Landscape Coefficients for Single- and Mixed-species Landscapes

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Abstract. Urban landscape irrigation is becoming increasingly important from a resource management point of view. Significant water use savings may be achieved if landscape irrigation is based on reference evapotranspiration (ET_o). This study measured landscape crop coefficients (K_L) for landscapes that are comprised of different vegetation types and irrigation water quality differences affecting K_L . The K_L was determined from the ratio of actual evapotranspiration to the ET_o calculated from the modified Penman-Monteith equation. Irrigation quantity was based on 100% replacement of ET_o . The K_L values were determined for the following landscape vegetation on a fine sandy loam: St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze.], a single shumard red oak (*Quercus shumardii* Buckl.), St. Augustinegrass plus red oak, native grasses [*Muhlenbergia capillaries* (Lam.) Trin. and *Schizachyrium scoparium* (Michx.) Nash], and native grasses plus Red Oak in both College Station (CS) and San Antonio (SA), TX. Soil was systematically placed into lysimeters containing a drainage system and soil moisture probes. Lysimeters (1136 L) were placed in-ground in a randomized complete block design with three blocks. Soil moisture measurements were made at 0- to 20-, 20- to 40-, and 40- to 60-cm depths. The K_L was determined after a rainfall or irrigation event for periods of 2 to 5 days. During the combined growing seasons of 2007 and 2008, K_L in SA increased from early, to mid, to late season. In CS, the K_L was unaffected by plant treatment or season. The St. Augustinegrass treatment K_L seasonally ranged from 0.45 to 0.62 in SA. In CS, soil sodium accumulation caused decreased K_L . These results of K_L for mixed-species landscapes on non-sodic sites trend toward seasonal values of 0.5 to 0.7 for irrigation decisions in southern Texas. Landscape coefficients can be used as a tool in irrigation decision-making, which could contribute to water savings in amenity landscapes.

Water is one of our most valuable natural resources and water conservation continues to be a major national priority [Vickers, 2001; Texas Water Development Board (TWDB), 2007]. As a result of population growth, current potable water supplies will be insufficient by the year 2050 in Texas (TWDB, 2003). Currently, 7.8 billion gallons, or $\approx 30\%$ of all potable water, is used outdoors (U.S. Geologic Survey, 2006) primarily for landscape irrigation (Kjelgren et al., 2000; Vickers, 2001; White et al., 2004).

Landscape plants provide an aesthetic appeal to urban landscapes, prevent erosion of the soil that impairs surface water supplies, sequester carbon, add oxygen to the atmosphere, and improve recharge of groundwater (Beard and Green, 1994). Irrigated areas within the built landscape can also increase property values. Yet, end-user lack of understanding of best management practices for landscape water management will routinely contribute to excess water use. In a study of 800 home consumers in College Station, TX, it was estimated that more than 24 to 34 million gallons of excess water, that is water in excess of an irrigation coefficient of 1.0 of the yearly reference evapotranspiration, were used annually for landscape irrigation during 2001 through 2003 (White et al., 2004).

Appropriate landscape design and planning has been heralded for decades as a step toward water conservation (Welsh et al., 2000), yet water consumer irrigation practices have not changed with landscapes designed for water conservation (Peterson et al., 1999).

Evapotranspiration (ET) is the amount of water lost through evaporation from the soil and plant surface plus that lost through plant transpiration. Reference evapotranspiration (ET_o) water loss rate is based on environmental demands for a cool-season turf completely covering the ground. Landscape irrigation based on ET_o is an emerging area of water conservation that links plant water use to irrigation water replacement rates and schedules. There is evidence that ET_o weather station data can be used in irrigating landscape plants (Shaw and Pittenger, 2004; White et al., 2004), yet there is a lack of information on the fundamental seasonal relationships between ET_o and actual evapotranspiration of turf-grasses, native grass species, tree species, and mixed species landscapes under different climates. An understanding of this relationship is critical to providing accurate recommendations for landscape irrigation based on ET_o .

A variety of state-of-the-art technologies are available for reducing irrigation water use in amenity landscapes. One of these “smart irrigation” technologies is an ET-based controller. McCready et al. (2009) compared the effectiveness of an ET-based controller technology treatment with a time-based system with 2 d of irrigation per week without any type of sensing mechanism. Compared with the time-based system, the ET-based treatments used 25% to 62% less water without compromising turf quality. This demonstrates the benefit of using ET-based controllers in landscape irrigation, but there is a gap in the knowledge of what fraction (e.g., 0.7, 0.8) of the ET_o is needed in the mixed-species landscape. Coupling ET-based plant water use with ET-based irrigation controllers can provide a means of accurately applying water to the landscape.

It is well documented that sodic and saline soil conditions can alter soil water use and transpiration in landscape plant materials (Eom et al., 2007; Munn, 2002; Wang and Nii, 2000). Dean et al. (1996) demonstrated a differential response in bermudagrass and tall fescue growth in arid climates where excess salt and water-induced stress were factors. The Dean et al. study also demonstrated that both grasses could be grown with moderately saline water if irrigation water volume was above a species-specific threshold value. Carrow and Duncan (1998) documented how excess soil sodium (Na) levels can lead to soil structural deterioration and to specific ion toxicity in shoot and root tissue. Sodic soil conditions may develop in amenity landscapes if high Na irrigation water is used. Therefore, the actual ET/ ET_o relationship of plants may vary between sodic landscape sites and non-sodic landscape sites. As sources of potable fresh water are depleted, lower-quality water increasingly becomes used for irrigation of turf and woody plants.

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The objectives of this study were to 1) compare landscape crop coefficients (K_L ; actual ET to ET_o) by landscape plant treatment; and 2) determine if seasonal differences in K_L occur within sites.

Materials and Methods

Site description. The experiment was conducted at two sites: the Texas A&M University Turfgrass Field Laboratory in College Station, TX, and at a site adjacent to the San Antonio Water System Leon Creek Waste Water Treatment Facility in San Antonio, TX. These two sites will be referred to as the College Station (CS) region and the San Antonio (SA) region. College Station on average has 1000 mm rainfall, 47.8% humidity, and an ET_o of 1430 mm. San Antonio on average has 764 mm rainfall, 42.9% humidity, and an ET_o of 1522 mm. Table 1 presents average seasonal rainfall and actual seasonal rainfall by site.

Irrigation water analysis. Irrigation water for each site was from the local potable water supply. Irrigation water samples from both sites were analyzed in July 2008. The pH, calcium (Ca), magnesium (Mg), HCO_3 , Na, and sodium adsorption ratio (SAR) were 9.1, 2, 0.5, 393, 232, and 38, respectively, for irrigation water at CS versus 7.9, 24, 16, 190, 12, and 0.5 for irrigation water in SA. Electrical conductivity of irrigation water was 0.089 and 0.057 $S\cdot m^{-1}$ in CS and SA, respectively.

Lysimeter construction and sensing. Individual waterproof lysimeter containers were 1136-L oval stock tanks (R.G. Applegate Steel Co., Saratoga, IN) 2.43 m long $\times$ 1.02 m wide $\times$ 0.68 m deep. The distance between the individual lysimeters was 30.5 cm. Tank bottoms were constructed from 1.0 mm galvanized steel and sides were made from 0.85 mm galvanized steel. Tanks were placed in-ground on a smooth level surface such that the tank tops were 5 cm beneath the surface grade. The bottom of each tank was filled to a depth of 5.1 cm with 1-cm diameter gravel. A chlorinated polyvinyl chloride (CPVC) leachate pipe system was embedded in this gravel layer to allow leachate removal

by vacuum. The leachate pipe consisted of three 1.83-m long pieces of 1.27-cm diameter pipe manifolded together at one end and equipped with a 0.76-m tall standpipe as shown in Figure 1. The end of each lateral was permanently capped. In the bottom of each lateral line, 3-mm diameter holes were drilled at 10-cm spacing to allow water to enter the pipes.

After the installation of the leachate lines and gravel layer, soil was added in lifts. The soil was from the A horizon of the Rader fine sandy loam soil series (fine-loamy, mixed, semiactive, thermic Aquic Paleustalfs). All soil was passed through a 1.27-cm diameter screen before placement in the lysimeter. Approximately 15 to 20 cm of loose soil was added and manually compacted with a hand tamper to a finished depth of 10 cm. The surface of each lift was lightly scarified with a garden rake before adding the next lift of soil. When the soil surface reached 10 to 15 cm below the top of the lysimeters, a 15-cm wide strip of 0.1 mm plastic was taped to the inside of the lysimeter wall using duct tape. This plastic sheet extended $\approx$ 5 cm up the lysimeter wall and 10 cm horizontally toward the center of the lysimeter on top of the compacted lift of soil. The plastic sheet provided a mechanical barrier to reduce the potential for side wall flow and helped force moving water downward and away from the side walls of the lysimeters so that it would flow through the bulk soil (Brown et al., 1985). Additional soil lifts were added until the lysimeters reached capacity. The average soil bulk density at 12 cm in July 2008 was $1.50 \pm 0.03\text{ Mg}\cdot\text{m}^{-3}$. Lysimeters for the SA location were built in CS, transported to SA, and installed in-ground.

Six soil moisture sensors (ECH2O Probes, Model EC-20; Decagon Devices, Pullman, WA) were placed in two locations (60 cm from each end) in each lysimeter (three sensors per location). Sensors monitored volumetric water content at 0- to 20-, 20- to 40-, and 40- to 60-cm depths (soil surface down to the gravel layer). Cables from the sensors were routed along the inside wall of the lysimeters. All wires were taped to the inside of the lysimeter walls (Fig. 1). From the lysimeters, the cables were enclosed in a 10-cm diameter perforated corrugated drainage pipe and routed to a nearby data collection station. Volumetric soil moisture content measurements were collected using a data logger (model 10X; Campbell Scientific Inc., Logan,

UT) coupled with Model AM 16/32 multiplexers. Measurements were taken every 15 min and averaged for every 30 min. At the CS location, a handheld PDA (Palm; Model 500m) and appropriate software (P Connect, Version 2.0; Campbell Scientific Inc.) was used to manually download data weekly. At the SA location, data collection was accomplished using a Com 210 modem and analog telephone line (Com 210; Campbell Scientific Inc.). This allowed daily transfer of data to a central computer in CS.

Lysimeters at each location were irrigated with a two-zone in-ground automatic system. Irrigation spray heads (Hunter PGJ Series, San Marcos, CA) were installed at 3.65-m triangulated spacing. A water meter was installed in each zone to allow measurement of total applied water.

A weather station was located within 250 m of the lysimeters at CS and SA. Environmental data included precipitation, radiant energy, wind speed, humidity, and temperature. Data from these stations were used to calculate reference evapotranspiration using the modified Penman-Monteith equation (FAO Irrigation and Drainage Papers-56, 1998). Irrigation was adjusted every 2 to 3 weeks to replace 100% of calculated reference evapotranspiration minus precipitation. During periods when irrigation water was required, water was applied 1 or 2 d per week.

Plant treatments. Treatments were arranged in a randomized complete block design with three replications. The plant treatments were randomly assigned to the lysimeters within each block and included: St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze.] 100% cover, Shumard red oak (*Quercus shumardii* Buckl.) tree alone with bare soil, native grasses little bluestem [*Schizachyrium scoparium* (Michx.) Nash] and pink Muhlygrass [*Muhlenbergia capillaries* (Lam.) Trin.], St. Augustinegrass plus one shumard red oak, and native grasses plus one shumard red oak.

Plant installation occurred on 19 Dec. 2006 and 20 Dec. 2006 for the SA and CS locations, respectively. To avoid disturbing sensors and sensor cables, container-grown (11.4 L) shumard red oak trees were planted in the center of the lysimeters. Treatments receiving St. Augustinegrass (All Seasons Turfgrass Inc., Brookshire, TX) were planted with sod grown on a Katy fine-sandy loam series (fine-loamy, siliceous, thermic Aquic Paleudalf). Native grass treatments received nine field-grown (3-L root ball) individual

Table 1. Average seasonal rainfall, actual seasonal rainfall, and percent variation from average rainfall during 2007 and 2008 in College Station and San Antonio, TX.

College Station			
Season	Avg (mm)	2007	2008
Early	248	223 (10%)	181 (25%)
Mid	270	311 (+15%)	270 (0) ^a
Late	225	202 (10%)	74 (67%)
San Antonio			
Season	Avg (mm)	2007	2008
Early	187	167 (11%)	57 (70%)
Mid	245	557 (+127%)	238 (3%) ^b
Late	179	36 (80%)	23 (87%)

^aA total of 34 mm (50% of season) in 3 weeks of August.

^bA total of 104 mm (43% of season) in 2 weeks of August.

Fig. 1. Schematic drawing of the lysimeter design.

little bluestem and two container-grown (5.7-L root ball) individual pink muhlygrass. The native grass plus red oak treatment received eight little bluestems and two pink muhlygrass. Native grasses were spaced equidistant across the lysimeter.

Site management. St. Augustinegrass was maintained at 5- to 7.6-cm cutting height with a mowing frequency of every 2 to 4 weeks. Clippings were returned to the plots. The bluestem and muhlygrass (native grass treatment) were trimmed to 15 to 18 cm each December. The soil in the St. Augustinegrass alone treatment was used as a reference for fertility decisions. The soil in the St. Augustinegrass alone treatment was sampled (0- to 15-cm depth) for laboratory analysis two to three times each year (Soil, Water, and Forage Testing Laboratory, College Station, TX). Phosphorus, potassium, Ca, Mg, Na, and sulfur were extracted using the Mehlich III extractant (Mehlich, 1978) and were determined by the inductively coupled plasma method. Based on soil analysis, a balanced fertilizer was added to all treatments during 2007 and 2008. Nitrogen at a rate of 48.8 kg-ha⁻¹ was applied in three separate events each year. Plant tissue analysis was conducted in July 2008 for the St. Augustinegrass treatment only to evaluate plant health and potential negative effects of soil salts. Lysimeters were evacuated every 2 to 4 weeks to avoid prolonged saturation of the gravel layer.

Landscape coefficient determination. Landscape coefficients were determined from changes in volumetric water content during 2 to 5 d of soil drying and from ET_o amounts during the same period. Soil drying periods occurred as a result of lack of precipitation and during intervals between irrigations. Soil drying periods began at 0001 HR 24 to 48 h after an irrigation or precipitation event and continued until 0001 HR before an irrigation or precipitation event ended the drying period. Changes in soil water volume during soil drying periods provided actual evapotranspiration data for each treatment. Actual evapotranspiration and ET_o data were used to calculate landscape coefficients by:

$K_L = \text{actual ET} \div \text{reference ET}$ in which:

K_L = landscape coefficient

Actual ET = actual evaporation and transpiration water loss

Reference ET = hypothetical evaporation and transpiration water loss as predicted by the modified Penman-Monteith equation.

Observations were grouped into early, mid, and late season (Table 2). Early season was designated as ordinal calendar Days 78 to 153 (75 d), midseason as Days 154 to 259 (105 d), and late season as Days 260 to 335 (75 d). This grouping of dates into three seasons corresponds to patterns of seasonal water deficit as shown in Figure 2, average ET_o – average rainfall for CS and SA.

Stomatal conductance. A steady-state diffusion porometer (Leaf Porometer, Model SC-1; Decagon Devices Pullman, WA) was used to measure leaf stomatal conductance (g_s). Every 4 to 6 weeks during active growth, conductance was measured in all treatments near solar noon under non-limiting soil moisture conditions. Three undamaged, recently matured leaves (subsamples) were randomly selected from each treatment block with St. Augustinegrass. The area of the St. Augustinegrass covering the lysimeter was visually divided into three equal areas, and one leaf from each of the three areas was selected for measurement. In treatments with red oak tree, a leaf from the lower, mid, and upper canopy in full sun exposure was used for measurement. The porometer's sensor was placed on the red oak leaf at the first or second lobe behind the apex at a point that would not cover a vein. Soil salinity affects a plant's ability to take up water for transpiration and for other metabolic processes (Munn, 2002). Stomatal conductance data measured in regular intervals during the growing season was a possible indicator of plant stress within species and between sites.

Grass biomass accumulation. In Nov. 2007 and Nov. 2008, the above-ground accumulation of native and turfgrass leaves and stems, both living and in various states of decay, were collected for a season-end grass biomass calculation. In those treatments with St. Augustinegrass and native grasses, a 100-cm² flat, square grid was randomly placed on the lysimeter. Leaves and stems, of the grasses only, in the three-dimensional volume of the square grid were harvested,

dried at 105 °C for 96 h, weighed, and converted to kilograms biomass/ha.

Statistical analysis. Treatment K_L values by region, biomass accumulation, and g_s were analyzed by using Proc GLM in SAS Version 9.2 (SAS Institute, 2008) for a randomized complete block design with a factorial structure that included plant treatment and seasons. Treatment means were separated by Scheffe's mean separation test. Effects were tested at an alpha level of $P \leq 0.05$. Statistical null hypotheses were as follows: mean K_Ls were the same by treatment and season for each region; mean grass biomass accumulations were the same by treatment and region; and mean g_s were the same by treatment and region.

Results

Landscape coefficients in San Antonio. The analysis of variance (ANOVA) model was significant with the source of variation in the main effects of plant treatment ($P < 0.0001$) and season ($P < 0.0001$). During the combined 2007 and 2008 growing seasons, the mean K_L was greater for native grass, native grass plus tree, and St. Augustinegrass plus tree than for tree alone (Table 3). The K_L for St. Augustinegrass did not differ significantly from the other plant treatments. The overall seasonal K_L increased from early season through late season by 61% (Table 3). The K_L for individual plant treatments by season increased from early season to late season.

Landscape coefficients in College Station. The ANOVA model was not significant ($P = 0.1078$) for K_L for the combined 2007 and 2008 growing seasons. The overall plant treatment K_Ls ranged from 0.21 to 0.34. The overall seasonal K_Ls ranged from 0.24 to 0.40. From 1 Mar. to 3 Oct. 2008 in CS, precipitation was 519 mm, and the average rainfall for this time period was 690 mm. The irrigation water used for 100% replacement of ET loss contributed Na and bicarbonate at each irrigation resulting in elevated soil Na in CS. In July 2008 in CS, the soil pH was 8.7 and the Na concentration was 402 parts per million (ppm).

Stomatal conductance. Mean g_s of the tree was greater in SA than in CS when grown alone and when grown with St. Augustinegrass (Table 4). This suggests that soil Na

Table 2. Calendar dates used for landscape coefficient calculations.

College Station	San Antonio
	2007
Early season 21–25 Mar., 27–28 Apr., 4–5 May, 1–2 June	21–25, 28–29 Mar., 26–27 Apr., 3–4, 28–29 May
Midseason 11–12 June, 9–13 July, 28 July to 1 Aug., 6–9 Aug., 11–16 Sept.	13–15 June, 26–31 July, 13–15, 27–30 Aug., 6–11 Sept.
Late season 8–11, 17–21, 23–24 Oct., 1–4 Nov.	9–12, 17–19 Oct., 30 Oct. to 4 Nov., 13–16 Nov.
	2008
Early season 21–25 Mar., 7–11 Apr., 8–9, 18–22, 24–28 May	19–21 Mar., 1–3, 27–30 Apr., 5–8, 20–23 May
Midseason 2–5, 9–12, 16–19, 23–26 June, 21–22, 28–31 July	3–6, 10–13, 17–20, 24–27 June, 15–18 July, 29 July to 1 Aug., 6–9 Aug.
Late season 23–26 Sept., 30 Sept. to 3 Oct., 12–14, 20–23 Oct.	16–18, 22–25 Sept., 6–9, 20–22 Oct.

Fig. 2. Historical monthly difference of evapotranspiration (ET_0) and rainfall (mm) in College Station and San Antonio, TX.

Table 3. The K_L for single- and mixed-species plantings by season and location.

	K_L					
	San Antonio			College Station		
St. Augustine	0.52 ab ²			0.34 NS		
St. Augustine + tree	0.61 a			0.34		
Tree	0.43 b			0.21		
Native grass	0.61 a			0.30		
Native + tree	0.61 a			0.33		
Seasonal mean	Early	Mid	Late	Early	Mid	Late
	0.44 C ³	0.55 B	0.71 A	0.39 NS	0.28	0.24
St. Augustine	Early	Mid	Late	Early	Mid	Late
	0.45 NS	0.52 NS	0.62 NS	0.51 NS	0.27 NS	0.24 NS
St. Augustine + tree	Early	Mid	Late	Early	Mid	Late
	0.56	0.56	0.72	0.47	0.32	0.23
Tree	Early	Mid	Late	Early	Mid	Late
	0.31	0.37	0.66	0.24	0.19	0.20
Native grass	Early	Mid	Late	Early	Mid	Late
	0.40	0.68	0.80	0.37	0.30	0.23
Native + tree	Early	Mid	Late	Early	Mid	Late
	0.48	0.62	0.75	0.40	0.29	0.31

²Means with the same lower case letter within column are not significantly different under Scheffe's mean separation test at $P \leq 0.05$.

³Means with the same upper case letter within row are not significantly different under Scheffe's mean separation test at $P \leq 0.05$.

NS = nonsignificant.

Table 4. The average stomatal conductance ($\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and SD of tree alone and tree when combined with native grasses and St. Augustine by region.

Region	Tree	Tree with native grasses	Tree with St. Augustine
CS	0.225 ± 0.119 B ²	0.240 ± 0.114 A	0.156 ± 0.069 B
SA	0.272 ± 0.114 A	0.198 ± 0.105 B	0.195 ± 0.103 A

²Stomatal conductance means with the same letter within column are not significantly different based on Scheffe's mean separation test.

accumulation in CS limited gas exchange and water use in the tree. However, the mean tree g_s was greater in CS than SA when grown with native grasses (Table 4). The mean tree alone K_L during the entire study was 0.43 for SA and 0.21 for CS.

The g_s of the St. Augustinegrass was the same regardless of the region or the presence of a tree. Mean g_s of the St. Augustinegrass during the entire study ranged from 0.056 ± 0.037 to 0.067 ± 0.047 $\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Mean g_s of the native grass is not presented as a result of lack of confidence in the data of the pink muhlygrass.

Grass biomass accumulation. Grass biomass accumulation was determined by random placement of grids in lysimeters with St.

Augustinegrass and native grasses. Because of the low-growing dense nature of the St. Augustinegrass, each sample completely filled the 100-cm² grid. As a result of the upright growth pattern of the native grasses, most grid samples were only partially occupied with leafy tissue. Therefore, in the native grass treatment, the bluestem mass was added to the *Muhlenbergia* mass for one composite native grass biomass.

The grass biomass accumulation data for 2007 were similar among grassy plant treatments within site (data not shown). In 2008, the overall grass biomass accumulation for SA was greater than for CS (41.9 and 25.5 $\text{Mg}\cdot\text{ha}^{-1}$, respectively). This is similar to the differences observed for K_L by region. The

mean overall K_L by region for this study was 0.61 and 0.34 for SA and CS, respectively.

Discussion

Water use of turfgrass increases in the fall typically displaying seasonality. Brown et al. (2001) reported that bermudagrass water use increased from June to September. Carrow (1995) also found that after averaging the water consumption from two growing seasons that 'Raleigh' St. Augustinegrass had greater water use in September and October than in July and August. In our study, St. Augustinegrass K_L increased seasonally in SA. The untrimmed native grasses increased in height and girth from spring until the first frost in November, whereas the mowed St. Augustinegrass had a relatively constant plant height and density during this time period. The native grasses with a more three-dimensional canopy thus have higher boundary layer resistance and therefore higher conductance. Plant canopy dimensions may have contributed to the seasonal differences in K_L in SA between the low-growing turfgrass and the upright bunchgrass-type growth of the native grass. However, during the study, the mean K_L for native grass was not statistically different from the K_L of St. Augustinegrass with or without a tree. This would imply that a seasonal K_L could be used in irrigation recommendations for amenity landscapes with mixed species.

Irrigation of turfgrass with water high in Na may be inducing sodic soil conditions (e.g., Aitkenhead-Peterson et al., 2009). Irrigation water, rather than precipitation, became a larger component of ET_0 replacement in late spring and summer (Table 1). Irrigation water quality may have influenced K_L . CS irrigation water ($\text{SAR} = 38$) was high in Na and bicarbonate and is assessed as a $\text{Na}\cdot\text{HCO}_3^-$ water, whereas SA irrigation water ($\text{SAR} = 0.5$) was high in Ca and carbonate and is assessed as $\text{Mg}\cdot\text{HCO}_3^-$ water. The effects of soil Na on landscape plant performance in CS are evidenced in the greater K_L and biomass accumulation in the SA region. Na accumulation in CS likely altered soil water potential and may have caused reduced evapotranspiration compared with SA. Leaf margin necrosis in the Shumard red oak trees in CS was observed initially in early July 2008, and this condition continued into October (data not presented). This marginal leaf necrosis appeared symmetrical, indicating a visual symptom of salt stress (Hammerschlag et al., 1986).

The decreasing K_L values with season in CS may be the result of the effects of Na in the soil and plant tissue. Tissue analysis from the St. Augustinegrass treatment was 11,362 ppm Na in CS compared with 7,882 ppm from SA. Soil and plant tissue Na content may have affected the plant's ability to take up water for transpiration and other metabolic processes (Ben-gal and Shani, 2002; Munn, 2002). Furthermore, the average leachate volume per treatment was 85.8 L in SA and 131.1 L in CS representing 53% more leachate from the CS site although

irrigation was at 100% replacement of ET_o losses at both sites. This is a further indication of reduced water use in CS.

High soil Na generally reduces plant transpiration and biomass accumulation in landscape vegetation (e.g., Eom et al., 2007; Sagi et al., 1998). Eom et al. (2007) found differential responses of six herbaceous perennials to soil Na concentrations, transpiration, and reduced biomass. In general, increasing soil Na concentrations reduced transpiration and biomass accumulation for the six ground covers. Increasing soil Na concentration also lowered biomass accumulation in annual ryegrass (*Lolium multiflorum* Lam.) grown in sand (Sagi et al., 1998). The overall grass biomass accumulation in CS may have also been affected by the presence of high soil Na concentrations (402 ppm Na in July 2008) compared with our site at SA. Stomatal conductance values were not necessarily reflective of seasonal or regional water use. Most of the species-to-species g_s comparisons were generally larger in SA. Potentially this was caused by a greater ET_o in SA and/or a soil Na-induced osmotic factor in water potential in CS. It is possible that the soil Na concentration in CS reduced the g_s as well as the water use.

Seasonal differences in plant treatment K_L s were much larger in SA than the K_L s in CS. The increase in K_L from early to midseason in the plant treatments in SA followed a corresponding increase in evaporative demand during this time period. Evidence now exists to use ET_o data as a predictor of seasonal water demand in mixed-species landscapes. Also, the negative influence of soil Na accumulation on plant water use is demonstrated.

The literature includes several examples of crop coefficients for turfgrass as a single species (Brown et al., 2001; Carrow, 1995; Ervin and Koski, 1998; Kim and Beard, 1988) and for woody plants as a single species (Levitt et al., 1995; Maupin and Struve, 1997) but very few examples for mixed-species plantings. White et al. (2004) described the potential for water savings in mixed-species landscapes by using a coefficient of 0.7. However, that study did not include field data measurements of actual water use. There is a lack of science-based information on seasonal irrigation coefficients for mixed-species landscapes. The results of this study trend toward acceptable irrigation coefficients of 0.5, 0.6, and 0.7 (early, mid, and late season, respectively) in non-sodic mixed-species landscape sites. St. Augustinegrass is widely used in the southern United States in mixed-species landscapes (Saha et al., 2007). This same seasonal K_L recommendation of 0.5, 0.6, and 0.7 may also be acceptable at landscape sites irrigated with sodic water to promote leaching of Na. This of course should be coupled with other remediation techniques such as gypsum applications. More work in landscape coefficients is needed. New studies should include other climatic regions and use of other woody plant species combinations. Corresponding work should also determine the aesthetic acceptability of the landscape plants grown under a landscape coefficient less than 1.0.

Municipalities and water planning agencies use several methods to promote water conservation among users (Barta, 2004; Desena, 1998; Vickers, 2001; Water Information, 2006). The use of a landscape coefficient for irrigating mixed-species landscapes has potential to be used in planning regional water needs. Seasonal landscape water demand could be closely predicted with a landscape coefficient, weather station data, and number of irrigated acres in the region.

The native grasses potentially have higher landscape coefficients than the turfgrass or tree alone. It appears the native grasses are opportunistic plants in regard to water use. Further study on the native grasses water use might determine if lower seasonal K_L s (e.g., 0.5) are acceptable for growth and maintenance that meets a specific aesthetic level in the landscape.

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