

Two studies were conducted to evaluate performance among species during severe dry downs. One study was conducted in the spring/summer and a second in the fall of 2010. Nursery containers (25 cm diam. by 29.5 cm deep) were filled with field soil from the Rocky Ford Turfgrass Research Center near Manhattan, Kansas. The soil was a Chase silt loam (fine, smectitic, mesic, Aquertic, Argiudolls). The bulk density inside the nursery containers was 1.53 g cm^{-3}. Plant species were established in the Throckmorton Plant Sciences Center greenhouse complex in Manhattan, Kansas (39°11’40” N, 96°35’5” W). One turfgrass species, *P. pratensis* ‘Apollo’, and eight commonly used ornamental landscape species were selected for the study. The ornamental species were *Achillea millifolium, Ajuga reptans* ‘Bronze Beauty’*, Liriope muscari, Pachysandra terminalis, Sedum album, Thymus serpyllum, Vinca major,* and *Vinca minor.* Turfgrass was established in nursery containers with sod from the Rocky Ford Turfgrass Research Center. The ornamental species were established by washing potting soil from the roots of three plants grown in nursery containers (11.4 cm diam. by 9.5 cm deep), purchased from a local garden center, and transplanted to the 25 cm diam. containers. Three nursery containers of each species were established in each study as replicates.

Continuous measurements of air temperature, relative humidity, and PAR were recorded at canopy height in the same vicinity as the containers during establishment and throughout each study. Air temperature and relative humidity were measured using a shaded, ventilated sensor (CS500, Campbell Scientific, Logan, UT) and PAR was measured using a quantum sensor (LI-190SA, LI-COR, Lincoln, NE). Measurements were automatically logged every minute, and then averaged and recorded every hour with a micrologger (CR10, Campbell Scientific, Logan, UT).

Establishment of plants for the spring/summer study took place from 19 Nov. 2009 through 17 May 2010. Average day/night air temperature was 25°C / 23°C and supplemental light was included for 12-h d^{-1}. Plants for the fall study were established from 6 June 2010 through 26 Sept. 2010. Average day/night air temperature was 26°C / 26°C and no supplemental light was used since establishment was during the summer. Daily maximum photosynthetically active radiation (PAR) during the establishment of the plants ranged from 296 to 874 μmol $m^{-2}s^{-1}$ (spring/summer) and 362 to 1207 μmol $m^{-2}s^{-1}$ (fall). Containers were maintained well-watered during establishment of both studies and fertilized approximately 60 d before the beginning of the dry down at a rate of 49 kg N ha^{-1} (46N-0P-0K). Turfgrass in the containers was mowed once weekly at 9 cm and both turfgrass and ornamentals were kept trimmed to the outside edge of the container to keep the area of vegetation cover consistent among species.

Insecticide applications for controlling aphids, white fly, spider mites, and scale during the establishment period included imidacloprid {1-[(6-Chloro-3-pyridinyl)methyl]-*N*-nitro-2-imidazolidinimine} at 0.014 kg a.i. ha^{-1} on 12 Jan. 2010 and 2 Feb. 2010; spinosad [mixture of (spinosyn A, R=H) and (spinosyn D, R=CH_3)] at 0.2 kg a.i. ha^{-1} on 12 Jan. 2010; bifenazate [hydrazine carboxylic acid, 2-(4-methoxy-[1,1-biphenyl]-3-yl) 1-methylethyl ester] at 0.06 kg a.i. ha^{-1} on 2 Feb. 2010 and 10 Sept. 2010; buprofezin (2-tert-butylimino-3-isopropyl-5-phenylperhydro-1,3,5-thiadiazin-4-one) at 0.4 kg a.i. ha^{-1} on 9 Mar. 2010; and pymetrozine [6-

methyl-4-(pyridine-3-ylmethylideneamino)-2,5-dihydro-1,2,4-triazin-3-one] at 0.37 kg a.i. ha^{-1} on 10 Sept. 2010.

Once plants were established, containers were arranged in the greenhouse in a randomized complete block design with three replications. To begin the severe drought, irrigation of the containers ceased on 18 May 2010 for the spring/summer study and 27 Sept. 2010 for the fall study. No irrigation was applied during each dry down. Plant visual quality, container weight, volumetric soil water content, and a number of physiological factors described below were measured until the plants were either dormant or dead. Irrigation was then applied to the container and percentage of plant density was evaluated for 60 days to determine the level of recovery, if any, from the severe drought.

Supplemental light was not used during the spring/summer study but was used in the fall study for 16-h d^{-1} to simulate the longer day lengths during the spring/summer study. Daily maximum PAR during each study ranged from 267 to 909 $\mu mol\ m^{-2}s^{-1}$ (spring/summer) and 301 to 1180 $\mu mol\ m^{-2}s^{-1}$ (fall).

Container water loss and visual plant quality

Measurements of container water loss and visual plant quality were taken three times per week. Container water loss was measured by weighing containers to the nearest gram using an electronic balance (Model GMBH, Sartorius Gottingen, Germany). Plant quality was evaluated visually using a scale of 1 to 9 (1=brown/dead, 6=minimally acceptable for home landscape, and 9=optimum quality) according to plant density, uniformity, and color. This scale is the standard for evaluating turfgrass in the National Turfgrass Evaluation Program (NTEP; Morris, 2000) and was adapted to ornamentals for consistency across all species. Plant density was evaluated using a similar scale of 1 to 9 (1=no green cover, 6= approx. 50% green cover, 9=100% green cover). Plant density ratings were made during both the dry down and recovery phases of the studies.

Leaf water potential, volumetric soil water content, and stomatal conductance

Measurements of leaf water potential (Ψ_{leaf}) were collected from plants in each container during the dry downs at pre-determined intervals of soil water potential (Ψ_{soil}). Because frequent measurements of Ψ_{soil} were impractical during the dry downs, Ψ_{soil} was approximated by volumetric soil water content (θ_v). Measurements of θ_v in the 0-20 cm soil profile were taken three times per week using time domain reflectometry (TDR) (model 6050X1, Soilmoisture Equipment Corp., Santa Barbara, CA). Relationships between Ψ_{soil} and θ_v were determined by developing a soil moisture release curve using a water potential meter (WP4-T PotentiaMeter, Decagon Devices, Pullman, WA) (Fig. 2.1). To construct the curve, Ψ_{soil} was measured in soil samples prepared at known, increasing increments of θ_v.

As θ_v declined during the dry downs, Ψ_{leaf} was measured from each container when θ_v was within the ranges indicated in Table 2.1. A final measurement of Ψ_{leaf} was taken when the plant in the container had declined to a quality rating of one. On measurement dates for each container, living leaves were randomly selected from the top of the plant canopy at approximately 1100 CST. Leaves were then placed in a Ziploc bag and transported quickly to the lab, where Ψ_{leaf} samples were prepared within one hour of being harvested from the pots.

Stomatal conductance (g_s) was measured at the beginning stages of the dry down until g_s was no longer detectable. Measurements were collected at 1300 CST every two to eight days, when sky conditions were clear, using a steady state diffusion porometer (SC-1, Decagon Devices, Pullman, WA). One living leaf of the ornamentals was randomly selected near the top of the canopy, and five or six *P. pratensis* leaves growing close to one another (enough to cover the measurement chamber orifice), were selected for measurements. One measurement was taken per container. Stomatal conductance was no longer detectable in any species after 35 and 36 days of treatment (DOT) during the spring/summer and fall studies, respectively.

To evaluate possible effects of PAR on g_s, PAR was measured with a quantum sensor (LI-190SA, LI-COR, Lincoln, NE) between each g_s measurement. All measurements of g_s and PAR generally required about 30-min on each measurement day. Stomatal conductance was not measured on three species (*A. millifolium*, *T. serpyllum*, and *S. album*) because their leaves were too small to cover the measurement chamber orifice of the porometer.

Data analysis

Weekly averages of θ_v, total water loss, and plant quality data were calculated among species. Plant quality, water loss, and θ_v were analyzed for differences among species using the general linear model (GLM) procedure in SAS as a randomized complete block design (SAS Institute, Cary, NC). Means were separated using Fisher's protected least significant difference (LSD) at P=0.05.

Within each pre-determined range of Ψ_{soil} (or θ_v), Ψ_{leaf} was compared among species. Additionally, g_s data were evaluated for differences among species on each measurement day. Due to missing data points in both Ψ_{leaf} and g_s, the mixed model procedure in SAS was used. Means were separated using LSD at P=0.05. During both studies, the containers sometimes dried down so rapidly between measurement days as to occasionally pass over pre-determined θ_v ranges, resulting in missing Ψ_{leaf} data points. Also, g_s was below detectable limits in some containers within a species treatment near the end of each dry down, resulting in no recorded measurement.

Results and Discussion

There was significant interaction between the two studies; therefore, data from each study are presented separately.

Visual plant quality

To illustrate transient trends among species, average plant quality is presented for weeks one, three, and six (Fig. 2.2). During the spring/summer study, individual containers of some species had declined to a quality rating of one by week six (i.e., no data was collected from those containers thereafter). All species maintained minimal acceptable quality (6 or higher) through week three in both studies with the exception of *P. pratensis* in the fall. In a field study in New Jersey, USA, visual turf quality in two *P. pratensis* cultivars also dropped below a rating of six by two to three weeks after irrigation was curtailed (Merewitz et al., 2010). In a field study near the present greenhouse study, the visual quality of *P. pratensis* declined below six by about two weeks after beginning a water-deficit treatment of 20% of evapotranspiration replacement (Fu et al., 2004).

S. album and *L. muscari* maintained a quality rating greater than six through week six of both dry downs (Fig. 2.2), longer than all other species. The quality of *P. terminalis* also remained greater than six through week six of the spring/summer study. *V. minor* and *V. major* maintained quality longer than the remainder of the species in both studies with the exception of *P. terminalis* which varied more between the spring/summer and fall studies than the other species. This suggests *S. album*, *L. muscari*, *V. major*, *V. minor*, and *P. terminalis* may be able to maintain quality longer in landscapes experiencing extended periods of drought. The quality of *A. millifolium*, *A. reptans*, *P. pratensis*, and *T. serpyllum* dropped below three by week six in both studies (Fig. 2.2) indicating they may have less ability to maintain their quality during severe drought than the remainder of species.

When evaluating the overall period of decline in quality to a rating of one among species, *S. album* persisted two to three times longer than the next best performing species during drought; *S. album* required 266 d in the spring/summer and 241 d in the fall before declining to a quality rating of one (Fig. 2.3). The quality of *L. muscari* and *P. terminalis* also declined slower than the remainder of species in the spring/summer, taking 122 d and 62 d, respectively, to decline to a rating of one. In the fall, *L. muscari* and *P. terminalis* also persisted well although not as pronouncedly better among species as in the spring/summer.

In the spring/summer, the fastest decline to a quality of one among species was in *A. reptans*, *A. millifolium*, and *P. pratensis* (39 d each), and in *T. serpyllum* (42 d) (Fig. 2.3). This is similar to the initial trend observed among these four species during the first six weeks in both studies (Fig. 2.2). In the fall, *T. serpyllum* declined the fastest, followed by *A. millifolium*, *P. pratensis*, and *V. minor*. Thus, in both studies the persistence in quality during drought was generally least in *T. serpyllum*, *A. millifolium*, and *P. pratensis*. Although the quality of *A. reptans* remained above one longer than the latter three species in the fall, its low quality by week six (Fig. 2.2) combined with its rapid decline in the spring/summer (Fig. 2.3) indicates a generally low endurance to prolonged drought.

Only three species recovered from the drought during the spring/summer: *P. pratensis* [46% Pot Cover (PC)]; *S. album* (38% PC); and *V. major* (35% PC). Given the general lack of recovery among species, it is likely that most had surpassed permanent wilting point by the time they received a quality rating of one. The recovery in *P. pratensis*, which was the greatest among species at the end of the 60-d recovery period, indicates its capacity to recover well from complete dormancy. Richardson et al. (2009) reported similar results in the recovery of 14 cultivars of *P. pratensis* after a severe dry down, in which irrigation was withheld until plots reached 25% green cover. Those authors found that all cultivars recovered to 50% green cover after 4.2 to 18.9 days of recovery. Merewitz et al. (2010) evaluated four *P. pratensis* cultivars through a five-week drought and the recovery after resuming irrigation. They reported almost full recovery of all four cultivars after 30 d. Goldsby et al. (2011) reported complete recovery in *P. pratensis* after 60 d without irrigation, although in the first year of a two year study, full recovery wasn't observed until the following spring. Bousselot et al. (2011) reported that *S. album* recovered to 58.3% pot cover, which was higher than in the present study; the length of the recovery period was not reported in their study.

In the present study none of the species recovered from prolonged drought in the fall, probably because of a 51% increase in vapor pressure deficit (VPD) that was caused, in part, by artificial lights (Fig. 2.4); daytime (0600 to 2000 CST) relative humidity inside the greenhouse averaged much higher in the spring/summer (71%) than the fall (26%). We speculate that greater VPD caused plants to dry rapidly, disrupting the normal physiological breakdown of chlorophyll in the leaves. This resulted in the leaves retaining green pigment longer, even after the leaves were completely desiccated. The delayed loss of green pigment in the fall probably delayed the time when most species received a rating of one compared with the spring/summer study. This probably confounded the results and contributed to the interactions observed between the spring/summer and fall studies.

Volumetric soil water content

The decline in θ_v was more rapid in the fall than in the spring/summer, illustrating the effects of greater VPD on evapotranspiration rates in the fall (Figs. 2.5 and 2.6). By week six in the spring/summer, θ_v of *S. album*, *P. terminalis*, and *L. muscari* was greater than 12% (i.e., Ψ_{soil} <-1.5 MPa, permanent wilting point) and significantly higher than the other species, with the exception of *P. terminalis*, which was similar to *A. reptans* (Fig. 2.5A). This, along with the number of days for *S. album*, *P. terminalis*, and *L. muscari* (266 d, 62 d, and 122 d, respectively) to decline to a quality rating of one in the spring/summer (Fig. 2.3A) indicates these species were using less water than the other species. In the fall, θ_v was similar among species and all were below 10% by week six, indicating Ψ_{soil} was below -1.5 MPa and had reached permanent wilting point (Fig. 2.5B and Table 2.1). Bousselot et al. (2011) reported the average number of days for θ_v to drop below 10% was just over six days for four *Sedum* species being evaluated for use on a green roof. However, the *Sedum* species in their study were being grown in smaller nursery pots (15.2 cm diam. by 10.8 cm deep) with a lightweight potting mix as a substrate.

Water loss rates from well-watered containers

Because the nursery containers were not sealed on the bottom, the observed water losses from the containers could not be attributed entirely to evapotranspiration. Although free drainage had ceased before the containers were first weighed, it is likely that some water evaporated through the holes in the bottom of the containers (Bremer, 2003). However, because all containers were the same it is likely that evaporation through the holes, though small, was similar among containers. Thus, the differences in water loss among species are likely caused by differences in evapotranspiration. In the first three days, water loss likely represented relative differences in evapotranspiration among species under well-watered conditions (Fig. 2.6).

During the first three days of the spring/summer study, water loss rates were greatest among species in *P. pratensis* at 3.17 mm d^{-1} (Fig. 2.6). During the same period, water loss rates of *A. millifolium* and *A. reptans* were also high at 2.78 mm d^{-1} and 2.62 mm d^{-1}, respectively, although the rate of water loss in *T. serpyllum* was similar to *A. reptans*. By week three, water loss continued to be the greatest among species in *A. millifolium*, *A. reptans*, *P. pratensis*, and *T. serpyllum* (data not shown). Greater water loss in these four species early in the spring/summer likely contributed to their faster decline in visual quality among species as soils dried (Figs. 2.2, 2.3, and 2.5).

In the spring/summer study water loss rates in the remaining five species were similarly low during the first three days under well-watered conditions (Fig. 2.6). By week three, however, *S. album* and *L. muscari* had the lowest water loss rates among species (data not shown). Interestingly, visual quality in the latter two species also persisted longer among species in the spring/summer. These data demonstrate that species with relatively lower water use maintain better visual quality for longer periods by conserving soil moisture.

In the fall study, under well-watered conditions, water loss rates among species averaged 37% greater than in the spring/summer (Fig. 2.6), primarily because of greater VPD in the fall (Fig. 2.4). The greatest water loss rate during the first three days of the fall was in *P. pratensis* at 5.32 mm d^{-1}. The consistently greatest water use rates observed in *P. pratensis* in both studies indicate *P. pratensis* had the greatest evapotranspiration among species. After *P. pratensis*, the greatest water loss rates were in *T. serpyllum* (3.97 mm d^{-1}), *A. millifolium* (3.91 mm d^{-1}), and *L. muscari* (3.84 mm d^{-1}). Greater water use rates in these species probably contributed to their faster decline in quality among species with the notable exception of *L. muscari*, which maintained acceptable quality even by week six (Figs. 2.2B and 2.3B). It is possible that *L. muscari* may have retained sufficient pigments during the rapid dry down in the fall to receive inflated quality ratings even after the plants had died.

Water potential

As a general trend in the spring/summer study, there was a slow decline of Ψ_{leaf} as Ψ_{soil} declined. The average Ψ_{leaf} of all nine species in the Ψ_{soil} ranges from high to low indicated in Table 2.1 were: -4.38 MPa, -4.98 MPa, -5.42 MPa, -6.52 MPa, and -8.76 MPa, respectively (Fig. 2.7A). This decline in Ψ_{leaf} illustrates the effects of drought stress as the dry down progressed.

P. terminalis consistently had lower Ψ_{leaf} during the spring/summer study than other species (Fig. 2.7A). The average Ψ_{leaf} of *P. terminalis* over all measurements was -14.9 MPa (spring/summer) and -25.9 MPa (fall). This is over two and a half times lower in the spring/summer, and about four times lower in the fall, than the combined average Ψ_{leaf} of the other species over all measurements at -5.4 MPa (spring/summer) and -6.2 MPa (fall). The Ψ_{leaf} of *P. terminalis* on the first day of the dry down (under well-watered conditions) was lower than the other eight species evaluated in both the spring/summer and fall studies. This may have been caused by the leathery, waxy, leaves of *P. terminalis* (Turner, 2001) tightly holding the moisture in the leaves as well as its ability to maintain leaf turgor pressure because of its two palisade layers directly below the upper epidermis of the leaf structure (Zhu and Beck, 1991). Additionally, the hydraulic mechanisms of *P. terminalis* may have caused lower Ψ_{leaf}. Species with small xylem vessels are typically more drought tolerant because greater tension from the atmosphere is needed to move water through the plant to the atmosphere (McDowell et al., 2008).

Because Ψ_{leaf} samples were gathered at mid-day (not pre-dawn) and samples were not kept cool while being transported to the lab, all measurements of Ψ_{leaf} in the present study were lower than Ψ_{leaf} measurements of other plant species reported in the literature. On day one of each dry down (under well-watered conditions) for eight out of the nine species (*P. terminalis* results not included in the average), the Ψ_{leaf} results in our study averaged -3.5 MPa in the spring/summer study and -5.5 MPa in the fall (Fig. 2.7). Our measurements are more than seven times (spring/summer) and 11 times (fall) lower than what VanderZanden and Cameron (1996) found when evaluating Ψ_{leaf} (~ -0.5 MPa) of another ornamental landscape species (*Fragaria chiloensis*) under well-watered conditions. VanderZanden and Cameron (1996) were measuring pre-dawn Ψ_{leaf} as opposed to our mid-day Ψ_{leaf} measurements. Qian and Fry (1997) reported Ψ_{leaf} of four turfgrass species taken between 1000 and 1100 CST, under well-watered conditions [*Festuca arundinacea* (-0.53 MPa), *Buchloe dactyloides* (-0.81 MPa), *Cynodon dacylon* (-0.99 MPa), and *Zoysia japonica* (-1.03 MPa)]. The Ψ_{leaf} results from our study ranged from about five times to more than ten times lower than average Ψ_{leaf} from the Qian and Fry (1997) study.

Additionally, our Ψ_{leaf} results are about two to three times lower than what Hamerlynck et al. (1997) reported when evaluating mid-day Ψ_{leaf} (-1.8 MPa) of a tallgrass prairie species (*Andropogon gerardii*) under wet conditions at ambient CO_2 levels. Also, Knapp (1984) measured Ψ_{leaf} of *A. gerardii* in both a burned and unburned tallgrass prairie with a precipitation of 64.2 cm for the season. Our Ψ_{leaf} results are over three (spring/summer) and five (fall) times lower than the season-long average of both the unburned (-1.07 MPa) and burned (-1.10 MPa) Ψ_{leaf} measurements taken at mid-day in the Knapp (1984) study.

Stomatal conductance

Stomatal conductance was highest among species early in both studies and generally began to decline around day ten in the spring/summer and day five in the fall as the soil dried (Fig. 2.8). Stomatal closure may have helped the plants maintain leaf water status, as evidenced by the slow decline in Ψ_{leaf} of most species (Fig. 2.7) (Hopkins, 1999; Kirkham, 2005; Taiz and

Zeiger, 2006). In the spring/summer, the increase in g_s on the second measurement day (DOT 7) was probably caused by a corresponding increase in PAR from 472 to 697 µmol $m^{-2}s^{-1}$.

In the spring/summer, g_s in *P. pratensis* was high early in the study but declined more rapidly than the other species with the exceptions of *L. muscari*, which was consistently low (Fig. 2.8A), and *A. reptans*. By day 17, g_s in *P. pratensis* had decreased to less than *V. major*, *V. minor*, and *P. terminalis*. *A. reptans* was also lower than *V. major* and *V. minor* on day 23. The faster decline in g_s in *P. pratensis* and, to a lesser degree *A. reptans*, may have resulted from their greater water use among species early in the study, which would presumably deplete soil moisture faster (Fig. 2.6).

While measurements of g_s are useful indicators of water relations in plants, differences in leaf area index among species may have confounded our measurements of g_s as they relate to total water use. For example, overall evapotranspiration may be less from a species with high g_s but low leaf area index than in another species with lower g_s and greater leaf area index. Unfortunately, we were not able to measure green leaf area index because plants had either died or were dormant by the end of the dry downs.

In *L. muscari*, g_s was never higher than 100 mmol $m^{-2}s^{-1}$ in the spring/summer and 130 mmol $m^{-2}s^{-1}$ in the fall (Fig. 2.8). In *P. terminalis*, g_s was also consistently low in the fall, with measurements never higher than 170 mmol m^{-2} s^{-1}. Interestingly, g_s in *P. terminalis* started moderately low in the spring/summer study but then increased slightly on days seven and eleven, after which it declined rapidly. Lower g_s of *L. muscari* and *P. terminalis* undoubtedly contributed to their low evapotranspiration among species (Fig. 2.6). This indicates these species may be better suited for landscapes experiencing drought.

No significant differences were found in g_s among the species after 31 DOT in the spring/summer and 26 DOT in the fall (Fig. 2.8). All g_s measurements were below detectable limits by 35 DOT in both studies, indicating complete stomatal closure. Other studies evaluating drought stress of plants grown in a greenhouse reported similar results. Ranney et al. (1991) reported g_s of six birch (*Betula*) trees was no longer detectable around day 32 of a dry down; and Huang and Gao (1999) were not able to detect g_s of *Festuca spp.* shortly after day 28 of a severe drought.

Conclusions

Results indicate *S. album*, *L. muscari*, and *P. terminalis* may be more successful in landscapes where severe drought may occur than the other species evaluated because of their ability to maintain greater plant quality and θ_v for a longer period during a drought. *V. major* and *V. minor* may also be good selections in landscapes with intermittent or less severe droughts. *P. pratensis* may be a good selection as well if periods of dormancy are acceptable to homeowners. *A. millifolium*, *A. reptans*, and *T. serpyllum* appeared least adaptable to severe drought.

References

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Figures

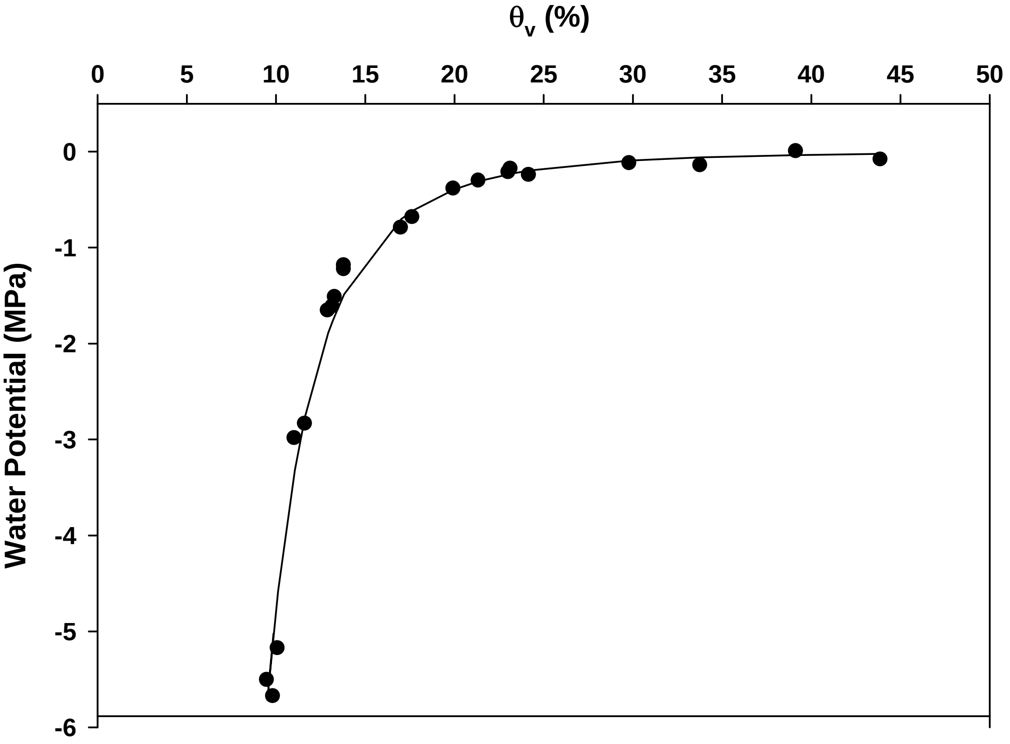

Figure 2.1 Soil moisture release curve used to determine relationship between soil water potential (Ψ_{soil}) and volumetric soil water content (θ_v). Leaf water potential (Ψ_{leaf}) was measured at predetermined intervals of Ψ_{soil}, as estimated by θ_v using this curve.

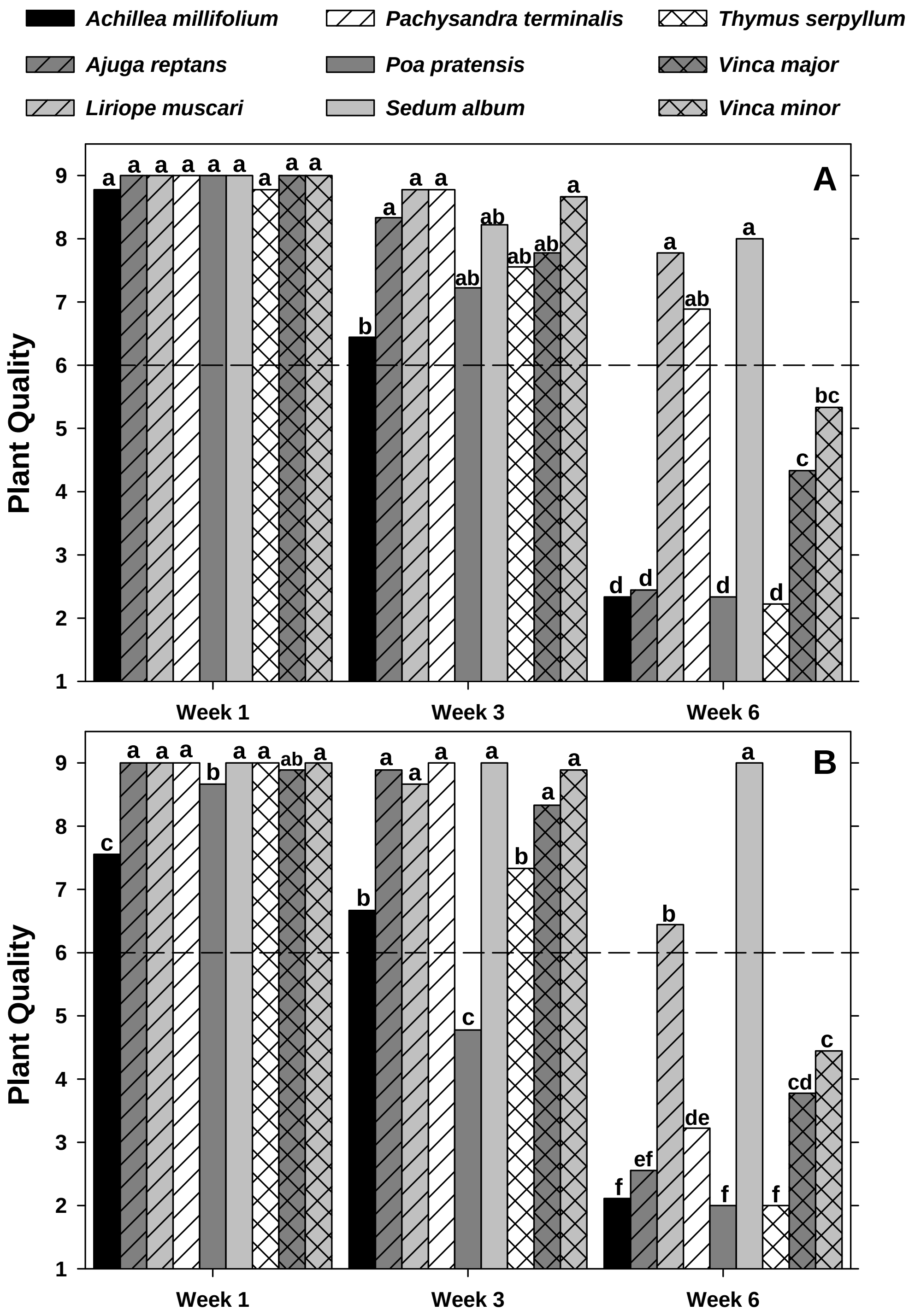

Figure 2.2 Visual estimates of plant quality of each species for weeks 1, 3, and 6 of the spring/summer (A) and the fall (B) dry down. Horizontal dashed line indicates minimal acceptability (quality rate of six). Means followed by the same letter within each week are not significantly different (*P*=0.05).

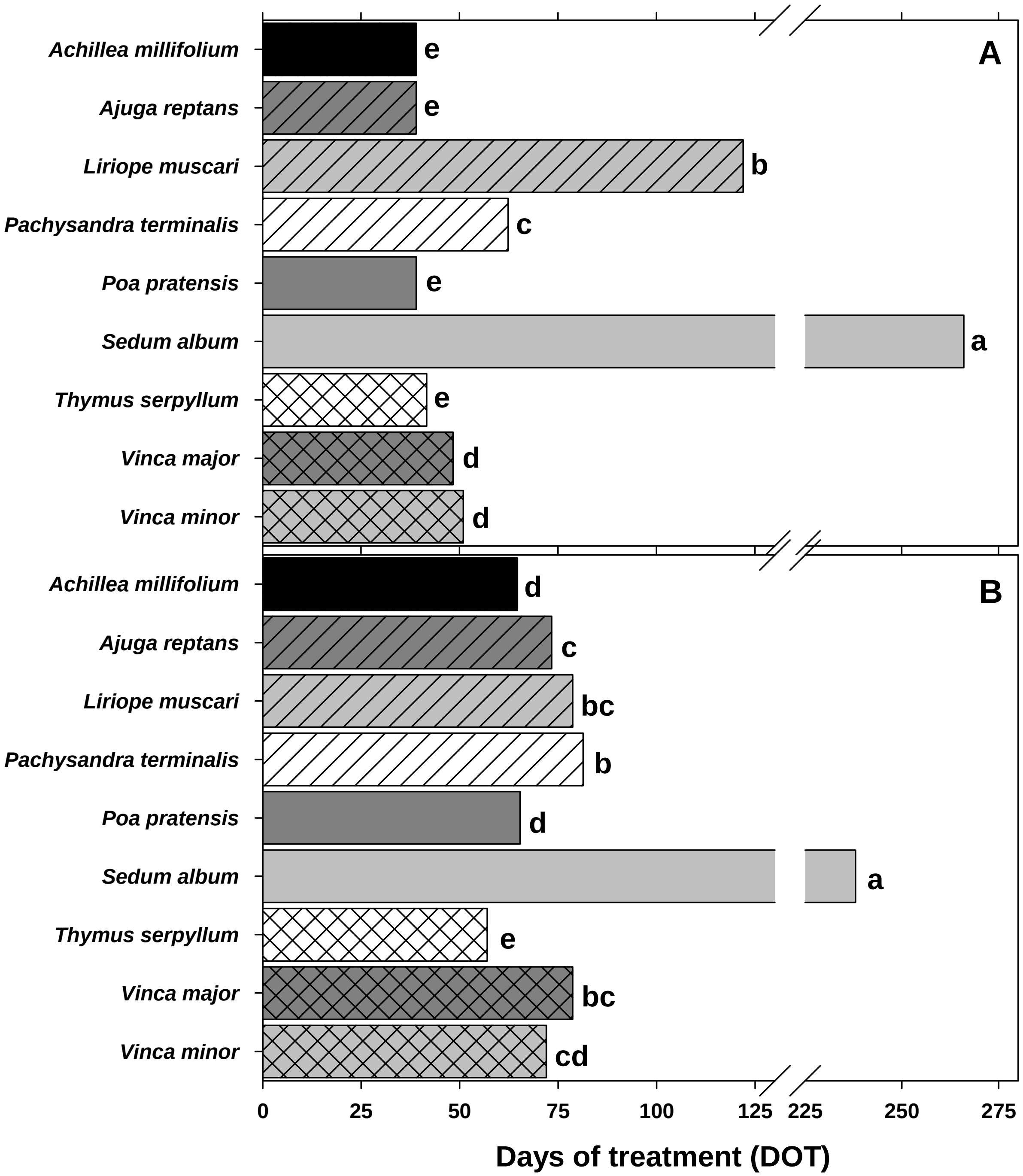

Figure 2.3 Number of days to decline to a quality rating of one among species during the spring/summer (A) and fall (B). Means followed by the same letter within each study period are not significantly different (*P*=0.05).

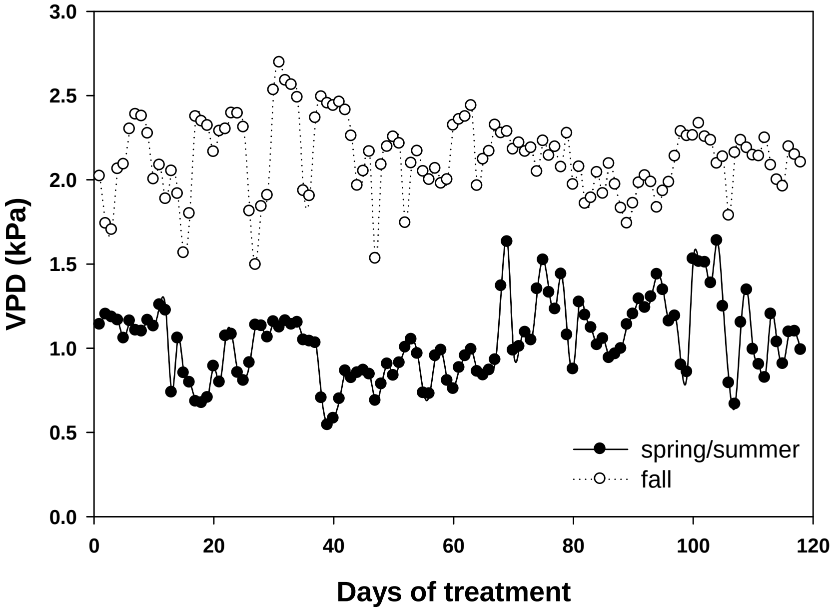

Figure 2.4 Daytime (0600 to 2000 CST) vapor pressure deficit (VPD) of the greenhouse environment in the spring/summer and fall studies.

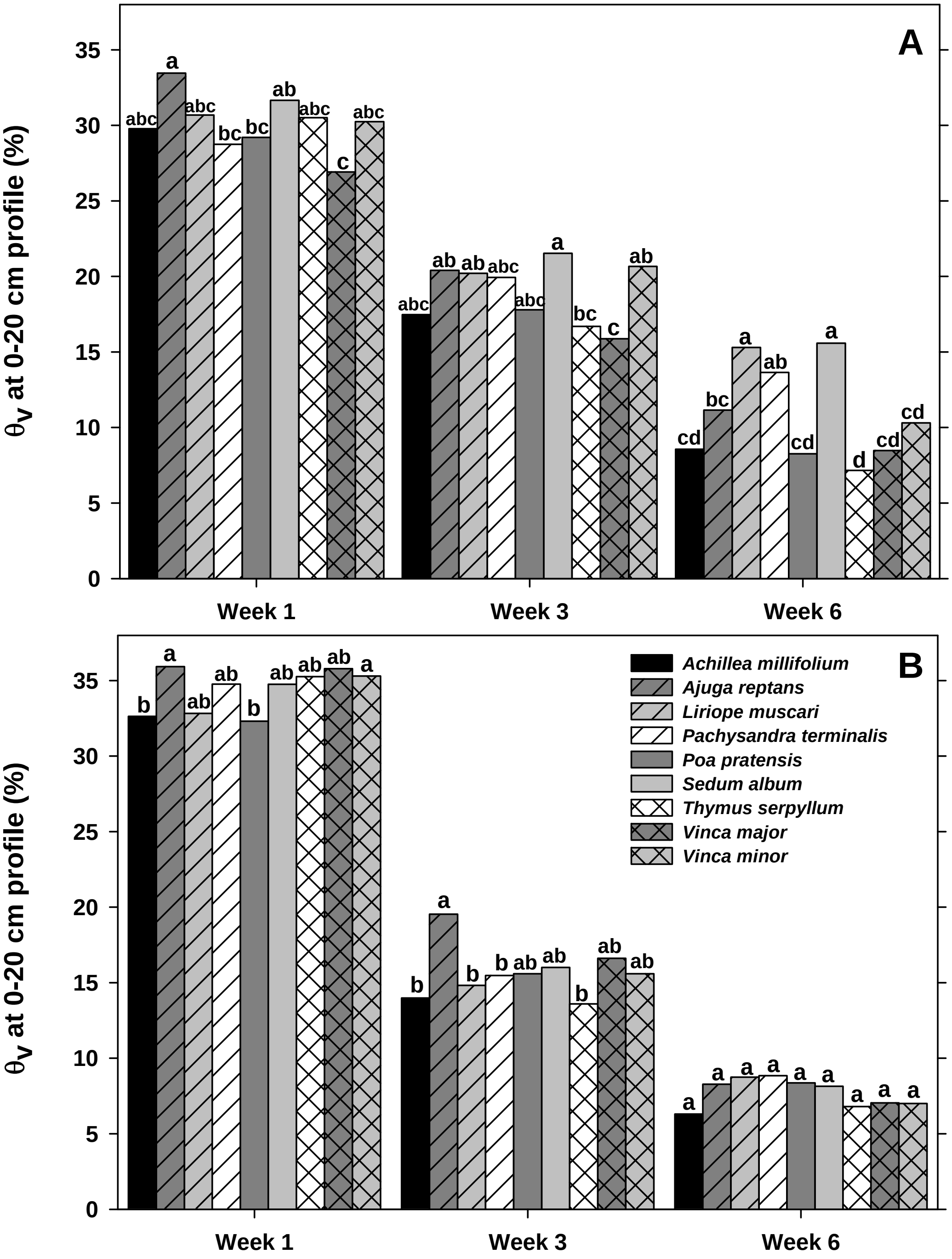

Figure 2.5 Volumetric soil water content (θ_v) of each species for weeks 1, 3, and 6 of the spring/summer (A) and the fall (B) dry down. Means followed by the same letter within each week are not significantly different (P=0.05).

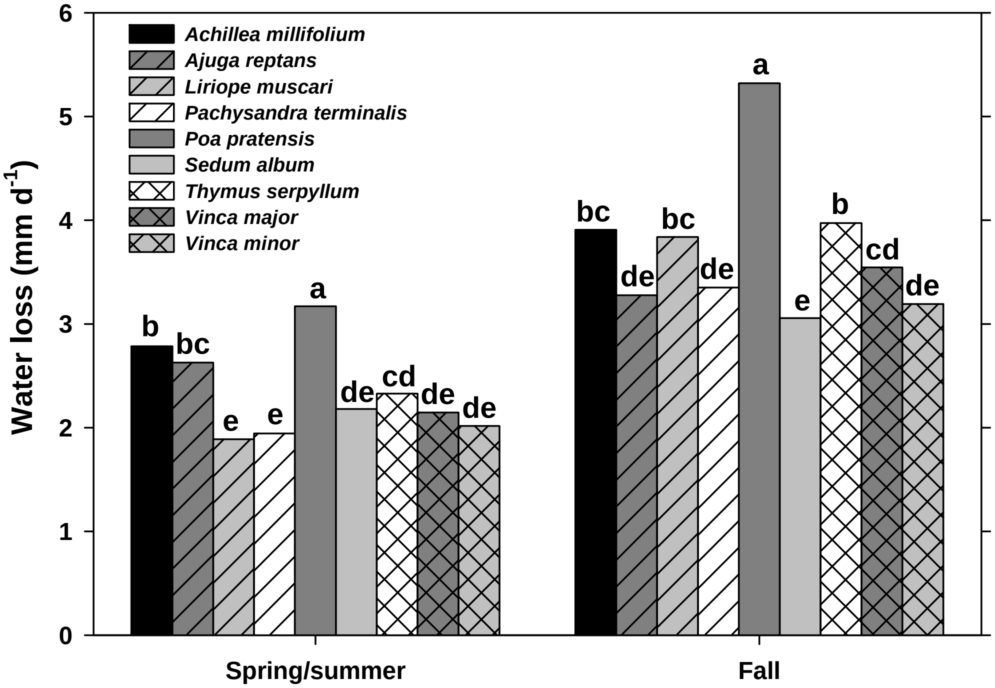

Figure 2.6 Average water loss (mm d^{-1}) of each species for the first three days of the spring/summer and the fall dry downs. Means followed by the same letter within each dry down (spring/summer and fall) are not significantly different (*P*=0.05).

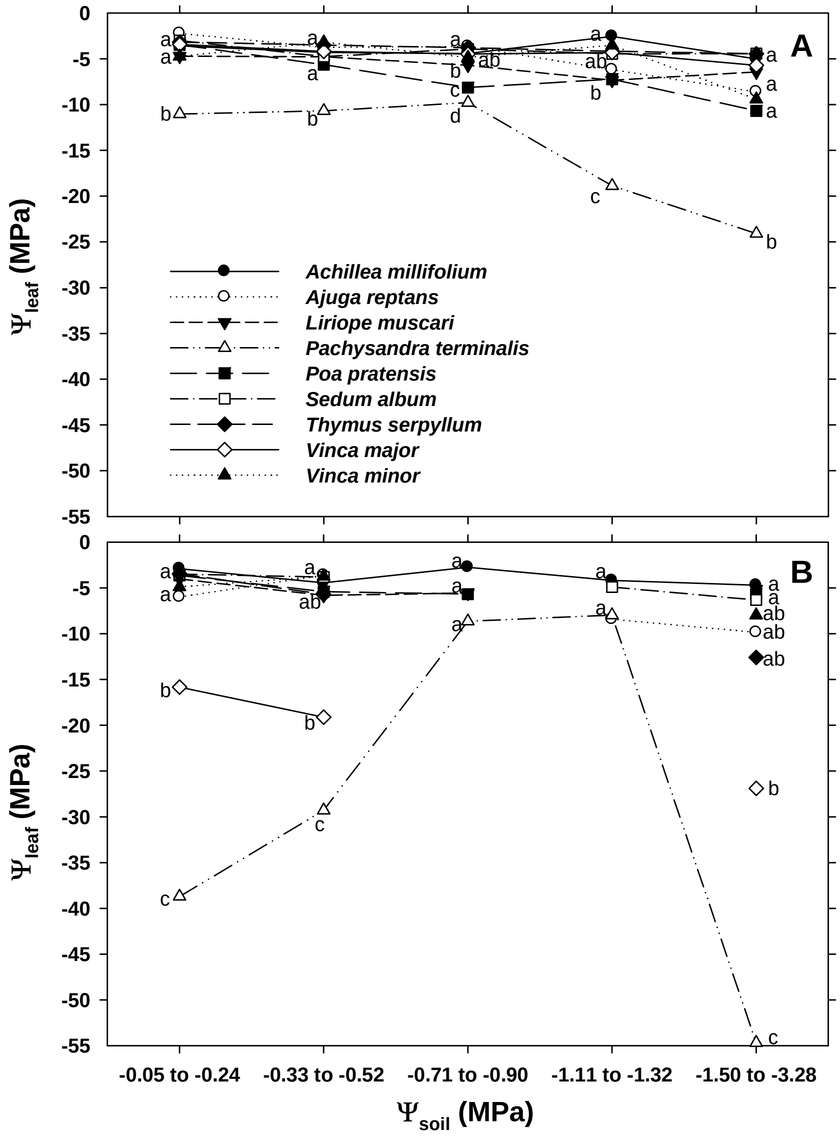

Figure 2.7 Changes in leaf water potential (Ψ_{leaf}) among species as the soils dried (i.e., Ψ_{soil} became more negative), during the spring/summer (A) and the fall (B) dry down. Means followed by the same letter within each Ψ_{soil} range are not significantly different (*P*=0.05).

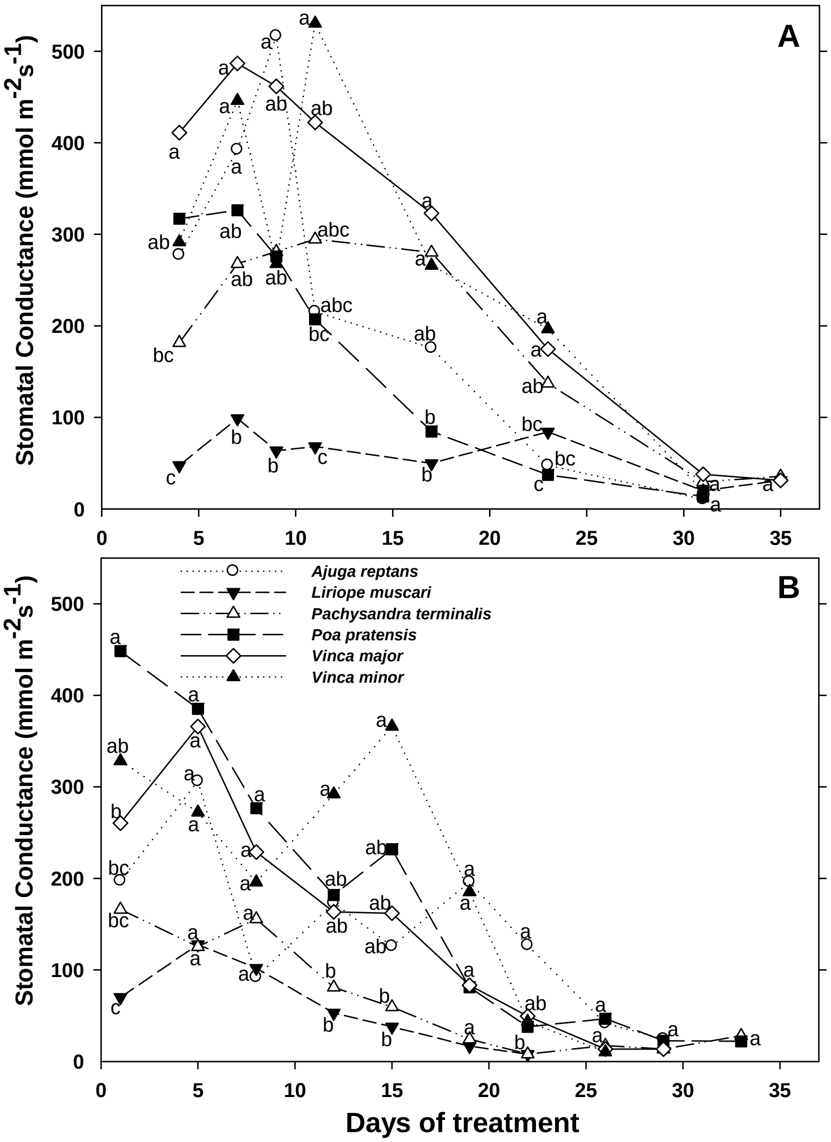

Figure 2.8 Changes in stomatal conductance (g_s) among species as the soils dried during the spring/summer (A) and the fall (B) dry down. Means followed by the same letter within each measurement day are not significantly different (*P*=0.05).

Tables

Table 2.1 Ranges of volumetric soil water content (θ_v), as related to pre-determined intervals of soil water potential (Ψ_{soil}), during which leaf water potential (Ψ_{leaf}) measurements were taken.

Ψ_{soil} (MPa)	θ_v (%)
-0.05 to -0.24	23.0 to 36.0
-0.33 to -0.52	18.5 to 21.0
-0.71 to -0.90	15.9 to 17.0
-1.11 to -1.32	14.3 to 15.0
-1.50[z] to -3.28	11.1 to 14.0

[z] -1.5 MPa is generally considered permanent wilting point.

Chapter 3 - Assessing Student Learning with Surveys and a Pre-/Post-Test in a New Online Course

Abstract

Distance education and the number of courses offered online have grown tremendously over the past several years. A survey method was developed to measure student learning in a new online course entitled “Water Issues in the Lawn and Landscape” offered at Kansas State University. The evaluated course examines critical water issues related to irrigation in urbanizing watersheds and is designed for students and industry professionals who want to enhance their knowledge and careers through distance education. This class is co-taught by four professors, each contributing from his or her area of expertise. In addition to conveying relevant content to students, the professors focused on the process in which the material was presented. Specifically, they emphasized creating sense and meaning while developing each assignment and lecture. If a lecture makes sense and has meaning for the learner, the probability of storing the information may be higher. A pre- and post-test was used to measure the level of student learning in each course module and surveys were used to evaluate the level of sense and meaning that each lecture, assignment, and exam had for the students. Results revealed that in modules with the highest post-test scores (i.e., higher level of student learning), the favorable survey responses were high in both sense and meaning questions. Conversely, modules with the lowest post-test scores had more favorable responses to the sense questions than the meaning questions. Results indicate both sense and meaning need to be present to increase the level of student learning in a course.

Introduction

Developments in technology have allowed distance education programs to expand in recent years, tremendously increasing the number of courses offered online. A number of studies have compared the level of effectiveness between online and traditional face-to-face courses (Grabau, 2000; Kahtz, 2000; Anderson and Walker, 2003; Schroeder-Moreno and Cooper, 2007; Bigelow, 2009; Peterson and Keeley, 2012). With the increase of online course availability, it is also important to evaluate the effectiveness of online delivery as it relates to meeting the objectives of the course for the students.

Whether a course is taught online or face-to-face, effective teaching is related to process and content. Most instructors know their content very well. However, the process of teaching content to students in a manner that facilitates learning and retention can be a challenge. Teachers should understand the teaching methods that result in the most effective learning experience for their students (Thien, 2003). Additionally, every person has a preferred learning style and learning environment (Dunn et al., 2002). Teachers need to know how their students learn information best and should strive to create that environment.

As researchers discover more about how the brain acquires and processes information, teachers can use this information strategically to design lesson plans. Sousa (2006) developed the Information Processing Model (Fig. 3.1) to illustrate how the brain handles information observed in the environment. Experiences observed by the five senses are initially put into immediate memory. If the information is important to the learner, the information will be moved to working memory. In order for information to be stored in long term memory the information needs to make *sense* to the students and have *meaning* for the students. Whether information makes sense to, and has meaning for, each student depends on the student's self-concept. A student's self-concept is shaped by their past experiences (Sousa, 2006). Positive experiences, such as placing first in a track event, can raise a student's self-concept; whereas negative experiences, such as forgetting the steps during a dance recital, can lower a student's self-concept.

According to Sousa (2006), sense and meaning can exist in course content independent of each other. They both do not have to be present in order for the student to remember the information. However, if a concept is presented to a learner in a manner that makes sense to the student and has meaning for the student, the probability of the learner storing the concept in long term memory is very high (Fig. 3.2). To better understand the difference between sense and meaning, Sousa (2006) gives an example of a 15-year-old student hearing that the minimum age to obtain a driver's license in his state is 16. The minimum age is 17 in a neighboring state. If the student understands the information, we say it makes *sense* to him. Knowing the minimum age in his own state is more relevant to him because that is the state where he will apply for his license, therefore the information also has *meaning* to the student. In summary, sense refers to the level of understanding and meaning refers to the level of significance the information has for a person.

When instructors made a conscious effort to teach with sense and meaning, they reported an increase in student learning (Reinartz and Hokanson, 2001). Therefore, the objectives of this research were to evaluate: 1) the level of student learning in a new online course using a pre-/post-test, and 2) the role of sense and meaning as they relate to student learning in the course. We hypothesized that student learning would be greater in areas of the course where both sense and meaning were high.

Background of the evaluated course

"Water Issues in the Lawn and Landscape" is an online course first offered in the spring semester of 2010 that examines critical water issues related to irrigation in urbanizing watersheds, with an emphasis on water quality and quantity. The course was designed for students and industry professionals who want to enhance their knowledge and careers through distance education. Students enrolled in the course learn about the interrelatedness of correct irrigation practices with water quality and quantity, and how to protect water resources through application of science-based irrigation practices.

Materials and Methods

Course development

The class is co-taught by four professors, each contributing from his or her area of expertise. In addition to conveying relevant content to students, the professors focused on the process by which the material was presented. Specifically, they emphasized creating sense and meaning while developing each assignment, lecture, and exam. For example, instructors made an effort to present lectures, communicate assignment instructions, and create exam questions in a manner that is easy for the students to understand so it will make *sense* to the students. Additionally, to create *meaning* for the students, instructors worked to create lectures, assignments, and exams that related to the students' interests. Because the course is strictly online and all course material was created prior to students enrolling in the course, instructors assumed that students enrolling in the course would have an interest in the lawn and landscape industry. Therefore, instructors chose a number of reading assignments, case studies, and examples to discuss in lectures from various aspects of the green industry.

The course was designed with seven topical modules presented in developmental order: Module 1 - homeowner perceptions (M1); Module 2 - water availability and quality (M2); Module 3 - relationship between irrigation practices and water quality (M3); Module 4 - weather-based irrigation decision making (M4); Module 5 - low-water-use-lawns and landscapes (M5); Module 6 - auditing irrigation systems (M6); and Module 7 - changing water users' habits (M7).

Sub-topics within each module were divided among the instructors. Lectures were recorded and edited using Camtasia Studio (TechSmith Corp., Okemos, MI). Edited videos of each lecture were converted to MPEG-4 (MP4) files and uploaded to the course website in K-State Online (KSOL) (http://public.online.ksu.edu/), an internet-based learning management system used at Kansas State University. A "Module Overview" (Appendix A) which students could download from the course website, accompanied each module with information pertaining to the respective module. In each module overview, students could find information regarding lecture titles, the name of the professor presenting each lecture, writing assignments, reading assignments, quizzes and exams, online discussions, and survey information. All assignment and exam point values and due dates were presented in the course syllabus. At the beginning of the semester students were asked to read the "Welcome Message" posted on the course website. The welcome message outlined instructions of the various course procedures. The documents used to communicate to students allow the course to be strictly online and never require a face-to-face meeting between instructors and students.

An evaluation was conducted over five semesters (summer and fall 2010 and spring, summer, and fall 2011) to measure learning in the course with a pre- and post-test. Surveys were administered at the completion of each module to evaluate the level of *sense* and *meaning* each lecture, assignment, and exam had for the students. Although the course was offered for the first time in the spring of 2010, no data were collected during that semester. Video recorded lectures, written assignments, reading assignments, and exams were the same across all semesters.

Student online discussions and email interaction between students and instructors varied from semester to semester.

Evaluation of the level of student learning using a pre- and post-test

A total of 35 students participated in the pre- and post-tests, both undergraduate (n=23) and graduate (n=12). Not all students who took the pre-test also took the post-test. Therefore, only results from students participating in both the pre- and post-tests were kept for analysis. The pre- and post-tests were available to the students in KSOL at pre-determined times during the semester. The pre- and post-tests were identical. Both tests were made available to the students for approximately one week. Students were given access to the pre-test starting five days prior to the first day of the semester until the third day of the semester. Students were asked to complete the pre-test before viewing any of the course material. Students were given access to the post-test starting four days prior to the last day of the semester until four days after the semester was over. Students were told: "The pre-test (post-test) is used only as an assessment tool for measuring the effectiveness of the course; therefore your performance on the pre-test (post-test) will not be reflected in your grade." Students received five participation points each for completing each test.

Each course "Module Overview" (Appendix A) included three to five student learning outcomes (SLO) designed by the course instructors. The SLOs are statements that specify what the students should know or be able to do after completing a particular section of the course (Allan, 1996). For example, a SLO from M3 states "students should know characteristics of fertilizers and pesticides which make them susceptible to leaching and runoff." The pre- and post-test used in this study contained 27 questions. Each question was linked to one of the 27 SLOs developed for the course (Appendix B).

Evaluation of sense and meaning with surveys after each module

Surveys were conducted to evaluate sense and meaning. Specifically, our objectives for the surveys were to *separately* evaluate the level of: 1) sense; and 2) meaning; that each lecture, assignment, and exam had for the students. Undergraduate and graduate students were surveyed. Not all students enrolled in the course completed each module survey and therefore, the number of students participating in each survey varied (Table 3.1). Additionally, the number of students participating in the surveys generally varied from the number participating in the pre-/post-test (n=35).

At the completion of each module, students were emailed a link to a survey (Appendix C) administered through the Axio survey system (Axio, 2011); Axio is a component of KSOL. Surveys were available to the students for one week following completion of the module. The Axio system automatically sent email reminders to students every day until the student completed the survey. After completing the survey, students were asked to email the instructor to confirm they had completed the survey. Students were given five participation points for each survey they completed to encourage student participation in the study.

Surveys were anonymous, allowing respondents to give their honest opinion about the contents of the module. Students were asked two questions about each specific content (lecture, assignment, or exam) in the module (Table 3.2 and Appendix C). Respondents were asked 1) if content X made *sense* to them; and 2) if content X had *meaning* for them. Respondents were asked to keep the following in mind about each question type. Regarding sense: "Questions that ask if an assignment or lecture made sense are referring to whether you understood and/or comprehended the item based on your experiences. Ask yourself 'Did that fit with *my previous knowledge base*?'" Regarding meaning: "Questions that ask if an assignment or lecture had meaning are referring to whether the item was relevant to you. Ask yourself 'Was the reason for learning this information apparent from either *my previous experiences* or *made apparent by the lesson*?'" For each question, students responded using a Likert scale (Breffle et al., 2011) of: "Definitely," "Yes," "Somewhat," "No," and "Not at all." A comment box followed each question allowing respondents the option to give more detailed feedback regarding that course content number. Each module varied in the number of lectures, reading assignments, and writing assignments; therefore, surveys varied in length (Tables 3.1 and 3.2). There were a total of 100 (50 sense and 50 meaning) questions asked over all seven module surveys.

Data analysis

Individual student scores on the pre- and post-tests were averaged and differences in means of the pre- and post-tests were compared. Student responses to each question were prepared for analysis by recording a "1" if the student got the question correct and recording a "0" if the student got the question incorrect. Responses (1 and 0) for each question were averaged to determine the mean percentage of correct answers. The means of the pre- and post-tests were compared for each SLO question and for each module. All pre- and post-test results were evaluated using the general linear model (GLM) procedure in SAS (SAS Institute, Cary, NC). Means were separated using Fisher's protected least significant difference (LSD) at P=0.05.

Survey data were evaluated using the frequency procedure in SAS with a contingency table output. This process was used to determine the frequency of "Definitely," "Yes," "Somewhat," "No," and "Not at all" responses for both sense and meaning within each module and for the overall course. Because the surveys were anonymous, it is unknown how each student responded to individual questions. Therefore, it was not possible to detect the level of significance between survey responses.

For the purposes of discussion, survey responses of “Definitely” or “Yes” were considered favorable; and responses of “Somewhat,” “No,” or “Not at all” were considered unfavorable. A response of “Somewhat” could be considered acceptable, but since we were measuring the level of student learning for specific lectures, assignments, and exams, we reasoned an average understanding of the course content was not desirable.

To test the hypothesis that student learning was greater where both sense and meaning were high, a correlation analysis was conducted between: 1) the percentage differences between sense and meaning responses in the favorable category; and 2) post-test scores for each module; using the Pearson Product Moment procedure in SigmaPlot 11.0 (Systat Software, Chicago, IL).

Results and Discussion

Pre- and post-test: Student learning

There was a 10% increase in student performance from the pre-test (79%) to the post-test (89%) (Table 3.3), indicating students learned concepts presented in the modules, as guided by the SLOs. Although a significant increase in student scores from pre- to post-test did occur, average student scores on the pre-test were higher than we expected. The questions were determined to be a low-level of difficulty which likely resulted in the high scores on the pre-test. Additionally, it is possible that some students may have used outside resources when working on the pre-test.

There was also a significant increase in the mean scores from the pre-test to the post-test for all modules, with the exception of M7 (Table 3.3). Module 7 consisted of four interviews with professionals in the irrigation industry who gave their opinion (not presenting facts) of how to change water users' habits. Since no facts were presented in this module, the pre- and post-test questions may not have been representative of the information presented in the module, which resulted with no significant increase in scores from pre- to post-test for M7.

The mean scores of SLO 1.3, 2.4, 3.2, 4.1, 5.1, and 6.2 (Appendix B) increased from the pre-test to the post-test (Table 3.3). Scores for each of these SLOs increased by 11 to 37% to an overall score of 94% or higher (above average, equivalent to an A) on the post-test, with the exception of SLO 3.2 which had a score of 86% on the post-test. Four of these SLOs (2.4, 4.1, 5.1, and 6.2) received high scores on the pre-test (80 to 89%), meaning 80 to 89% of the students got these questions correct on the pre-test. The remaining two SLOs (1.3 and 3.2) received relatively low scores on the pre-test, or specifically 71% (SLO 1.3) and 49% (SLO 3.2). Although SLO 3.2 had the lowest post-test score (86%) of the group, it also exhibited the greatest increase (37%) in score from pre- to post-test. This indicates SLOs 1.3, 2.4, 3.2, 4.1, 5.1, and 6.2 were thoroughly covered in the course and a high percentage of the students (86 to 100%) retained the information needed to understand these SLOs.

The scores for the pre- and post-test questions representing SLO 4.4 [(63/74)(pre-test score/post-test score)] and 5.3 (69/74) (Table 3.3) were below 75%. Additionally, SLO 1.1 (26/40) and 7.3 (43/54) were below 60%. This suggests the concepts students are expected to learn in SLOs 1.1, 4.4, 5.3, and 7.3 may be too difficult for the students to understand using the implemented methods. Based on these below average scores (C or below), SLOs 1.1, 4.4, 5.3, and 7.3 should likely be taught using a different strategy to increase student learning (Dunn et al., 2002). Conversely, for the remaining SLOs in the course, students scored above 80% on the post-test, indicating the teaching methods used to convey these concepts are conducive to student learning.

Surveys: Sense and meaning

More than 83% of all responses (both sense and meaning questions combined) were favorable (Tables 3.4 and 3.5), indicating the majority of students felt the lectures, assignments, and exams made sense and had meaning. Approximately 16% of all survey responses were unfavorable, but only 2% of responses were “No” or “Not at all.” These results show that a majority of the students felt sense and meaning were present in the course content. As mentioned previously, instructors of this course made a conscious effort to include both sense and meaning in the content as the course was developed. Based on these results, it appears these goals were met.

We designated that if the favorable responses for a specific content number (Table 3.2) were less than 70%, which indicated more than 30% unfavorable, it qualified for revision in future courses. We arbitrarily chose this as our guideline because it indicates approximately one-third of the students provided unfavorable responses. Having this many students in a consensus over the course material provides validation for altering the content.

Five course content numbers were identified for revision including 13, 29, 37, 42, and 43 (Fig. 3.3; Table 3.2). All five were written assignments with the exception of number 43, which is one of the course exams. The responses for all course lectures and reading assignments were more than 70% favorable, which indicates no revisions are needed other than standard addition of new information to keep the content up to date.

Overall, there were more favorable responses for sense questions than for meaning questions (Table 3.5). The sum of favorable (“Definitely” and “Yes”) responses was 3.3%

greater for the sense questions (43.5%) than for meaning questions (40.2%). Conversely, the sum of unfavorable (“Somewhat,” “No,” and “Not at all”) responses was 3.3% greater for meaning questions (9.8%) than for sense questions (6.5%). This indicates sense was present in lectures, assignments, and exams more often than meaning for the students surveyed. This is logical because designing a lecture or assignment that makes sense to students is more attainable than designing one that has meaning for them (Ignelzi, 2000). An instructor needs to know information about individual students and their past experiences in order to create lectures and assignments with meaning for them (Sousa, 2006), which will increase the probability of students retaining the information in their long-term memory (Figs. 3.1 and 3.2).

One potential strategy for online instructors to become better informed about their students’ past experiences is to begin the course with a “getting to know you” survey or assignment. Questions within this assignment can target student experiences in relation to each of the broad topics to be covered in the course. While it may be difficult to adapt course content to fit specific students’ previous experiences, it is possible that assignments within the course can be designed uniquely for each student. With this approach students could better understand the relationship of the course content to their real world.

Relating sense and meaning to student learning

Within the favorable responses of the surveys (i.e., “Definitely” or “Yes”), student learning was greater when both sense and meaning were high. In general, post-test scores declined among modules as the difference between sense and meaning increased ($r = -0.82$; $P=0.03$; Fig. 3.4). The highest scores for individual modules on the post-test, which indicated greater learning, were 97 and 94% for M2 and M6, respectively (Table 3.3). Among favorable responses, the sense questions were only 1.2 to 3.1% higher than the meaning questions for these two modules (Fig. 3.4 and Table 3.5). In contrast, M1 and M7 had the lowest scores among modules on the post-test at 77 and 79%, respectively. In the favorable responses for M1 and M7, the sense questions were 5.7% (M7) and 8.6% (M1) greater than the meaning questions. Although statistical differences between the sense and meaning responses could not be determined, these results imply the importance that both sense and meaning be present in order to achieve student learning. These findings support the model illustrated in Figures 3.1 and 3.2 (Sousa, 2006) and support our hypothesis that student learning is greater where both sense and meaning are high.

Summary

Modules with the greatest student learning (i.e., post-test scores) were also high in both sense and meaning among favorable responses. Conversely, in modules with the lowest post-test scores, responses were lower in the meaning questions than the sense questions. These results support the model of Sousa (2006) (Fig. 3.2) by demonstrating the importance of both sense and meaning being present to increase the probability that students will retain information learned in a course.

Four course assignments and one course exam have been identified for revisions through survey responses. The goal of these revisions is to improve the level of sense and meaning each content piece has for the students to increase student learning. We will consider comments made on surveys and evaluate the percentage of unfavorable sense and meaning responses regarding each content piece identified for revisions to determine changes that need to be made. For example, content 29 (Table 3.2) required students to use a water budget tool designed in an Excel document. More than 25% of survey respondents made comments regarding the difficulty of using this tool. To address this revision we will create examples illustrating how to properly use the water budget tool, making the document more user friendly for the students.

Determining sense and meaning for each SLO was not possible in the present study. It would have been useful to compare sense and meaning results to the level of student learning (post-test scores) in each SLO. Sense and meaning were surveyed based on individual lectures, assignments, and exams within each module. These contents were not necessarily designed to target one specific SLO, but rather incorporated several SLOs within each content piece. In future class evaluations, lectures and assignments could be developed that target one SLO.

Additionally, future research evaluating sense and meaning as it relates to student learning should develop a tracking strategy, perhaps with an identification code that matches responses from each survey but maintains the anonymity of the students; it is essential that students remain anonymous to the instructors to avoid biased responses. Being able to track survey responses will enable researchers to determine significant differences between sense and meaning responses in each category. This will provide a more concrete understanding of sense and meaning for overall student learning.

Results indicate the survey method developed is a useful tool to evaluate sense and meaning in this online class. Future research is needed to test this assessment tool in other courses, including online and traditional face-to-face class formats.

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Figures

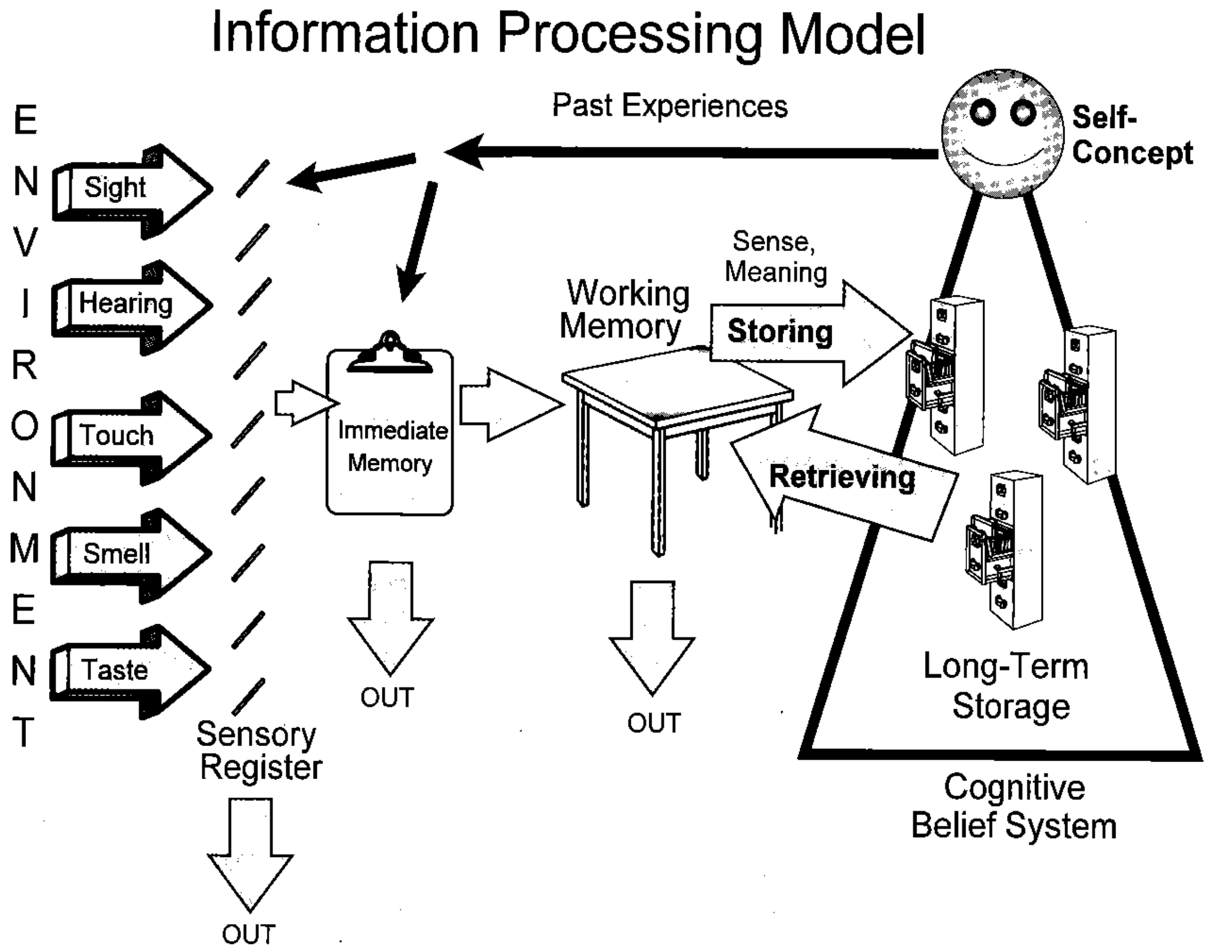
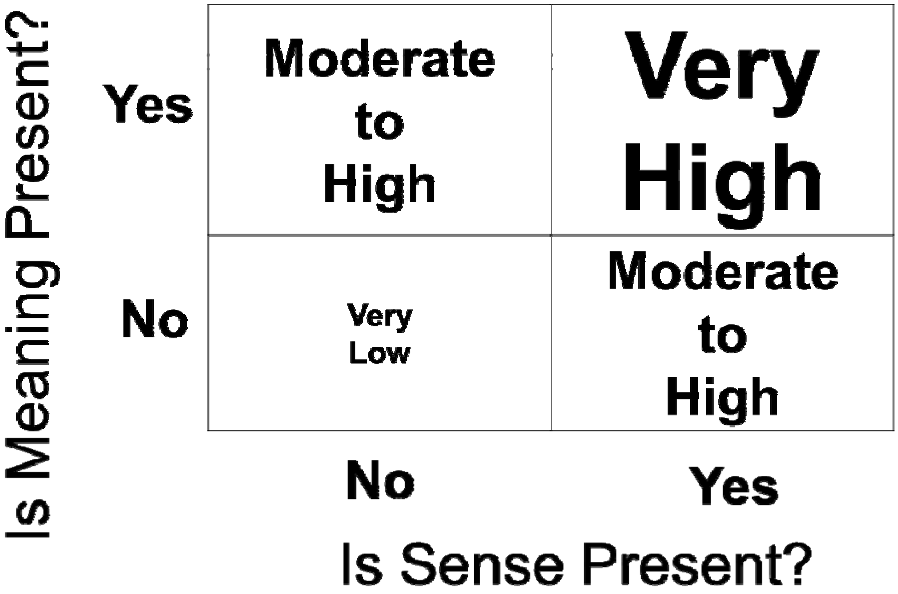


Figure 3.1 The Information Processing Model represents how the brain handles information gathered from the environment.
(Sousa, 2006, p. 39).



	Is Sense Present?	
Is Meaning Present?	No	Yes
Yes	Moderate to High	Very High
No	Very Low	Moderate to High

Figure 3.2 The probability of a student storing the information learned varies with the level of sense and meaning present.
(Sousa, 2006, p. 49).

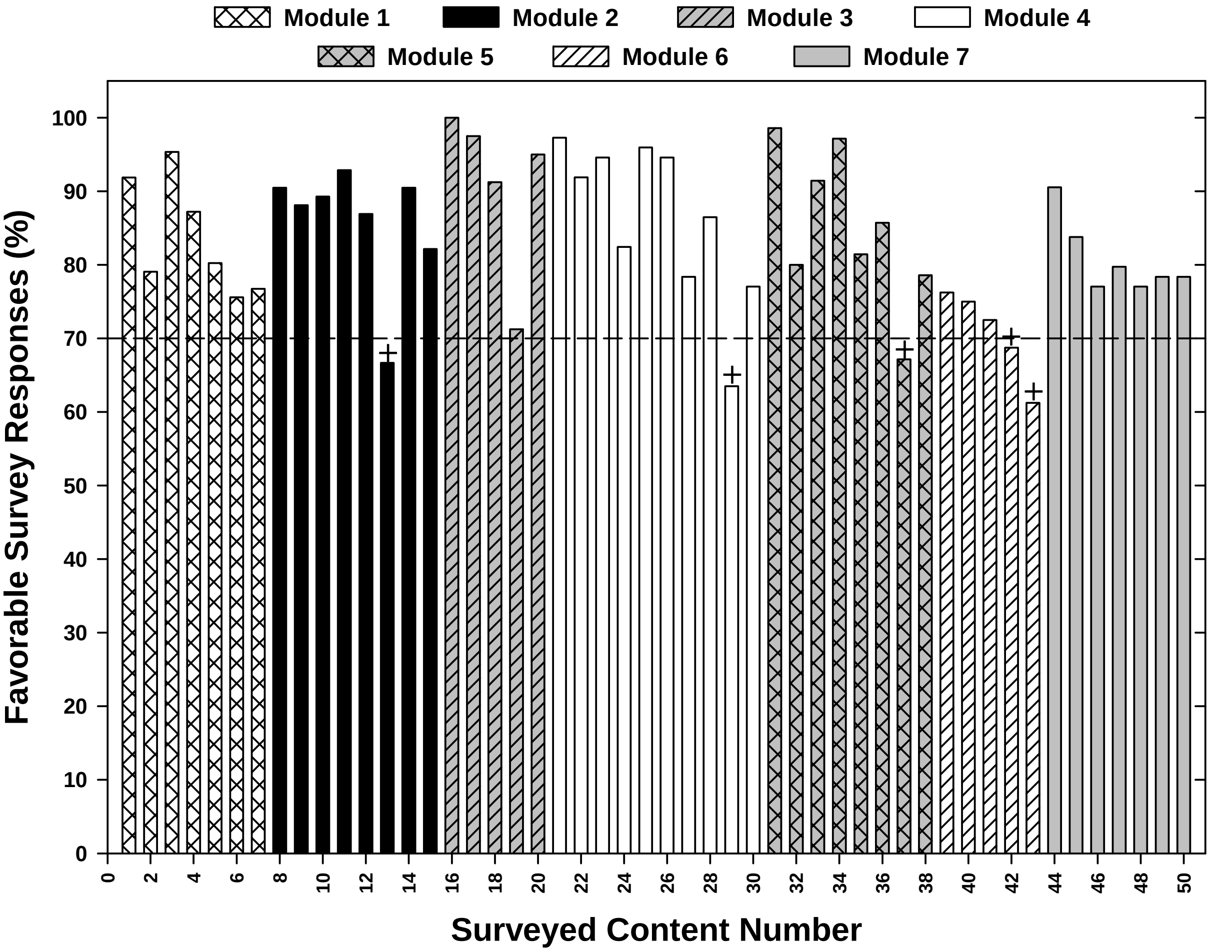


Figure 3.3 Percentage of favorable survey responses ("Definitely" and "Yes" responses combined) for each surveyed content number within each module. Horizontal dashed line indicates minimal acceptability of favorable responses. A (+) indicates course content that has been identified for revision.

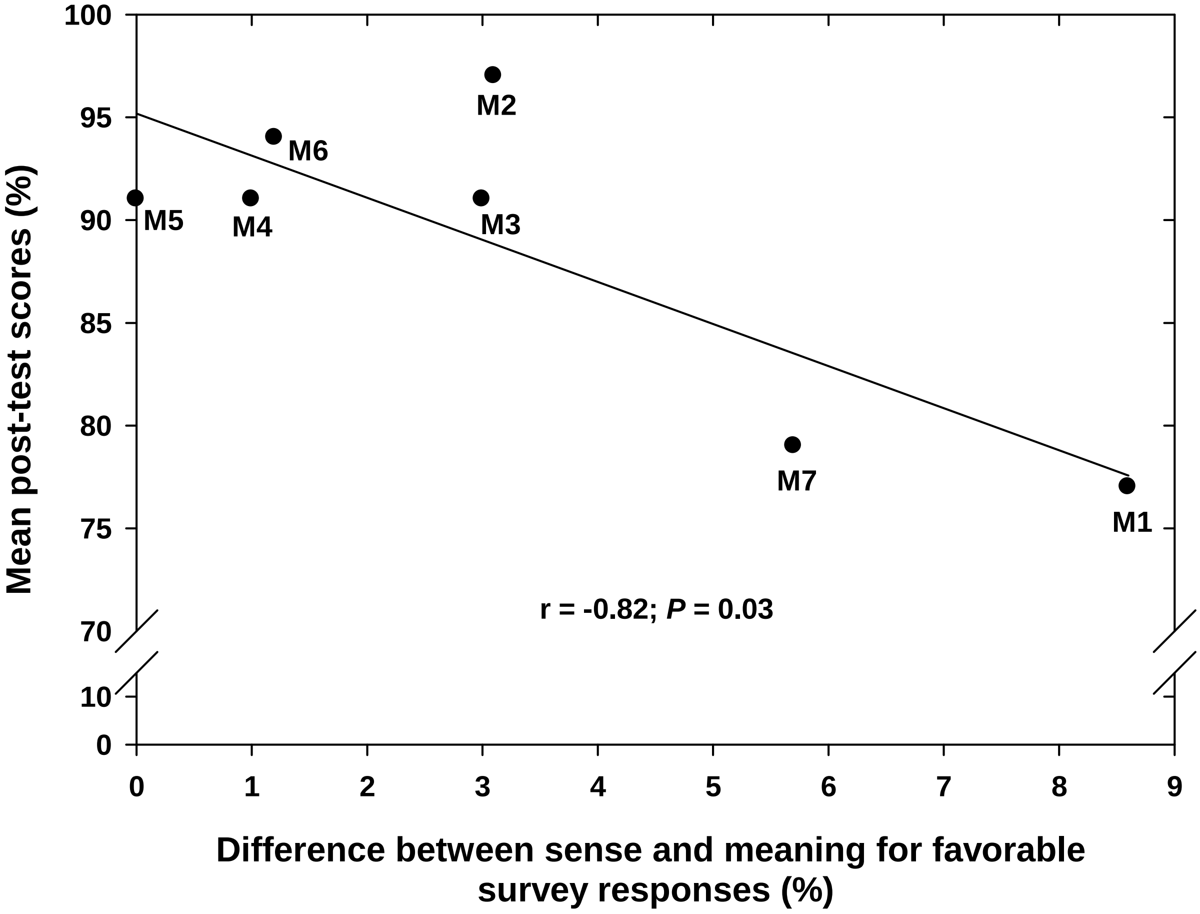


Figure 3.4 Regression model between mean post-test scores and the percent difference between sense and meaning for favorable survey responses for Module 1 (M1), Module 2 (M2), Module 3 (M3), Module 4 (M4), Module 5 (M5), Module 6 (M6), and Module 7 (M7).

Tables

Table 3.1 Number of questions asked on each module survey and the number of students who participated in each module survey.

		Number of students participating in each survey (n)[†]					
Module	Questions per survey (n)[‡]	Summer 2010	Fall 2010	Spring 2011	Summer 2011	Fall 2011	Total
1	14	1	10	16	7	9	43
2	16	1	10	16	5	10	42
3	10	1	9	17	5	8	40
4	20	1	9	14	5	8	37
5	16	1	8	14	4	8	35
6	10	1	10	16	5	9	40
7	14	1	9	15	4	8	37

[†] Not all students enrolled in the course completed each module survey, therefore the number of students who participated in each survey varied.

[‡] A total of 100 questions were asked in all seven module surveys with the number of questions varying between surveys.

Table 3.2 Surveyed content type and topic within each module.

Module	Content #	Description
1	1	Lecture: History of the American Lawn
1	2	Lecture: Howeowner Survey
1	3	Lecture: Turf Quality and Expectations
1	4	Assignment 1: History of the American Lawn
1	5	Assignment 2: Survey Assignment
1	6	Assignment 3: Essay and Reaction Paper
1	7	Module 1 Exam
2	8	Lecture: Water Availability and Quality
2	9	Video: Where does your water come from and where does it go?
2	10	Lecture: Las Vegas Case Study
2	11	Lecture: Effluent Water
2	12	Module 2 Reading Assignments
2	13	Assignment 4: EPA-Envirofacts Website
2	14	Assignment 5: Las Vegas Case Study Essay
2	15	Module 2 Exam
3	16	Lecture: How Irrigation Practices affect Water Quality, Overview and Leaching
3	17	Lecture: How Irrigation Practices affect Water Quality, Runoff
3	18	Module 3 Reading Assignments
3	19	Assignment 6: Letter to the Editor
3	20	Module 3 Exam
4	21	Lecture: Effects of Weather on Plant Water Use
4	22	Lecture: Effects of Surface Factors on Plant Water Use
4	23	Lecture: Effects of Cultural Practices on Plant Water Use
4	24	Lecture: Estimating ET from Weather Data
4	25	Lecture: Irrigation Frequency and Timing
4	26	Lecture: Effects of Lawn and Landscape Microclimates on ET
4	27	Lecture: Current Technology Involving ET/Soil Moisture Controlled Irrigation System
4	28	Module 4 Reading Assignments
4	29	Assignment 7: EPA WaterSense Program
4	30	Module 4 Exam
5	31	Lecture: Alternate Lawn Grasses
5	32	Lecture: Alternate Ornamentals
5	33	Lecture: Deficit Irrigation
5	34	Lecture: Drought Dormancy and Recovery
5	35	Lecture: New Technologies for Irrigation Applications
5	36	Module 5 Reading Assignments
5	37	Assignment 8: Drought Tolerant Plants
5	38	Module 5 Exam
6	39	Video: Irrigation Audit
6	40	Lecture: Irrigation System Performance Audit
6	41	Module 6 Reading Assignments
6	42	Assignment 9: Perform an Irrigation Audit
6	43	Module 6 Exam
7	44	Lecture: Communication Strategies for Educating Homeowners
7	45	Video: Interview with Dana Nichols
7	46	Video: Interview with Kevin Marks
7	47	Video: Interview with Karen Guz
7	48	Video: Interview with Mike Mason
7	49	Module 7 Reading Assignments
7	50	Assignment 10: Changing Irrigation Users' Behaviors – Pamphlet and Essay

Table 3.3 Overall, module, and student learning outcome (SLO) mean scores of the pre- and post-test.

	Pre-test	Post-test				Pre-test	Post-test		
	Score (%)		Sig.†	Diff.‡ (%)		Score (%)		Sig.†	Diff.‡ (%)
Overall	79	89	*	10	Module 4	82	91	*	9
					SLO 4.1	86	100	*	14
Module 1	67	77	*	10	SLO 4.2	89	94	NS	5
SLO 1.1	26	40	NS	14	SLO 4.3	91	97	NS	6
SLO 1.2	69	80	NS	11	SLO 4.4	63	74	NS	11
SLO 1.3	71	94	*	23	Module 5	83	91	*	8
SLO 1.4	100	94	NS	6	SLO 5.1	86	100	*	14
Module 2	91	97	*	6	SLO 5.2	83	94	NS	11
SLO 2.1	82	91	NS	9	SLO 5.3	69	74	NS	5
SLO 2.2	91	97	NS	6	SLO 5.4	94	97	NS	3
SLO 2.3	100	100	NS	0	Module 6	82	94	*	12
SLO 2.4	89	100	*	11	SLO 6.1	89	97	NS	8
Module 3	78	91	*	13	SLO 6.2	80	97	*	17
SLO 3.1	89	97	NS	8	SLO 6.3	77	89	NS	12
SLO 3.2	49	86	*	37	Module 7	72	79	NS	7
SLO 3.3	86	94	NS	8	SLO 7.1	94	97	NS	3
SLO 3.4	83	94	NS	11	SLO 7.2	88	86	NS	-2
SLO 3.5	83	83	NS	0	SLO 7.3	43	54	NS	11

† Nonsignificant (NS) or significant (*) differences between pre- and post-test scores at *P*=0.05.
‡ Difference in scores from pre-test to post-test.

Table 3.4 Percentage of participants' responses to level of sense and meaning for each module and for the course overall.

		Definitely[†]	Yes	Somewhat	No	Not at all
Module 1[‡]	Sense	17.8	28.4	3.5	0.3	0.0
	Meaning	15.7	21.9	11.1	1.3	0.0
Module 2	Sense	14.4	30.1	5.4	0.1	0.0
	Meaning	15.5	25.9	8.5	0.1	0.0
Module 3	Sense	20.0	27.0	2.2	0.8	0.0
	Meaning	16.5	27.5	5.0	1.0	0.0
Module 4	Sense	17.8	25.8	5.9	0.5	0.0
	Meaning	17.0	25.6	6.6	0.7	0.1
Module 5	Sense	17.0	25.5	5.5	1.6	0.4
	Meaning	16.4	26.1	5.3	1.8	0.4
Module 6	Sense	10.7	25.2	11.5	2.3	0.3
	Meaning	11.7	23.0	14.0	1.0	0.3
Module 7	Sense	13.1	30.1	6.8	0.0	0.0
	Meaning	11.0	26.5	10.6	1.7	0.2
Overall[§]	Sense	16.0	27.5	5.7	0.7	0.1
	Meaning	15.1	25.1	8.6	1.1	0.1

[†] Five-point Likert-type scale used for responses: "Definitely," "Yes," "Somewhat," "No," and "Not at all."

[‡] The sum of all percentages in each module rows (sense and meaning combined) equals 100%.

[§] Overall is a report of the responses for all seven modules combined.

Table 3.5 Percentage of favorable and unfavorable sense and meaning responses for each module and for the course overall.

		Favorable[†]	Unfavorable[‡]
Module 1	Sense	46.2	3.8
	Meaning	37.6	12.4
	Sum[§]	83.8	16.2
	Difference[¶]	8.6	-8.6
Module 2	Sense	44.5	5.5
	Meaning	41.4	8.6
	Sum	85.9	14.1
	Difference	3.1	-3.1
Module 3	Sense	47.0	3.0
	Meaning	44.0	6.0
	Sum	91.0	9.0
	Difference	3.0	-3.0
Module 4	Sense	43.6	6.4
	Meaning	42.6	7.4
	Sum	86.2	13.8
	Difference	1.0	-1.0
Module 5	Sense	42.5	7.5
	Meaning	42.5	7.5
	Sum	85.0	15.0
	Difference	0.0	0.0
Module 6	Sense	35.9	14.1
	Meaning	34.7	15.3
	Sum	70.6	29.4
	Difference	1.2	-1.2
Module 7	Sense	43.2	6.8
	Meaning	37.5	12.5
	Sum	80.7	19.3
	Difference	5.7	-5.7
Overall[#]	Sense	43.5	6.5
	Meaning	40.2	9.8
	Sum	83.7	16.3
	Difference	3.3	-3.3

[†] Favorable is the combination of "Definitely" and "Yes" survey responses.

[‡] Unfavorable is the combination of "Somewhat," "No," and "Not at all" survey response.

[§] Sum of the percent sense and meaning responses in the favorable and unfavorable categories within each module.

[¶] Difference among the percent sense and meaning responses within each module (sense – meaning).

[#] Overall is a summary of the responses for all seven modules combined.

Appendix A – Example of the Module Overviews used in the course

Water Issues in the
Lawn and Landscape
Kansas State University

HORT 405: Water Issues in the Lawn and Landscape

Module 1 Overview

Module 1 – Perceptions: What kind of lawn do homeowners expect?

Student Learning Outcomes

- Trace the historical events and their contribution to the rise of the American lawn.
- Identify the important individuals in the history of the American lawn and their contribution.
- Explain homeowner lawn quality expectations in Kansas.
- Based on survey results, describe the homeowner's perception of the amount of water they think they apply to their lawn and how the homeowners make irrigation decisions.

Please read over the checklist below and complete all tasks by the due dates, or during the time allowed, in order to meet all of the requirements for Module 1.

- **Topic 1** – History of the American Lawn; **Presented by** Dr. Steve Keeley
  - ☐ Watch the video/PowerPoint **"Lecture – History of the American Lawn"** and take notes
  - ☐ **Assignment #1**: Open the document **"History of the American Lawn Articles"** and read the two articles on the history of the American lawn that come from websites of two groups with divergent views on lawns- one group detests lawns, the other group is supportive of lawns (yet not blindly so– there is a section on their website with recommendations on ways to reduce lawns, for example). Read the articles and type up your answers to the four questions listed below. Please see **Returning Assignments** in the course syllabus for directions on how to submit assignments. The point value and due date for this assignment can be found in the course syllabus in the Assignment List and/or Semester Calendar sections.

1. From Article #1, what were the major developments that led to the widespread use of lawns around homes?
2. What is a "cottage garden" and how does it differ from today's lawn?
3. From Article #2, find three examples of sentences or phrases that reveal the author's bias for or against lawns. List the sentences or phrases and comment on how the sentence or phrase reveals the author's bias.
4. As you begin this course, what is your opinion on the value of lawns? Is it positive or negative, and why?

- <u>**Topic 2** – Homeowner Survey; **Presented by** Dr. Dale Bremer</u>
  - ☐ Watch the video/PowerPoint **"Lecture – Homeowner Survey Part I"** and take notes
  - ☐ Watch the video/PowerPoint **"Lecture – Homeowner Survey Part II"** and take notes
  - ☐ Watch the video/PowerPoint **"Lecture – Homeowner Survey Part III"** and take notes
  - ☐ <u>**Assignment** #2</u>: Open the document **"Survey Assignment"** and print off color copies of the two-page survey and distribute to five or more single-family residential homeowners. Please ask that they return the surveys within a week so you can meet your assignment deadline. Summarize your results for **all five surveys** in a written report (include the names and addresses of the people surveyed). Include graphics to illustrate the most significant findings, in your opinion. The point value and due date for this assignment can be found in the course syllabus in the <u>Assignment List</u> and/or <u>Semester Calendar</u> sections.

    ****Start this assignment early to allow time for the surveys to be returned to you.**
- <u>**Topic 3** – Turf quality and expectations; **Presented by** Dr. Steve Keeley</u>
  - ☐ Watch the video/PowerPoint **"Lecture – Turf quality and expectations"** and take notes
  - ☐ <u>**Assignment** #3</u>: Open the document **"Why My Friend Griswold Doesn't Like Turf"** and read the essay. The essay was written by a turfgrass researcher, to an audience of people who are employed in various segments of the turfgrass industry. Write a one-page (approximately) reaction paper, addressing, at a minimum, the questions listed on the next page. The point value and due date for this assignment can be found in the course syllabus in the <u>Assignment List</u> and/or <u>Semester Calendar</u> sections.

1. What is the author's thesis?
2. Why is Griswold upset?
3. Why is the author's friend in Beijing more appreciative of turf?
4. What is your reaction to the author's description of lawn irrigation habits in Denver vs. the small town in Illinois?
5. Why does the author propose a "brown turf can be beautiful too" campaign?
6. Do you agree or disagree with the author's perspective? Why?

☐ **"Module 1 Exam":** You will have **50 minutes** to complete this exam. Access the exam, through K-State Online, sometime during the availability time. Review the file **"HORT 405 Exam Overview"** for procedures and guidelines on taking exams for this course. The point value and availability times/dates for this exam can be found in the course syllabus in the Assignment List and/or Semester Calendar sections.

☐ **"Module 1 Survey"**: You will receive a link to the survey via email at the beginning of the survey's availability window. Please complete the anonymous survey before it expires. Please send an email to jcdom@ksu.edu once you have completed the survey so you can receive your points. The point value and availability times/dates for this survey can be found in the course syllabus in the Assignment List and/or Semester Calendar sections.

Once you have completed all of the above ☐ check boxes, you have met the requirements for Module 1.

Appendix B – Pre- and Post-Test used to evaluate the course.

Module 1 - Perceptions: What kind of lawn do homeowners expect?				Ans.
SLO	**1.1**		**Trace the historical events and their contribution to the rise of the American lawn.**	
Quest.	1	T/F	The earliest lawns are thought to have originated in 16th century Europe.	F
SLO	**1.2**		**Identify the important individuals in the history of the American lawn and their contribution.**	
Quest.	2	T/F	The Davey Co. treated lawns for grubs in the 1930's.	T
SLO	**1.3**		**Understand turfgrass quality expectations.**	
Quest.	3	T/F	A darker green color is always healthier for the turfgrass plant.	F
SLO	**1.4**		**Describe the homeowner's perception of the amount of water they think they apply to their lawn and how the homeowners make irrigation decisions.**	
Quest.	4	T/F	More than 70% of residential homeowners in Wichita, Olathe, and Salina, Kansas, don't know the amount of water they apply to their lawns when they water.	T

Module 2 - Water sources: Availability and quality				Ans.
SLO	**2.1**		**Identify any water shortages in your local area and briefly discuss the basic facts of US water use.**	
Quest.	5	T/F	Less than 1% of the world's fresh water is readily accessible for direct human use.	T
SLO	**2.2**		**Explain where your water comes from and how to use the EPA-Envirofacts website to discover the welfare of your local water.**	
Quest.	6	T/F	The EPA-Envirofacts website can be used to determine the source of your local water.	T
SLO	**2.3**		**Define water quality, describe storm water pollution and discuss possible solutions.**	
Quest.	7	T/F	Urbanization has not affected the water quality of our streams, ponds, lakes, etc.	F
SLO	**2.4**		**Identify common daily habits that contribute to water waste and water pollution.**	
Quest.	8	T/F	A 10 minute shower can use 40 gallons of water.	T

Module 3 - How irrigation practices affect water quality				Ans.
SLO	**3.1**		**Understand landscape characteristics that increase potential for leaching and runoff.**	
Quest.	9	MC	Which site is most susceptible to runoff:	B
		A	Dense turf on a 4% slope	
		B	A concrete driveway with a 1% slope	
		C	An English ivy bed on a 2% slope	
SLO	**3.2**		**Understand the potential fate of nutrients and pesticides in the environment.**	
Quest.	10	MC	Regarding phosphorus and leaching:	A
		A	Leaching of phosphorus is rare because phosphorus is bound in the soil.	
		B	Phosphorus leaches readily because phosphorus is soluble and mobile	
SLO	**3.3**		**Become familiar with research results related to nutrient and pesticide leaching and runoff.**	
Quest.	11	MC	Research on nitrogen leaching has shown that:	B
		A	Leaching of over 10% of nitrogen applied is common on most turf sites.	
		B	Leaching has been found to range from less than 1% to over 11%, depending on soil type and type of nitrogen fertilizer.	
		C	Leaching is always less than 1%	
SLO	**3.4**		**Know characteristics of fertilizers and pesticides which make them susceptible to leaching and runoff.**	
Quest.	12	MC	Which fertilizer increases the potential for nitrogen leaching?	C
		A	A slow release synthetic fertilizer, such as a polymer coated urea.	
		B	A natural organic fertilizer.	
		C	A soluble, quick-release fertilizer.	
SLO	**3.5**		**Understand how cultural and irrigation management practices can be used to reduce the potential for leaching and runoff.**	
Quest.	13	T/F	Leaching is less likely with frequent, lighter applications of water.	T

Module 4 - Irrigation decision making				Ans.
SLO	**4.1**		**Understand evapotranspiration and the factors that influence evapotranspiration**	
Quest.	14	T/F	The greatest water loss from a turfgrass ecosystem is typically from evapotranspiration (ET).	T

SLO	**4.2**		**Explain various irrigation practices that reduce water use.**	
Quest.	15	MC	Morning irrigation of turf is preferred, because:	D
		A	Length of leaf wetness is kept to a minimum and potential for disease is reduced.	
		B	Irrigation can be applied more uniformly due to less wind.	
		C	Less evaporation of water occurs compared to midday irrigation.	
		D	All of the above.	

SLO	**4.3**		**Understand lawn and landscape microclimates and how they influence evapotranspiration**	
Quest.	16	T/F	Examples of microclimates include small areas that are shaded or where the wind is blocked by obstructions such as buildings or hedgerows.	T

SLO	**4.4**		**Understand new irrigation technology that incorporates both evapotranspiration and soil-moisture sensors.**	
Quest.	17	T/F	Where the goal is to keep turfgrass green, the use of ET-based irrigation controllers usually increases the amount of water used compared with standard controllers with rain sensors.	F

Module 5 - Low-water lawns and landscapes				Ans.
SLO	**5.1**		**List alternative lawn and landscape species that use less water than commonly used species.**	
Quest.	18	T/F	A hydrozone is an area of a landscape containing plants with similar water requirements.	T
SLO	**5.2**		**Explain deficit irrigation and how the practice of deficit irrigation can conserve water.**	
Quest.	19	T/F	Deficit irrigation increases root growth deeper in the profile where water is adequate and therefore, helps turfgrass to withstand subsequent drought.	T
SLO	**5.3**		**Identify new technologies in irrigation applications and explain how the new technologies help conserve water.**	
Quest.	20	T/F	One of the latest irrigation technologies is rotating nozzles; these help conserve water by applying more water per unit of time.	F
SLO	**5.4**		**Understand the effects of drought on plants and how plants recover from drought.**	
Quest.	21	T/F	Unlike some ornamentals, turfgrass has the capability to enter dormancy for long periods of time and then recover when adequate water becomes available.	T

Module 6 - Irrigation system auditing: Evaluating water delivery amounts and efficiency				Ans.
SLO	**6.1**		**Perform field tests (audits) on real systems.**	
Quest.	22	T/F	A field audit should not be performed if the wind speed is greater than 8 mph.	T
SLO	**6.2**		**Identify problems that cause poor uniformity.**	
Quest.	23	MC	Which one of the following improves water distribution uniformity?	A
		A	Matched precipitation rate nozzles	
		B	Rain sensors	
		C	Check valves	
		D	Accurately scheduling irrigation runtimes	
SLO	**6.3**		**Calculate an accurate water schedule using a base water schedule.**	
Quest.	24	T/F	A base watering schedule uses net precipitation rate.	T

Module 7 - Changing water users' habits				Ans.
SLO	**7.1**		**Describe possible long-term perspectives on water conservation regarding the lawn and landscape industries.**	
Quest.	25	T/F	There usually needs to be an incentive (usually money savings) in order to get the general public to conserve water.	T
SLO	**7.2**		**Understand common methods of disseminating water conservation information.**	
Quest.	26	MC	Water districts typically use which of the following methods to inform the general public about water conservation:	D
		A	Flyer inserts in monthly water bills	
		B	Newsletter	
		C	Presentations at service club meetings	
		D	All of the above	
SLO	**7.3**		**Evaluate the effectiveness of the common methods of disseminating water conservation information.**	
Quest.	27	T/F	Inserting information about water conservation in the monthly water bills of residential homeowners is an effective way of informing the general public about water conservation.	F

Appendix C – Example of the surveys used to evaluate the course.

Module 1 Survey

Opening Instructions

Please complete the following questions regarding Module 1. We are truly interested in your comments and suggestions.

All of the questions are asking if an assignment or lecture made "sense" and/or had "meaning" to you. Keep the following in mind while answering these questions:

- Sense – Questions that ask if an assignment or lecture made sense are referring to whether you understood and/or comprehended the item based on your experiences. Ask yourself "Did that fit with *my previous knowledge base*?"
- Meaning – Questions that ask if an assignment or lecture had meaning are referring to whether the item was relevant to you. Ask yourself "Was the reason for learning this information apparent from either *my previous experiences* or *made apparent by the lesson*?"

Module 1 lectures. Rate each of the following lecture topics and give your comments and suggestions on how to improve each lecture for future classes.

1. Did Dr. Keeley's lecture on the History of the American Lawn make sense to you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

2. Did Dr. Keeley's lecture on the History of the American Lawn have meaning for you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

3. Did Dr. Bremer's lecture on the Homeowner Survey make <u>sense</u> to you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

4. Did Dr. Bremer's lecture on the Homeowner Survey have <u>meaning</u> for you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

5. Did Dr. Keeley's lecture on Turf quality and expectations make <u>sense</u> to you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

6. Did Dr. Keeley's lecture on Turf quality and expectations have <u>meaning</u> for you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

Module 1 assignments. Rate each of the following assignments and give your comments and suggestions on how to improve each assignment for future classes.

7. Did "Assignment #1: History of the American Lawn" make sense to you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

8. Did "Assignment #1: History of the American Lawn" have meaning for you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

9. Did "Assignment #2: Survey Assignment" make sense to you?
   - ☐ Definitely
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Not at all

   Further comments about your response:

10. Did "Assignment #2: Survey Assignment" have meaning for you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

11. Did "Assignment #3: 'Why My Friend Griswald Doesn't Like Turf' – essay and reaction paper" make <u>sense</u> to you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

12. Did "Assignment #3: 'Why My Friend Griswald Doesn't Like Turf' – essay and reaction paper" have <u>meaning</u> for you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

<u>Module 1 exam.</u> Give your overall rating of the exam and give your comments and suggestions regarding the exam.

13. Did the exam for this module make <u>sense</u> to you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

14. Did the exam for this module have <u>meaning</u> for you?
    - ☐ Definitely
    - ☐ Yes
    - ☐ Somewhat
    - ☐ No
    - ☐ Not at all

    Further comments about your response:

Closing Statement

Thank you for taking the time to answer these questions.