Plant Factors for Irrigating Mixed Turfgrass and Shrub Landscapes in a Humid Environment

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SUMMARY. Landscape water conservation methods and techniques contribute to managing water resources. Use of reference evapotranspiration (ET_o) data and landscape coefficients is one method that needs further development. Local ET_o data and actual plant water use were used to calculate plant factors (PFs) for three model landscapes composed of mixtures of turfgrass and shrubs. Model landscapes using a sandy loam soil included st. augustinegrass (*Stenotaphrum secundatum*), privet (*Ligustrum japonicum*), dwarf burford holly (*Ilex cornuta* 'Burfordii Nana'), and dwarf yaupon holly (*Ilex vomitoria* 'Nana') at three ratios of turfgrass to shrub vegetative cover: 80:20, 50:50, and 20:80. Soil was placed into inground lysimeters in a complete randomized block design with soil moisture sensors and a drainage system. Lysimeters were irrigated with a sprinkler system, and water was applied at a rate of 100% replacement of ET_o minus precipitation. Lysimeter soil leachate was collected from the drainage system and quantified. After 2 years, the PF of 20:80 and 50:50 turfgrass/shrub combination were greater than the PF of the 80:20 combination. Plant factors for the 80:20, 50:50, and 20:80 turfgrass:shrub combinations were 0.68, 0.97, and 1.01, respectively. There were no seasonal differences in PFs. Total growing season leachate depth over 2 years was 63.4, 30.7, and 12.6 mm for 80:20, 50:50, and 20:80, respectively. Further work on PFs should include other plant combinations, and evaluation in other climatic zones.

Amenity landscape water use continues to be a focus of conservation efforts across the United States (U.S. Environmental Protection Agency, 2014). Water purveyors and municipalities struggle with water salinity, population increases, and drought, which place considerable strain on water supplies (Metropolitan Water District of Southern California, 2014; Niemczynowicz, 1999; Toze, 2006). As fresh water becomes increasingly scarce in terms of meeting demand for it, methods of reducing demand for water will take an increasing precedence in municipal water management (Moss et al., 2013). Landscape water conservation methods and techniques using new technology or science-based principles will continue to contribute to managing water resources (Cabrera et al., 2013).

The benefits of having landscape plants in the built environment include noise reduction, erosion prevention, shade, increased property value, and aesthetic benefits (Frank, 2003). Turfgrasses have been shown to improve percolation of rainfall, urban heat

dissipation, and reduced fire hazard to structures (Beard and Green, 1994). Irrigation water needed in landscapes to supplement non-sufficient precipitation during the growing season is a well-documented and a substantial portion of municipal water use (Cabrera et al., 2013; Romero and Dukes, 2011; Runfola et al., 2013). A study by Mayer et al. (1999) found average outdoor water use across 12 geographically diverse American cities was 58% of total residential consumption. In central Florida, Haley et al. (2007) found 64% of residential water use was outdoors. That study was based upon 27 cooperating residential homes over a 30-month period. The City of Phoenix estimates 45% of its potable water delivered to residents is used outdoors (City of Phoenix, 2011). Hermitte and

Mace (2012) documented indoor and outdoor residential water use for 259 Texas cities from 2004 through 2008. Their study determined on average 31% of residential water usage was outdoors.

The quantity of water used to irrigate a landscape may be influenced by several very broad factors. Spinti et al. (2004) found the amount of time a resident had spent in a desert climate influenced landscape irrigation habits. Those residents spending a shorter period of time in a desert were more likely to conserve water in their landscape. Use of an automatic sprinkler system in a landscape may have an impact on water quantity applied (Mayer et al., 1999). Mayer et al. (1999) and Runfola et al. (2013) determined total lawn area was a significant predictor of annual landscape water use providing a positive correlation. Landscapes in climates with higher average temperatures tend to use more irrigation water than landscapes with moderate temperatures (Breyer et al., 2012; Mayer et al., 1999). Landscape water use also tends to increase during warmer months of the year (Breyer et al., 2012; Kjølgen et al., 2000).

Landscape water conservation methods and techniques continue to gain acceptance in the United States. The Irvine Ranch Water District (Irvine, CA) created an increasing block structure to water pricing that reduced outdoor water consumption among its users by 50% (Desena, 1998). In 1995, a comprehensive water conservation education program was started by the Albuquerque, NM Water System to reduce per capita use. This program included time-of-day for watering restrictions, odd-even street address for watering days, and promotion of xeric plants. Time-of-day violations could be fined from \$20 up to \$1000. This program had reduced water use in 2004 by 34%

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
100	bar	kPa	0.01
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
1.1209	lb/acre	kg·ha ⁻¹	0.8922
0.0254	mil	mm	39.3701

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compared with 1995 figures (City of Albuquerque, 2014). The city of San Antonio, TX, has implemented a water conservation program over the previous 20 years which can be described as remarkable. Despite a 67% increase in population, San Antonio's current water use is very near to what the water use was in 1984 (Postel, 2011). Most of the San Antonio Water System Management Plan places emphasis in landscape irrigation, which include outreach education, time-of-day, and day-of-week irrigation. These programs provide fine examples for other municipalities to emulate and adapt. However, research-based results and outreach education will still be needed for landscape water use efficiency and conservation in amenity landscapes. This may include smart-irrigation controllers, alternative water sources, use of native and adapted plants, and mixed landscape crop coefficients (Cabrera et al., 2013; McCready et al., 2009; Pannkuk et al., 2010; Parsons et al., 2010).

Landscape irrigation based on mixed species crop coefficients is an emerging area of water conservation based on climatological conditions. Crop coefficients for irrigation exist for most turfgrass species and a few woody ornamental species, but crop coefficient type irrigation information on amenity landscapes with mixtures of two plant types is quite limited (Pannkuk et al., 2010). Urban landscapes are a heterogeneous mosaic of plant types that are managed in patches (Stabler, 2008). Further studies are needed to provide refinement to a mixed species landscape coefficient suitable to specific regions (Cabrera et al., 2013). The American Society of Agricultural and Biological Engineers (ASABE) has recently defined mixed-species landscape water use normalized to reference evapotranspiration as plant factors, rather than crop coefficients (ASABE, 2012; Beeson et al., 2014; Sun et al., 2012a). The new S623 Standard attempts to define landscape water use requirements nationally across various humidity zones (Beeson et al., 2014).

The mixtures of plant forms in landscapes (grasses vs. woody plants) may also influence the amount of water entering soil and percolating downward to potentially recharge

groundwater. Beard and Green (1994) summarized benefits of turfgrasses to groundwater recharge and surface water quality. Groundwater recharge is generally greater in areas of annual crops and grasses than it is in areas of trees and shrubs (Prych, 1998). Allison et al. (1990) demonstrated an impact of vegetation in Australia where deep-rooted eucalyptus (*Eucalyptus* sp.) trees were replaced with shallow-rooted crops resulting in recharge increases of about two orders of magnitude. Therefore, as recharge is evaluated, there is some dependence on land use/land cover. Irrigated areas contribute to water returned to soil for groundwater flow and may have a significant impact on recharge.

There is growing interest in use of ET_o data from weather stations for irrigation recommendations in amenity landscapes. Therefore, objectives of this study were to determine PFs of model landscapes composed of mixed turfgrass and shrub species, and determine any seasonal effects on PFs. Second, as a result of irrigation in amenity landscapes with various plant forms, amounts of leachate were measured in each plant combination. Water percolating downward and potentially recharging groundwater in amenity landscapes has not been measured in previous work; therefore, this research would address this gap in literature.

Materials and methods

The experiment was conducted in Huntsville, TX, at the Sam Houston State University Plant Science Field Laboratory. Nine drainage lysimeters were constructed during Jan. to Mar. 2011 in an area which does not have trees within 260 ft. The surrounding vegetation was a mixture of grasses. Rectangular-shaped excavations $7 \times 4 \times 2$ ft (length $\times$ width $\times$ depth) were made in native soil to create each lysimeter. Each excavation was lined with a 45-mil ethylene propylene diene monomer (EPDM) rubber pond liner. Gravel (0.375-inch diameter) was placed in the bottom to a depth of 2 inches. A polyvinyl chloride (PVC) pipe (0.5 inch i.d.) drainage system was embedded into the gravel layer. The PVC pipe system consisted of four horizontal pipes capped at one end. These horizontal pipes had 2-mm holes drilled every 6 inches on the bottom side to allow leachate to enter. As shown in Figure 1,

these four pipes were joined through a manifold into a vertical riser pipe (30 inches). This PVC pipe system allowed vacuum evacuation of leachate during saturated conditions.

The A horizon material of a Falba fine sandy loam (fine, montmorillonitic, thermic Typic Albaqualfs) was systematically passed through a 0.4-inch screen to remove roots and debris before being placed into each lysimeter. A 6-inch lift of soil was added and tamped to 4 inches. This process was continued until lysimeters were filled. Six soil moisture sensors (model 10HS; Decagon Devices, Pullman, WA) were placed at two locations in each lysimeter. Each location is 24 inches from edge of the short sides of the lysimeter (Fig. 1). At each location, a sensor was placed at 0- to 8-inch, 8- to 16-inch, and 16- to 24-inch depths. Sensor cables were routed to the outer edge of the lysimeter. From lysimeters, cables were below surface grade to a nearby data collection station. A datalogger (model 10X; Campbell Scientific, Logan, UT) coupled with model AM 16/32 multiplexers (Campbell Scientific) allowed volumetric soil moisture content measurements to be made and recorded hourly. A laptop computer with LoggerNet software (Campbell Scientific) was used to manually download data from the datalogger.

Lysimeters were irrigated with an in-ground automatic system. Irrigation spray heads (MP Rotator Series; Hunter Industries, San Marcos, CA) were installed at a 12-ft triangular spacing. A water meter was installed to allow measurement of total applied water. A weather station was located 50 ft from lysimeters sited in turfgrass. Weather station components include: datalogger, temperature/relative humidity probe, tipping-bucket rain gauge with 6-inch orifice, pyranometer with leveling base, and wind sentry set. Environmental data from the station was used to calculate both ET_o using a modified Penman-Monteith equation (Food and Agriculture Organization of the United Nations, 1998). Irrigation was adjusted weekly to replace 100% of calculated (ET_o) minus precipitation. During periods when irrigation water was required, water was applied 1 or 2 d per week. Irrigation remained off during winter seasons. Table 1 includes mean monthly actual ET_o and precipitation,

and historic precipitation rates during the experiment.

Plant combinations were arranged in a complete randomized block design with three blocks. Each plant combination consisted of turfgrass and woody

ornamental shrubs based on vegetative coverage of the lysimeter surface. Plant combinations are defined in Table 2. Plant installation occurred on 12 May 2011 without disturbing sensors and sensor cables. St. augustinegrass was

sod grown (All Seasons Turfgrass, Brookshire, TX) on a Katy fine-sandy loam (fine-loamy, siliceous, thermic Aquic Paleudalf). Woody plants were grown (Magnolia Gardens Nursery, Waller, TX) in a composted pine bark, and when planted, were placed in center of the lysimeter surface with turfgrass on either side. The soil surface beneath the shrubs remained bare throughout the study. A 4-month period was allowed for establishment. After these 4 months, each of the three plant combinations had green plant tissue (turfgrass and shrub) over 100% of the plot surface area.

Turfgrass was maintained at 3 inches height, and trimmed bi-weekly to ensure percent coverage over the plot remained consistent (e.g., combination 1 was trimmed so turfgrass consistently covered only 80% of plot surface area). Shrubs were trimmed every 8–10 weeks, and each plot was maintained at a consistent canopy height throughout all treatments. Shrub count and surface area are in Table 2. Plots received granular fertilizers based on an annual soil test result from Texas Agrilife Soil, Water, and Forage Testing Laboratory recommendation for ‘Raleigh’ st. augustinegrass. A 13N-0P-21.6K (115 lb/acre) was applied spring, summer, and fall. A 0N-0P-51.5K (137 lb/acre) was applied each fall. Prilled limestone was applied (870 lb/acre) in Jan. 2012 for pH adjustment as recommended by the same soil test report. Fipronil was applied seasonally to control ants (*Formica* sp.). Azoxystrobin fungicide was applied in Sept. 2012 to the st. augustinegrass at the onset of mild brownpatch disease (*Rhizoctonia solani*). Brownpatch was not observed during Fall 2011. Glyphosate herbicide was applied every 4 to 8 weeks between plots for vegetation control.

Plant factors were determined by actual plant water use data (actual evapotranspiration) divided by ET_o data during periods of time between precipitation events and/or irrigation (dry downs): Actual evapotranspiration/ ET_o = PF.

Actual evapotranspiration was determined from changes in soil volumetric water content during a 2- to 6-d period soil dry down. Actual evapotranspiration measurements began 24 to 48 h after an irrigation or precipitation event. Reference evapotranspiration was determined for the

Fig. 1. Representation of an in-ground drainage lysimeter used for experiment involving three model landscapes in Huntsville, TX. Shown is the polyvinyl chloride (PVC) pipe system that is embedded in 2 inches (5.1 cm) of gravel for leachate evacuation, soil moisture sensors which measure volumetric water content of soil, and sensor cables routed to a nearby databox (datalogger) where soil moisture data are stored until downloaded. Changes in soil moisture over time (actual evapotranspiration) was used along with reference evapotranspiration to calculate plant factors. Not shown is the ethylene propylene diene monomer rubber pond liner that was placed into the square hole before filling with gravel and soil. Plant materials not shown; 1 ft = 0.3048 m.

Table 1. Monthly actual reference evapotranspiration (ET_o), monthly actual precipitation, and historic monthly precipitation at Huntsville, TX, during experiment to measure plant factors (PFs) among three model landscapes. Actual ET_o and actual precipitation data taken from a weather station located 50 ft (15.2 m) from experimental plots.

Mo. and yr	Actual ET_o	Actual precipitation (inches) ^z	Historic precipitation
Sept. 2011	5.99	0.98	4.17
Oct. 2011	3.81	2.08	4.69
Nov. 2011	2.58	3.55	5.20
Dec. 2011	1.67	3.94	4.13
Jan. 2012	2.45	3.49	4.25
Feb. 2012	2.36	6.38	3.35
Mar. 2012	3.67	6.00	3.70
Apr. 2012	4.97	1.21	3.27
May 2012	5.58	2.21	4.45
June 2012	5.98	2.63	5.43
July 2012	5.65	2.34	2.80
Aug. 2012	6.49	0.92	3.66
Sept. 2012	4.72	5.46	4.17
Oct. 2012	3.42	3.37	4.69
Nov. 2012	2.41	0.02	5.20
Dec. 2012	2.14	1.44	4.13
Jan. 2013	2.06	3.44	4.25
Feb. 2013	2.58	1.30	3.35
Mar. 2013	4.34	1.34	3.70
Apr. 2013	4.25	3.54	3.27
May 2013	5.49	6.41	4.45
June 2013	6.35	2.45	5.43
July 2013	6.00	1.21	2.80
Aug. 2013	6.23	0.64	3.66

^z1 inch = 25.4 mm.

same 2- to 6-d time period. Plant factors were grouped into early, mid, and late season (Table 3). PF calculations began in late season 2011 and concluded with midseason 2013.

Leachate from each lysimeter was evacuated and the volume measured every 1 to 2 weeks during the duration of the study. The leachate volume was converted to a leachate depth over plot surface area, and summarized by plant combination and season.

Plant combination PF values were analyzed by season over the 2-year period. Mean leachate depth was analyzed by plant combination and season using analysis of variance (SAS version 9.3 for Windows; SAS Institute, Cary, NC). Leachate means are mean depth when evacuated from gravel layer of the lysimeter. Analysis of the randomized complete block design with a factorial structure that included plant combination and season used Scheffé's mean separation test to separate treatment means. Effects were considered significant at an alpha level of $P \leq 0.05$.

Results

PLANT FACTORS. Analysis of variance (ANOVA) indicated that plant combination ($P < 0.0001$) and season effects ($P < 0.046$) were significant. There was no significant difference in the interaction of plant combination and season. During the combined growing seasons (Sept. 2011–Sept. 2013), PFs for the 20:80 turfgrass and 50:50 turfgrass treatments were greater than the PF of 80:20 turfgrass treatment (Table 4). The PF for 80:20 was about 30% less than PFs of the two other plant combinations. Analysis of variance mean separation test did not discern differences among mean PFs seasonally. Seasonal PFs were 0.84, 0.94, and 0.87 for early, mid, and late season, respectively. Overall PF after 2 years was 0.89. Drought stress and nutritional stress symptoms were not observed in plant materials during the experiment. New leaf blade extension in the st. augustinegrass began 10–15 Mar. each season indicating a return to active growth, and new leaf blade extension ceased 25–30 Nov. each season.

LEACHATE. Total leachate depth values are the sum of all leaching events presented over the 2 years and seasonally for each plant combination

Table 2. Turfgrass and shrub combinations of three model landscapes in which plant factors were measured in Huntsville, TX. Ratios indicate percent cover over the plot surface area by turfgrass:shrubs. Surface areas of shrub's canopies indicate areas occupied by shrubs in each plant combination.

Plant	Turfgrass:shrubs (% cover)			Pot size ^z
	80:20	50:50	20:80	
	Plants (no.)			
St. augustinegrass				Sod
Privet	1	2	4	Number 3
Dwarf burford holly	2	5	8	Number 1
Dwarf yaupon holly	1	4	6	Number 1
	----- (ft ²) ^y -----			
Surface area of shrub's canopies	37.2	65.6	76.9	
Surface area of turfgrass	22.4	14.0	5.7	

^aNumber 1 = 0.7 gal, number 3 = 2.7 gal; 1 gal = 3.7854 L.

^y1 ft² = 0.0929 m².

Table 3. Timetable of experiment with calendar dates used in calculating early, mid, and late season plant factors among three model landscapes in Huntsville, TX. Data used in the experiment began 22 Sept. 2011 and ended 12 Sept. 2013.

Season	2011	2012	2013
Early	—	12 April–24 May	15 Mar.–20 May
Mid	—	1 June–13 Sept.	29 May–12 Sept.
Late	22 Sept.–18 Nov.	21 Sept.–7 Nov.	—

Table 4. The mean plant factors (PFs) of three model landscape plots by plant combination ($n = 3$), season ($n = 9$), and plant combination $\times$ season ($n = 3$) during the 2 years of the experiment in Huntsville, TX. Plant factors calculated as actual evapotranspiration divided by reference evapotranspiration during multiday soil drydown periods.

	PF		
20:80 Turfgrass:shrub	1.01 a ^z		
50:50 Turfgrass:shrub	0.97 a		
80:20 Turfgrass:shrub	0.68 b		
	Early	Mid	Late
Seasonal mean	0.84 NS ^z	0.94	0.87
	Early	Mid	Late
20:80 Turfgrass:shrub	1.04 NS	1.01 NS	0.97 NS
50:50 Turfgrass:shrub	0.88	1.05	0.98
80:20 Turfgrass:shrub	0.60	0.78	0.65

^zMeans followed by the same capital letter within column are not significantly different under Scheffé's mean separation test; NS = not significant.

(Table 5). Analysis of variance for mean leachate depth during the growing season was significant for both plant combination ($P < 0.0001$) and season ($P < 0.0001$). Plant combination by season interaction was not significant. As percent area covered by turfgrass increases, so did mean leachate depth (Table 5). Mean late season leachate depth was greater than early and mid-season means. The late, mid, and early

season leachate means were 1.3, 0.3, and 0.7 mm, respectively. Total leachate depth of 80:20 turfgrass:shrub was about five times larger and two times larger when compared total leachate depths of the 50:50 and 20:80, respectively (Table 5). Seasonally, all three plant combinations yielded more total leachate depth in late season when compared with early or midseasonal depths.

During winter seasons (late November to mid March) the irrigation was off, and leachate depth was analyzed separately. Analysis of variance model was significant with both plant combination and year contributing to variation. The winter mean leachate depth of 80:20 turfgrass:shrub was greater when compared with 20:80, but not greater than 50:50 turfgrass:shrub (Table 6). Total winter season leachate depth was greater in the first winter season when compared with the other 2 winter seasons (Table 6). The precipitation during this first winter of the experiment was 458 mm vs. 181 and 210 mm during second and third winter seasons (Fig. 2). Average precipitation during December to February is 301 mm. However, mean winter leachate for 2011–12 was the same as 2013–14 and greater than 2012–13 (Table 6).

Discussion

PLANT FACTORS. Irrigation based on crop coefficients and ET_o data has been quite valuable in resource management in food/feed/fiber crop production and in monoculture turfgrass systems. Research on its use in irrigation management of woody landscape plants or landscapes with mixed turfgrass/woody plants is limited. A study by Pannkuk et al. (2010) determined seasonal landscape plant factors ranging from 0.5 to 0.8 for a treatment composed of a single shumard oak (*Quercus shumardii*) and ornamental bunch grasses, muhly grass (*Muhlenbergia capillaries*) and bluestem (*Schizachyrium scoparium*). The ornamental grasses in that study were cutback to 6-inch height each winter thereby removing most of the leaf surface area, and then remained untrimmed through the growing season. This varies from our study in which evergreen woody shrubs were trimmed to a consistent size through the year. Three of the treatments in the Pannkuk et al. (2010) study had one shumard oak per plot with the single shumard oak from a number 3 nursery container and a trunk diameter of 1.3 inches (Pannkuk, 2009). The leaf surface area of the tree was not reported. Those effects reported in the Pannkuk et al. (2010) study differ from our study in which landscape factors varied seasonally from 0.7 to 1.0. Plant density and surface area of the shrubs most likely contributed to the larger landscape

Table 5. Mean leachate depth during growing seasons for three model landscapes by plant combination and season, 2 year total leachate depth by plant combination, and seasonal leachate depths by plant combination during early, mid, and late seasons. Leachate was vacuumed from the gravel layer at bottom of drainage lysimeters used for calculating plant factors in Huntsville, TX.

	Mean	2 yr total depth	Seasonal depth		
	leachate depth		Early	Mid	Late
	----- (mm) ^z -----				
20:80 Turfgrass:shrub	0.3 c ^y	12.6	1.7	0.6	10.3
50:50 Turfgrass:shrub	0.6 b	30.7	5.4	4.1	21.1
80:20 Turfgrass:shrub	1.3 a	63.4	14.7	15.7	33.0
Early season	0.7 b				
Midseason	0.3 b				
Late season	1.3 a				

^z1 mm = 0.0394 inch.

^yMeans followed by the same capital letter within column are not significantly different under Scheffe's mean separation test.

Table 6. Mean winter-season leachate depth for three model landscapes in Huntsville, TX, by plant combination and winter season, and total leachate depth during each winter season. Leachate was vacuumed from the gravel layer at bottom of drainage lysimeters used for model landscapes. Irrigation system was not operational during the winter season.

	Winter-season mean depth	Total depth during winter		
		2011–12	2012–13	2013–14
		----- (mm) ^z -----		
20:80 Turfgrass:shrub	2.0 B ^y	44.6	0.0	8.6
50:50 Turfgrass:shrub	2.2 AB	39.3	6.5	12.5
80:20 Turfgrass:shrub	2.9 A	42.3	12.5	20.4
Winter 2011–12	2.8 A			
Winter 2012–13	1.3 B			
Winter 2013–14	2.3 A			

^z1 mm = 0.0394 inch.

^yMeans followed by the same capital letter within column are not significantly different under Scheffe's mean separation test.

Fig. 2. Depth of precipitation and evapotranspiration during the winter seasons at Huntsville, TX. During the winter season, irrigation was shutoff for the three model landscapes and plant factors were not calculated; 1 mm = 0.0394 inch.

factors reported here. Sun et al. (2012a) reported mixed-species landscape factors ranged from 0.6 to 0.8 under well-watered conditions of

their study that included deciduous and evergreen woody plants, herbaceous perennials, and turfgrass. That study suggested plant canopy cover,

rather than plant material water use categorization, was the controlling factor in woody plant and perennial water use. Sun et al. also concludes that adjustments to percentage of landscape area covered by woody plants, perennials, and turf based on plant factor (K_p) may be another method for conserving water in landscapes. The Sun et al. (2012a) study included plant treatments (turf, woody, and perennials) which varied in their canopy cover fraction. In our study, all three treatments had 100% cover, yet vary in woody plant density. The surface area of the shrubs in this study are 37.2, 65.6, and 76.9 ft² for the 80:20, 50:50, and 20:80 turf:shrub treatments, respectively. This corresponds to mean PFs over 2 years of 0.7, 1.0, and 1.0, respectively.

Our study reveals greater surface area of plant cover due to plant density in a landscape contributes to differences in landscape water use and therefore PF. Amenity landscapes tend to be a mixture of plant forms from low growing two-dimensional turfgrass, to shrubs and trees which are more vertically oriented and three-dimensional. More upright growing shrubs of this study have greater leaf surface area than that of turfgrass. Landscapes with a larger percentage of plants which are three-dimensionally oriented, more leaf transpiring area, may have larger PFs for this reason. Vapor pressure deficit (VPD), the difference between how much moisture is in the air and how much moisture the air can hold when saturated, is a driving force in transpiration. When daily high VPDs were averaged over the month, mean VPD during summer months were greater than 3.0 kPa with the exception of July 2012 (Fig. 3). With treatments irrigated at 100% replacement of ET_o minus rainfall, the plants were never exposed to soil moisture deficits and presumably no stomatal closure due to water stress. However, stomatal conductance was not measured. High VPD values appear to increase transpiration and subsequent PFs as shrub surface area increases in the model landscapes. The ANOVA table indicated a significant difference in main effect of season, but Scheffe's mean separation test did not discern a difference. A lack of significant difference by season may be partially due to evergreen shrubs being continually trimmed to a specified size

Fig. 3. Depth of monthly total evapotranspiration (ET_o) and precipitation (top). Daily late-afternoon vapor pressure deficits averaged by month (bottom); vapor pressure deficit (VPD) is the difference between the amount of moisture in the air and how much moisture the air can hold when it is saturated. Data collected in Huntsville, TX, at site where plant factors of three model landscapes were measured; 1 mm = 0.0394 inch, 1 kPa = 0.01 bar.

during the period of the experiment, and therefore similar water use compared with ET_o during each of the three seasons. Pannkuk et al. (2010) documented seasonal differences among treatments when determining a landscape coefficient. However, in that experiment the plant palette included a small deciduous tree and ornamental bunch grasses which were only cutback each winter. That change in leaf canopy area, and ostensible seasonal growth, in tree and ornamental grasses probably contributed to a seasonal effect in observed landscape coefficient. Presence and combination of deciduous and evergreen plants in landscapes may therefore also influence seasonal water use and resulting PF.

LANDSCAPE IRRIGATION. Most woody plants produced in nurseries

have a confined root system from being grown in a container. Once these plants are established in a landscape, root systems of establishing shrubs and trees spread into the surrounding soil (Gilman and Beeson, 1996; Gilman and Kane, 1991). Depending on site conditions, woody plant root spread from the trunk may extend two to three times the dripline (Gilman, 2011). This implies that roots of plants in one irrigation zone may grow into the soil of a different irrigation zone. Potentially, soil in the amenity landscape can become a heterogeneous mix of plant roots after establishment. Zoning practices in irrigation management has largely ignored spread of plant roots outside of "their irrigation zone" over time. The concept of zoning in irrigation design and management is commonplace

(Colorado State University, 2014; Florida-Friendly Landscaping, 2000; Texas A&M Agrilife Extension, 2014). This study considered turfgrass and shrubs as one continuous irrigation zone since evidence indicates plant roots spread away from their crown and intermingle in the soil matrix (Gilman and Beeson, 1996; Gilman and Kane, 1991). Considering the mixture of roots from various plant types in soil of an established landscape, a PF which considers percentage of plant types (turfgrass, shrub, and tree) and plant density should be further studied. A plant type with the highest PF in an amenity landscape may have roots extending into the soil of other irrigated zones competing with other species for water. Turfgrass areas within an amenity landscape setting will likely have resource competing roots from nearby trees and shrubs, and vice versa. A review of the literature reveals there is a lack of science-based research whereby grouping plants into water-use irrigation zones is evaluated based on plant form, root distribution through the soil, and actual plant water use.

This experiment used pop-up irrigation spray heads to irrigate lysimeters. In this irrigation method, some of the water is deposited on the plant tissue and evaporates. More three-dimensionally shaped shrubs intercept more water than turfgrass in their canopy which in turn may evaporate. The usefulness of drip irrigation for shrubs in landscape water conservation is confirmed. However, use of spray-type irrigation equipment in amenity landscapes remains common (Kjelgren et al., 2000).

LEACHATE VOLUMES. Efficient irrigation results in minimal deep percolation of water. Increased leaching during the growing season represents wasted water from the irrigator's perspective. In a well-watered landscape, this experiment demonstrates potential for deep percolation during the growing season which is considered wasted water. Irrigation water and precipitation caught in the canopy of the dense shrubs, and thereby evaporating back into the atmosphere, partially explains the lower volumes of leachate from treatments with greater density of shrubs.

Soil leachate depth results from this experiment suggest in those winters

with less than average precipitation, landscapes with greater turfgrass cover will receive more water entering the root zone for soil percolation. It is noted that turfgrass entered dormancy in late November and remained dormant until early March based on new leaf blade extension. This finding also indicates more water evaporates and/or transpires from landscapes with greater woody plant canopy density during winter. Two-year cumulative leachate data suggests amenity landscapes containing greater woody plant density might reduce the amount of water percolating into soil and potentially recharge groundwater. Groundwater plays an important role in the ecological environment and in economic development. Therefore, investigation of dynamics of groundwater is important in the built environment. Sun et al. (2012b) found land use involving human activity is a driving factor in interception, infiltration capacity and surface evaporation. As humans continue to develop societies and economies, great changes occur on the land, and such changes can improve or degenerate water resources within a region (Garmendia et al., 2012).

This study was conducted in a warm humid region of North America with a limited number of woody plant species. The density of woody plants had impact on PF and amount of deep soil water percolation. More information is now available for use in landscape water conservation. More refinement of PFs is needed through testing with other combinations of plant species and plant density. Additional studies should also include designating lower coefficients (e.g., 0.5, 0.6) and assessing plant quality over time. Precise irrigation of amenity landscapes is complex, and plant visual expectations are also variable among landscape managers. Society would also benefit from future studies which examine groundwater recharge quantity and quality in the built environment.

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