RESEARCH

Drought Response and Recovery Characteristics of St. Augustinegrass Cultivars

K. Steinke,* D. Chalmers, J. Thomas, R. White, and G. Fipps

ABSTRACT

As water resources become restricted for use on amenity turfgrass systems, the inability for consumers to delineate incremental drought stress relating to plant health can result in the misuse of water resources during drought conditions. Seven cultivars of St. Augustinegrass (SA) [*Stenotaphrum secundatum* (Walt.) Kuntze] and two root zone depths were evaluated for drought response and recovery during consecutive 60-d drought and 60-d recovery periods over 2 yr. Using digital image analysis, drought response and recovery were quantified as the number of days to decrease or increase to 50% green ground cover, respectively. Both study years provided unique conditions for investigating drought response as the mean time to reach 50% green ground cover differed by 24 d between the 2 yr of study. Some SA cultivars lost 50% green ground cover in 23 d while other cultivars lasted the entire 60 d drought period without losing 50% green ground cover. Floratam provided the most consistent drought response and recovery compared to other SA cultivars. Once water was no longer limited, cultivars demonstrated up to a 52 d difference in attaining 50% green ground cover. Results could significantly impact home consumer irrigation behaviors and influence consumer expectations of turfgrass following drought conditions.

K. Steinke, Dep. of Crop and Soil Sciences, Michigan State Univ., East Lansing, MI 48824. D. Chalmers, J. Thomas, and R. White, Dep. of Soil and Crop Sciences, Texas A&M Univ., College Station, TX 77843. G. Fipps, Dep. of Biological and Agricultural Engineering, Texas A&M Univ., College Station, TX 77843. Received 28 Oct. 2009. *Corresponding author (ksteinke@msu.edu).

Abbreviations: PET, Potential evapotranspiration; SA, St. Augustinegrass; SAWS, San Antonio Water System.

Periods of prolonged drought and water shortages throughout the United States have resulted in an uncertain future concerning water resource availability. Water use for the maintenance of urban plant vegetation may result in a threefold increase in domestic water use during the summer months (Kjelgren et al., 2000). In arid regions of the United States, 40 to 45% of residential water use is applied to the irrigation of urban landscapes (Devitt and Morris, 2010). To improve water conservation, municipalities have explored ideas to help allocate and conserve water supplies. Strategies focused on residential lawn irrigation and adherence to recommended drought tolerant plant lists have been encouraged. Water restrictions focusing on amenity turfgrass systems have become a critical component of many state and local water contingency plans.

Due to home consumers' heavy reliance on the presence of green tissue to determine plant health, irrigation is frequently initiated at the first sign of leaf wilt. The inability to distinguish between drought stress and plant survivability can lead to the misuse of water resources. The inability to maintain green ground cover during droughty periods has caused municipalities and water districts to reconsider turfgrass species and cultivar selections available for home

Published in Crop Sci. 50:2076–2083 (2010).
doi: 10.2135/cropsci2009.10.0635
Published online 16 June 2010.

consumer use. In 2005, the city of San Antonio, TX passed a Water Conservation Ordinance that may potentially impact the use of turfgrass within San Antonio by exceeding the current water conservation measures. To coincide with local water restriction guidelines relating to the 2005 Conservation Ordinance, the San Antonio Water System (SAWS) hoped to identify and maintain a list of turfgrasses that demonstrated summer dormancy capabilities (San Antonio Water System, 2007). Summer dormancy was defined as the ability of turfgrass to survive without water for a 60-d period between the months of May through September. An additional provision of the Conservation Ordinance included turfgrass established or associated with new construction shall have a minimum soil depth of 10.2 cm beneath the turfgrass. The regulations were drafted with little scientific information regarding turfgrass drought response or cultivar performance once water was no longer limiting.

St. Augustinegrass is a widely used warm-season turfgrass found throughout the southern United States and Gulf Coastal regions. St. Augustinegrass can tolerate high pH (>7.5) soil conditions and contains moderate shade tolerance making this grass one of the better options for shaded warm-season turfgrass systems. Although drought response has been documented across cool-season turfgrass species and cultivars (Abraham et al., 2004; Su et al., 2007), data documenting SA drought response are limited. Carrow (1996) documented drought response across warm-season turfgrass species but only assessed one cultivar of SA under a maximum of 19 d without water. Kim and Beard (1988) and Atkins et al. (1991) assessed evapotranspiration rates across SA genotypes, but drought response data were not collected. Additionally, these studies were either conducted under greenhouse or well-watered conditions and may not represent cultivar performance under field drought stress conditions. Data comparing cultivar performance of SA during an extended drought (60 d) and recovery period (60 d) are needed to aid decision-making processes for creating sustainable urban environments.

The objectives of this study were to (i) assess the drought response of seven St. Augustinegrass cultivars subjected to a 60-d drought without irrigation when grown on an unrestricted native agricultural soil and (ii) assess the drought response of seven St. Augustinegrass cultivars subjected to a 60-d drought without irrigation when grown on a 10.2-cm depth soil profile.

MATERIALS AND METHODS

Experimental Area

Research site preparation began in 2005 on a Lewisville silty clay (fine-silty, mixed, active, thermic, Udic Calciustoll) located 4.8 km south of San Antonio, TX previously used for sod production. The soil had a 7.9 pH and contained 204 mg kg^{-1} P and 606 mg kg^{-1} K (2.54-cm depth) as determined by the Olsen method. An area measuring approximately 30 m wide by 152 m in length was stripped of vegetation and leveled. A 15 by 107 m area was laser leveled to provide two 15 by 30 m experimental areas at each end of the 107 m rectangle. The two separate but identical experimental areas allowed individual establishment, drought, and recovery periods to be performed over a 2-yr period. The existing area between the two experimental plots was given a 1% slope toward the plot center. A trench measuring 60 cm wide by 45 cm deep was cut along each side of the experimental area to accommodate the construction of a concrete footer and wall for the rainout shelter.

Each experimental area was divided into eight 6.1 by 6.1 m blocks. Each 6.1 by 6.1 m block was subdivided into 1.2 by 1.2 m plots with individual cultivars replicated four times in a randomized complete block experimental design. Individual experimental areas were separated by a 60 cm border on all sides. The soil on four blocks represented native soil with unrestricted rooting potential and remained undisturbed. To adhere to the proposed minimum soil depth requirements for new construction in the San Antonio, TX area, the remaining four blocks were planted on a 10-cm soil depth. The restricted rooting depth blocks had the upper 10 cm of soil removed using a front end loader and the subgrade leveled to provide a 0.5% slope from the center line to the outside and center drains. A 0.076-cm thick (30 mil) HDPE plastic sheet was placed over the subgrade and the 10-cm layer of stockpiled topsoil was replaced. A 10-cm diam. slotted drain line bedded in washed 0.95-cm gravel was installed immediately inside and parallel to each concrete track wall. A third drain line was centrally installed down the center of the experimental blocks. All three drain lines joined into a center cross drain that exited through the wall and emptied into a 2800 L underground concrete storage tank. The tank was equipped with a float activated pump to maintain a level of 50 to 70% capacity. Excess water was discharged onto adjacent crop land.

Irrigation was accomplished using a two-zone automatic irrigation system. The system was controlled by an Irritrol Systems, KwikDial automatic sprinkler controller that operated two 2.54-cm electric valves. One zone controlled irrigation to the four blocks containing the 10-cm soil depth while the second zone controlled irrigation to the four blocks containing the unrestricted soil depth. To provide head-to-head coverage, each block was equipped with irrigation heads at each corner (Model PGJ-06, Hunter Industries, San Marcos, CA).

Plot Management and Drought Evaluation

To prevent weed contamination, all plots were treated with granular Basamid G [tetrahydro-3,5-dimethyl-2H-1,3,5-thiadiazine-2-thione] (392.5 kg ha^{-1}) before establishment. On 20 Sept. 2005 and 21 Sept. 2006, seven cultivars of SA that were commercially available in the San Antonio, TX market (Table 1) were established using washed sod. Sod was harvested, washed, labeled, and transported to the research site 1 d before planting. Sod was stored overnight in a refrigerated truck trailer. Before the 60-d drought, all plots had a 9.5 to 10-mo establishment period which encompassed 20 Sept. 2005 to 22 July 2006 and 21 Sept. 2006 to 5 July 2007 for Years 1 and 2, respectively. Irrigation was provided as needed during establishment to promote rooting and provide optimal growing conditions. During drought recovery, irrigation was provided at a rate of 1.3 cm every 3 d and adjusted for precipitation events. Plots were

Table 1. Turf dry-down and recovery characteristics of St. Augustinegrass cultivars. $Days_{50}$ is the actual number of days without water required to reach 50% green ground cover (drought) or the actual number of days with water to reach 50% green ground cover (recovery). Larger negative slope values indicate increased rate of loss in percent green ground cover while larger positive slope values indicate increased rate of recovery in percent green ground cover.

Cultivar	2006					2007				
	Slope	SE†	$Days_{50}$	SE‡	R^2	Slope	SE†	$Days_{50}$	SE‡	R^2
					Drought stress					
Amerishade	−0.055	0.008	26.3	1.31	0.85	−0.031	0.007	51.8	2.75	0.68
Common	−0.075	0.007	23.8	0.61	0.96	−0.028	0.005	55.9	2.54	0.74
Delmar	−0.057	0.008	23.8	1.10	0.88	−0.028	0.006	51.1	2.96	0.67
Floratam	−0.036	0.004	33.9	1.21	0.87	−0.030	0.004	59.4	1.78	0.84
Palmetto	−0.072	0.006	25.3	0.56	0.96	−0.032	0.006	49.5	2.49	0.72
Raleigh	−0.075	0.007	22.6	0.63	0.95	−0.026	0.005	49.8	2.89	0.69
Sapphire	−0.079	0.009	23.3	0.67	0.95	−0.033	0.004	59.6	1.50	0.88
Mean	−0.064		25.6		0.92	−0.030		53.9		0.75
					Drought recovery					
Amerishade	0.015	0.003	44.8	4.98	0.49	0.041	0.011	6.2	2.40	0.62
Common	0.023	0.003	30.7	2.65	0.72	0.039	0.008	4.1	1.87	0.75
Delmar	0.016	0.003	40.8	4.42	0.52	0.037	0.009	5.2	2.27	0.69
Floratam	0.023	0.004	8.5	2.43	0.70	0.045	0.007	1.9	1.31	0.83
Palmetto	0.023	0.003	31.6	2.21	0.79	0.049	0.011	7.0	1.77	0.74
Raleigh	0.018	0.003	50.8	3.71	0.65	0.041	0.010	5.6	2.22	0.68
Sapphire	0.014	0.003	60.8	7.39	0.43	0.049	0.007	1.5	1.13	0.85
Mean	0.019		38.3		0.62	0.043		4.5		0.74

†Standard error of slope.

‡Standard error of $Days_{50}$.

mowed weekly at a height of 5.7 cm with clippings collected and removed to minimize the potential for cross contamination. Plots were mowed once at a 3.2-cm height in the first week of drought recovery to reduce competition from browned off leaf canopy. Fertilizer was applied in April, June, September, and October each season using a 24-6-12 ($N:P_2O_5:K_2O$) granular fertilizer (BWI Fairway Grade, BWI Companies, Inc., Schulenburg, TX) at a rate of 48 kg N ha^{-1}.

Turf evaluations were conducted at 7- to 10-d intervals to assess drought response and recovery symptoms. Digital image analysis was used to quantify percent green ground cover for individual plots during the 60-d drought and 60-d recovery periods (SigmaScan Pro version 5.0, SPSS, Chicago, IL) (Richardson et al., 2001). Plots were visually rated for turf quality (1 = necrotic turf, 9 = optimum quality, 6 = acceptable), leaf firing (1 = 100% fired, 9 = 100% green), and uniformity of recovery (1 = non-uniform, 9 = dense, uniform turf).

Environmental data were monitored using an on-site weather station (Campbell Scientific, Logan, UT). Data collected included temperature, humidity, wind speed, wind direction, solar radiation, and precipitation. Weather station data were remotely downloaded daily and used to calculate the potential evapotranspiration (PET) rate using the Pennman-Monteith equation (Monteith, 1965).

Rainout Shelter Construction and Operation

To protect the plots from undesired precipitation during the drought period, a 465 m^2 movable rainout shelter was constructed by the Texas A&M Agricultural Engineering Department. Two parallel 107-m concrete beams measuring 30 cm wide by 60 cm tall were spaced 15 m apart and served as the foundation of the rainout shelter. The concrete beams were reinforced with 1.27-cm diam. rebar. The railing system was constructed from 18 12.2-m lengths of 15-cm I-beams welded together. Precise holes were drilled in the concrete and slotted washers were welded to the I-beams. Anchor bolts 1.27 by 17.8 cm were then driven and tightened through the hole of the slotted washer to fasten the I-beams to the concrete. Angle iron measuring 3.8 by 3.8 by 0.64 cm was welded on top of the I-beam to provide a groove for the V-grooved casters to roll on. Twenty-two V-grooved wheel casters were bolted to 15-cm C-channel to support the roof structure and allow movement up and down the rail system. The roof structure consisted of a 15 by 30 m clear span, continuous roof with five 6.1-m bays and both gable ends sheeted to the base of the truss. Sixty centimeters long uprights of 11.4-cm pipe were welded onto the C-channel to provide 1.22 m of ground clearance. The oval trusses were 15-m long and constructed of 7.3-cm pipe and 2.2-cm round rod bracing. The roof material consisted of 16.2-m PBC panels with a Galvalume Plus (BIEC International, Inc., Vancouver, WA) finish. To prevent water intrusion from the sides during precipitation events, 10 heavy-duty tarps, 76.2 cm by 6.1 m, with D rings were mounted on the side of the rainout shelter.

The rainout shelter was powered by a 7.5 horsepower motor attached to a 15:1 speed reducer. The cable drive pulleys were framed into two 15-cm C-channels and spaced 45-cm apart. Wire cable (0.96 cm) was attached along both sides of the rainout shelter to the four corners of the facility with 1.27-cm turnbuckles. The wire cables were run through and on top of a series of pulleys located inside the I-beam and along the west end on reaching the cable drive pulleys. At the cable drive pulleys, the wire cable entered and was wrapped around both pulleys four times. Smaller guide pulleys were used to direct the wire cable into the proper alignment for entering and exiting from the cable drive pulleys.

In total, 365 m of wire cable was used to move the rainout shelter. On the north concrete beam, several two-way microswitches were used to monitor the location, control the speed, and stop the movement of the rainout shelter. All electrical components were located inside an air-conditioned storage building.

To detect and record precipitation volumes, two rain gauges were installed on site and wired to send electronic signals to the control panel. The rainout shelter was programmed to automatically deploy and cover the experimental area when either both rain gauges detected 0.03 cm of precipitation or when one gauge detected 0.05 cm of precipitation. Upon deployment, the rainout shelter fully covered the experimental area in less than a 2-min timeframe. After 30 min of no precipitation, the rainout shelter was automatically removed from above the experimental area. To avoid shaded conditions, the rainout shelter was only located above the experimental area for minimal time periods necessary to protect the experimental area from precipitation events during the 60-d drought periods. Runoff water from roof of the shelter fell 40 to 45 cm outside the concrete track walls onto adjacent crop land.

Statistical Analysis

Similar to recent cool-season turfgrass drought studies (Karcher et al., 2008; Richardson et al., 2008), scatter plots of percent green ground cover data vs. number of days of drought and number of days of recovery data indicated a strong nonlinear relationship. Nonlinear regression was then used to quantify drought severity for individual cultivars by determining the number of days without (drought) or with (recovery) water to cause a response halfway in between the maximum and minimum digital percent green ground cover data. Data fit well to a variable slope sigmoid model, [percent green ground cover = 100/{1+10^[($Days_{50}$– DAI) × Slope]} where DAI = days after irrigation was terminated or initiated for drought or recovery, respectively. $Days_{50}$ was estimated to be the number of days to achieve 50% green ground cover and the slope variable documented how rapidly green ground cover changed over time with large positive or negative values indicating more rapid gain or loss of green ground cover on the sigmoid curve.

According to Motulsky and Christopoulos (2003), a sum of squares reduction *F* test was used to determine whether SA cultivars influenced percent green ground cover during the drought and recovery periods. Global curve fitting was used to create a model that minimized the sum of squares and was then compared to a family of curves representing individual cultivars. The *F* test compared the sum of squares from a global model that shared $days_{50}$ and slope parameters against a cumulative sum of squares model for each cultivar where $days_{50}$ and slope were determined individually. If the sum of squares were significant ($p \leq 0.05$) using individual parameter values, cultivar effects were resolved to be significant. Nonlinear regression analyses of percent green ground cover data were accomplished using GraphPad Prism version 5.0 for Windows (GraphPad Software, San Diego, CA). Analysis of variance procedures were used to test the main effects of year and cultivar and their interaction. A significant year × cultivar interaction was observed for all data collected and therefore data could not be pooled across years for analysis. Means of turfgrass quality, leaf firing, and uniformity were separated using Fisher's protected least significance difference test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Environmental Data

Climatic conditions during the 2-yr study provided two unique drought periods in which to examine SA drought response. Average high temperatures during the first 40 d of drought were 35.9 and 31.3°C during the 2006 and 2007 seasons, respectively (Fig. 1). Potential evapotranspiration totaled 346 and 240 mm during the 60-d drought period for the 2006 and 2007 seasons, respectively, resulting in average daily potential evapotranspiration rates of 6.46 and 4.27 mm d^{-1} during the first 40 d of these time periods. The combination of heat and drought in 2006 resulted in more severe moisture stress as compared to 2007 where moisture stress alone was the dominant factor. Minimum temperatures during the 60-d irrigated recovery periods dropped below 15.5°C on 27 and 15 nights during the 2006 and 2007 recovery periods, respectively (Fig. 1). The greater number of chilling night temperatures in 2006 may have delayed turf recovery.

Root Zone Depth

No SA cultivars survived the 60-d drought when planted on the restricted 10 cm soil depth in 2006 (high heat and PET, low humidity) or 2007 (lower heat and PET, high humidity) (data not shown). All SA cultivars growing on the shallow soil depth (10 cm) completely browned off over a 6 to 12 d period in 2006 and a 10 to 20 d period in 2007. In both study years, all SA cultivars survived the 60-d drought when planted on the unrestricted native soil depth. Due to these results, all subsequent reported data focus on the drought response of SA cultivars planted on the unrestricted native soil depth.

Anthropogenic disturbances that manipulate soil depth and homogeneity appear to impact drought stress and drought recovery characteristics of turfgrass during extended periods without water. Plant root development and penetration will differ according to soil texture, soil structure, bulk density, aeration, and soil depth ultimately impacting a plant's ability to extract soil moisture. Root restriction due to soil compaction is prevalent in turfgrass environments forcing root accumulation near the soil surface in lieu of growing deeper within the soil profile. In this study, a 10-cm soil depth was not capable of supporting turfgrass through a 60-d drought while grasses on an unrestricted soil depth survived. The early onset of leaf firing from shallow soil depths may reinforce poor irrigation management behaviors in consumers who attempt to offset poor turf quality through enhanced rates of irrigation.

Drought Stress

St. Augustinegrass cultivar effects were significant ($p \leq 0.05$) for percent green ground cover during the 60 d dry-down periods of both study years. In 2006, SA cultivars began to lose green ground cover at 15 d of drought (Fig. 2). During the 2007 study, SA cultivars began to lose green ground cover at 30 d of

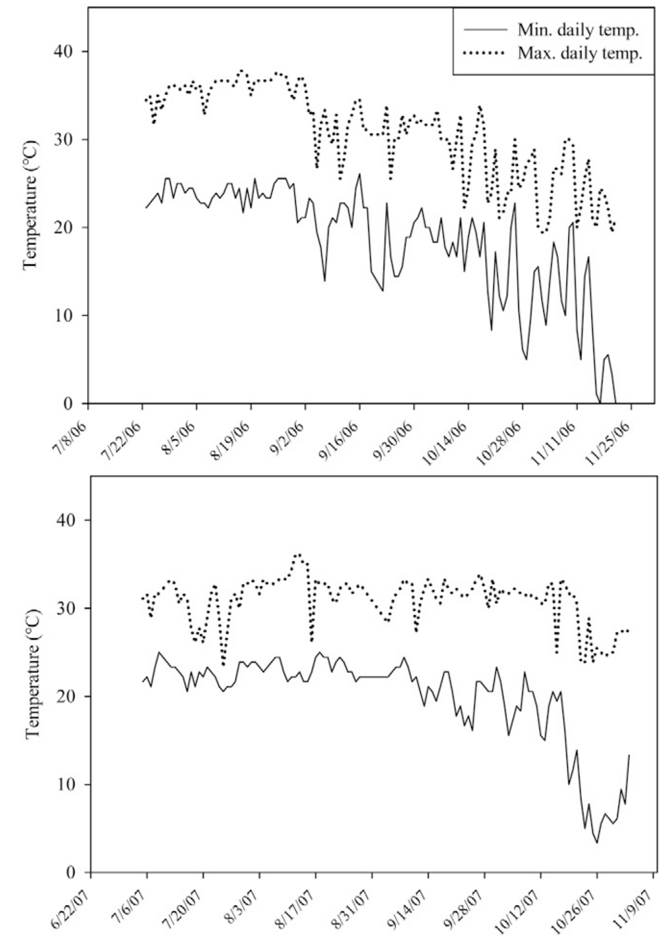

Figure 1. Daily maximum and minimum temperatures during the drought stress and drought recovery periods, San Antonio, TX.

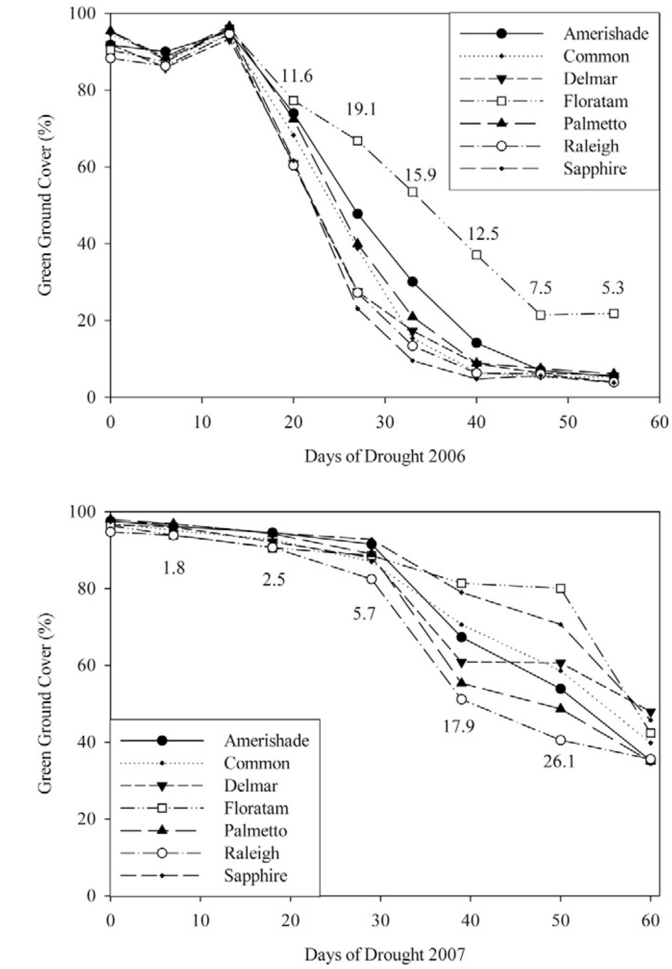

Figure 2. Dry-down curves, reflecting leaf firing, measured by digital image analysis for St. Augustinegrass cultivars in 2006 and 2007, San Antonio, TX. Least significant difference values are shown when treatment means were significantly different at $p \leq 0.05$.

drought (Fig. 2). The average number of days for cultivars to reach 50% green ground cover was 25.6 and 53.9 d of drought in 2006 and 2007, respectively (Table 1). The contrast in days to reach 50% green ground cover between years can be attributed to the impact of heat stress compounding the impact of soil drying (data not shown). Steinke et al. (2009) reported SA mean canopy temperatures to be approximately 9.0°C warmer in 2006 as compared to 2007. The 2007 drought period did not approach the temperature maxima attained in the 2006 study and required nearly twice as many days to reach peak canopy temperatures as compared to the 2006 drought period (Steinke et al., 2009).

The SA cultivar Floratam demonstrated the most consistent drought response over both study years by persisting well into the drought period and reaching 50% green ground cover at 33.9 and 59.4 d, respectively, during the two study years (Table 1). Floratam also exhibited a significant ($p \leq 0.05$) pattern of delayed leaf firing symptoms and elevated turfgrass quality ratings when compared to the other cultivars over both study years (Tables 2 and 3). The SA cultivars Common and Sapphire performed well in Year 2 of the study (Fig. 2, Table 1).

Cultivars that exhibited the least drought tolerance, as quantified by days to reach 50% green ground cover, included Common, Delmar, Raleigh, and Sapphire in 2006 and Delmar, Palmetto, and Raleigh in 2007 (Table 1, Fig. 2). In 2006, the most drought-tolerant cultivar, Floratam, decreased to 50% green ground cover 11.3 d later than Raleigh, the cultivar that lost green ground coverage most quickly (Table 1, Fig. 2). In 2007, Sapphire and Floratam were the most drought-tolerant cultivars and deceased to 50% green ground cover 10 d later than the least drought-tolerant cultivars, Palmetto and Raleigh (Table 1, Fig. 2). Qualitative assessments on leaf firing severity and turfgrass quality measurements paralleled the quantitative percent green ground cover data (Table 2 and 3).

The results demonstrate that cultivars of SA perform differently from each other and drought response may depend on the number of environmental stressors occurring together at one time (i.e., soil drying alone or in combination with heat and humidity). In some instances, cultivar drought response of SA differed by >10 d which may significantly impact water conservation efforts. While the maintenance of green ground cover does not solely indicate drought performance, color retention will influence

Table 2. Visual leaf firing of St. Augustinegrass cultivars during the 2006 and 2007 60-d drought periods, San Antonio, TX.

Cultivar	Days of drought 2006†						
	13 4 Aug.	20 11 Aug.	27 18 Aug.	33 24 Aug.	40 31 Aug.	47 7 Sept.	55 15 Sept.
Amerishade	8.5ab‡	6.8a	5.5ab	3.5b	2.5b	1.5b	1.3b
Common	8.0ab	5.8a	4.5b	2.5b	2.0b	1.8b	1.0b
Delmar	8.5ab	5.5a	4.8ab	2.8b	2.3b	2.0b	1.3b
Floratam	8.8a	6.5a	6.3a	5.0a	3.8a	3.0a	2.3a
Palmetto	8.8a	6.0a	4.8ab	2.8b	2.0b	1.8b	1.0b
Raleigh	7.8b	5.8a	4.5b	2.8b	2.0b	1.3b	1.0b
Sapphire	8.5ab	5.5a	4.5b	2.3b	2.0b	1.3b	1.0b
	Days of drought 2007§						
	8 12 July	14 18 July	19 23 July	30 3 Aug.	40 13 Aug.	51 24 Aug.	61 3 Sept.
Amerishade	9.0a	8.3b	8.7b	8.3ab	7.0a	5.0ab	4.0b
Common	9.0a	9.0a	9.0a	8.7ab	7.0a	5.7ab	4.0b
Delmar	9.0a	9.0a	9.0a	8.5ab	6.5a	4.8b	3.8b
Floratam	9.0a	9.0a	9.0a	8.5ab	7.3a	7.5a	7.0a
Palmetto	9.0a	9.0a	9.0a	8.8ab	6.5a	4.5b	4.0b
Raleigh	9.0a	9.0a	9.0a	7.7b	6.3a	4.0b	3.3b
Sapphire	9.0a	9.0a	9.0a	9.0a	7.3a	6.0ab	4.7b

†2006 drought began 23 July and ended 21 September.

‡1–9; 1 = 100% fired, 9 = green.

§2007 drought began 5 July and ended 3 September.

Table 3. Visual turf quality of St. Augustinegrass cultivars during the 2006 and 2007 60-d drought periods, San Antonio, TX.

Cultivar	Days of drought 2006†							
	6 28 July	13 4 Aug.	20 11 Aug.	27 18 Aug.	33 24 Aug.	40 31 Aug.	47 7 Sept.	55 15 Sept.
Amerishade	6.5a‡	6.5a	5.5ab	4.8ab	3.3ab	2.0b	1.5b	1.5b
Common	7.0a	5.5a	4.8b	3.8b	2.5b	1.5b	1.3b	1.3b
Delmar	6.8a	6.0a	4.8b	4.3b	3.0ab	2.3b	1.5b	1.8b
Floratam	6.5a	6.3a	6.3a	5.8a	4.0a	3.8a	2.3a	2.8a
Palmetto	6.3a	6.3a	4.8b	4.3b	3.0ab	1.8b	1.3b	1.3b
Raleigh	6.5a	6.0a	4.5b	4.3b	2.3b	1.3b	1.0b	1.0b
Sapphire	6.3a	5.8a	4.3b	3.8b	2.3b	1.3b	1.3b	1.3b
	Days of drought 2007§							
	1 5 July	8 12 July	14 18 July	19 23 July	30 3 Aug.	40 13 Aug.	51 24 Aug.	61 3 Sept.
Amerishade	6.5a	6.5a	8.0a	6.8a	6.3ab	4.8a	4.3ab	4.5ab
Common	6.5a	6.5a	8.3a	6.8a	6.0ab	4.3ab	4.5ab	4.3ab
Delmar	6.8a	6.3a	7.8a	7.0a	6.0ab	3.8ab	3.8ab	3.5b
Floratam	6.3a	6.3a	8.0a	6.8a	6.3ab	4.5ab	5.0a	5.8a
Palmetto	6.0a	6.5a	8.0a	6.5a	6.0ab	4.0ab	3.3b	3.3b
Raleigh	6.3a	6.3a	8.0a	6.8a	5.5b	3.5b	3.8ab	4.0b
Sapphire	6.0a	6.5a	8.0a	6.3a	6.5a	4.0ab	4.5ab	4.5ab

†2006 drought began 23 July and ended 21 September.

‡1–9; 9 = optimum quality.

§2007 drought began 5 July and ended 3 September.

home consumer irrigation behaviors. Regulations governing water restrictions have the potential to increase conservation by considering cultivar performance and restriction intervals other than weekly or biweekly limits.

Drought Recovery

Drought recovery, quantified through percent green ground cover during green-up, was significantly ($p \leq 0.05$) influenced by SA cultivars in both study years. In 2006 and 2007, SA cultivars began to steadily increase green ground coverage after a 10 to 15 d recovery period with water (Fig. 3). The average number of days for SA cultivars to achieve 50% green ground cover was 38.3 and 4.5 d of recovery in 2006 and 2007, respectively (Table 1). The disparity in days to reach 50% green ground cover between years can be accredited to the drought induced canopy injury between years and the

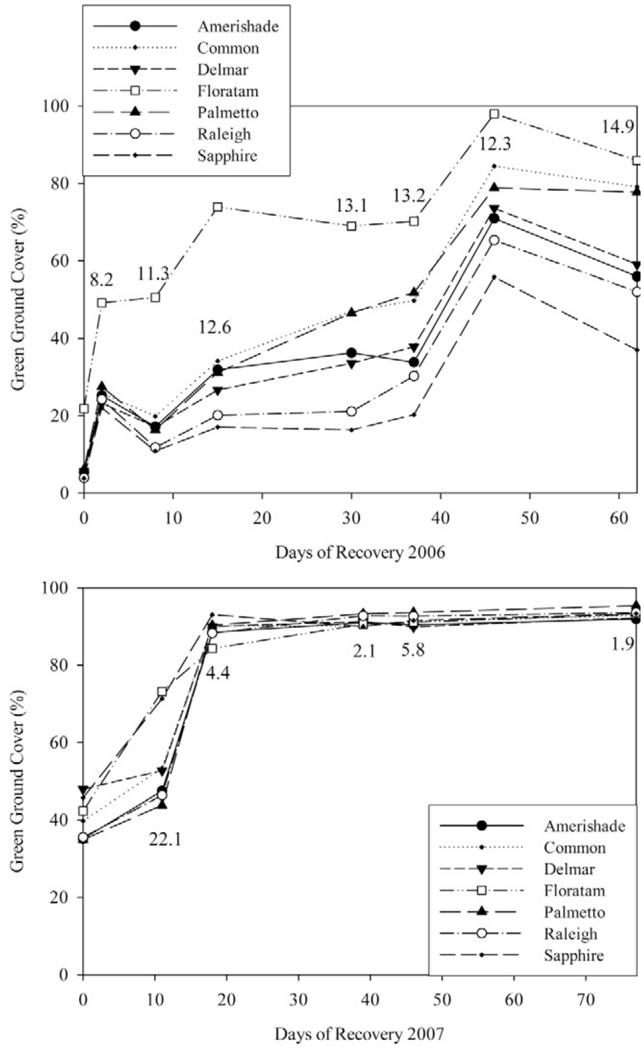

Figure 3. (left) Turfgrass recovery curves, reflecting percent green canopy, derived from digital image analysis for St. Augustinegrass cultivars in 2006 and 2007, San Antonio, TX. Least significant difference values are shown when treatment means were significantly different at $p \leq 0.05$.

presence or absence of additional environmental stresses. As reported in Steinke et al. (2009) and Steinke and Chalmers (2010), the number of days to reach maximum turf canopy temperatures was lower and the number of days remaining at maximum canopy temperatures was greater during the 2006 drought period as compared to 2007.

As evidenced in cool-season turfgrass drought studies (Karcher et al., 2008), cultivars that were slowest to lose green ground cover during this drought study were also the quickest to recover once water was no longer limiting (Table 1). Floratam SA, which was a consistent top performer during both years of drought stress, increased to 50% cover in 8.5 and 1.9 d of recovery during 2006 and 2007, respectively (Table 1, Fig. 3). All remaining SA cultivars were 22 to 52 d slower in attaining the 50% green coverage mark in 2006 (Table 1). Both Sapphire and Floratam SA achieved 50% green cover in <2 d of recovery during the 2007 study as compared to the remaining cultivars which required 4 to 7 d recovery time (Table 1). Turfgrass quality ratings paralleled increases in percent green ground cover during plant recovery (data not shown). The SA cultivars tested in this trial demonstrated variable drought response and drought recovery capabilities but all entries survived though recovery periods varied during the arbitrarily defined time periods.

Table 4. Visual uniformity of recovery for St. Augustinegrass cultivars during the 2006 and 2007 drought recovery periods, San Antonio, TX.

	Days of recovery 2006†						
	62	205	240				
Cultivar	21 Nov.	13 Apr.	18 May				
Amerishade	4.5bc‡	4.3cd	5.0bc				
Common	6.0ab	6.8ab	7.8ab				
Delmar	4.8bc	5.3bc	5.8ab				
Floratam	8.5a	8.3a	8.8a				
Palmetto	4.8bc	5.5bc	5.8ab				
Raleigh	4.5bc	4.8bc	5.3bc				
Sapphire	3.0c	2.0d	2.5c				
	Days of recovery 2007§						
	11	18	22	31	39	46	77
	14 Sept.	21 Sept.	25 Sept.	4 Oct.	12 Oct.	19 Oct.	19 Nov.
Amerishade	6.8a	8.8a	9.0a	9.0a	9.0a	9.0a	9.0a
Common	8.3a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a
Delmar	7.8a	8.8a	9.0a	9.0a	9.0a	9.0a	9.0a
Floratam	8.3a	9.0a	8.8a	9.0a	9.0a	9.0a	9.0a
Palmetto	7.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a
Raleigh	8.0a	8.8a	9.0a	9.0a	9.0a	9.0a	9.0a
Sapphire	8.5a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a

†2006 recovery began 21 September and ended 19 November.

‡1–9; 9 = completely uniform.

§2007 recovery began 3 September and ended 1 November.

Uniformity of drought recovery with regards to the density of active growth centers may greatly impact a plant's ability to repopulate a turf area. Differences in uniformity of recovery between cultivars were greater in 2006 as compared to 2007 when each grass recovered with a similar high degree of uniformity (Table 4). The extent as to how uniform a turf recovers from drought may provide insight into whether or not a plant (i) exhibits a physiological dormancy mechanism through lowering water potentials, (ii) exhibits drought tolerance in the absence of dormancy through increased water potentials, or (iii) exhibits drought escape by seeking channels in a shrink-swell clay soil to allow for deeper rooting.

CONCLUSIONS

Concerns over current and future water resource availability have generated interest in the implementation of municipal water restrictions focused on urban amenity turfgrass systems. Before this study, municipalities around South and Central Texas were of the opinion that all SA cultivars were not drought tolerant and should not be recommended for planting within urban landscapes. Our results demonstrate that SA cultivars can have as much as a 10 to 15 d difference in expressing drought symptoms which can have a significant impact on long-term water conservation efforts. The drought response exhibited during the 60-d drought may or may not indicate the ability of SA to survive a drought. St. Augustinegrass cultivars that maintain green ground cover appear to better avoid short-term drought and are better positioned to recover with a green and functioning canopy. Very few studies have been published focusing on turfgrass response once water is no longer limiting. In some instances, our data demonstrated in so far as a 52 d difference in attaining 50% green ground cover during the irrigated drought recovery period. This result could significantly impact home consumer irrigation behaviors and expectations of a turfgrass following drought conditions. In addition to differential cultivar response to drought, municipalities should recognize other environmental stresses (e.g., shade) before implementing a complete ban on a plant species as SA is frequently selected for tolerating shade in Texas landscapes. St. Augustinegrass cultivar response to early and late season drought intervals should be evaluated to better gauge drought response under a variety of environmental conditions.

Acknowledgments

This research was supported by the Texas AgriLife Research and Texas AgriLife Extension Service. Financial support from the San Antonio Water System, the Turfgrass Producers of Texas, the Irrigation Technology Center, and the Rio Grande Basin Initiative is gratefully appreciated. We wish to thank Dr. Doug Karcher and Dr. Mike Richardson from the Univ. of Arkansas for assistance with statistical analysis and interpretation.

References

Abraham, E.M., B. Huang, S.A. Bonos, and W.A. Meyer. 2004. Evaluation of drought resistance for Texas bluegrass, Kentucky bluegrass, and their hybrids. Crop Sci. 44:1746–1753.

Atkins, C.E., R.L. Green, S.I. Sifers, and J.B. Beard. 1991. Evapotranspiration rates and growth characteristics of ten St. Augustinegrass genotypes. HortScience 26:1488–1491.

Carrow, R.N. 1996. Drought resistance aspects of turfgrasses in the southeast: Root-shoot responses. Crop Sci. 36:687–694.

Devitt, D., and R. Morris. 2010. Sustainable water use in urban landscapes in the 21st century: A Las Vegas perspective. Acta Hortic. (ISHS) (in press).

Karcher, D.E., M.D. Richardson, K. Hignight, and D. Rush. 2008. Drought tolerance of tall fescue populations selected for high root/shoot ratios and summer survival. Crop Sci. 48:771–777.

Kim, K.S., and J.B. Beard. 1988. Comparative turfgrass evapotranspiration rates and associated plant morphological characteristics. Crop Sci. 28:328–331.

Kjelgren, R., L. Rupp, and D. Kilgren. 2000. Water conservation in urban landscapes. HortScience 35:1037–1040.

Monteith, J.L. 1965. Evaporation and environment. p. 205–234. *In* G.E. Fogg (ed.) The state and movement of water in living organisms. Symp. of Soc. Exp. Biol. No. XIX, Swansea, UK. 8–12 Sept. 1964. Cambridge Univ. Press, Cambridge, UK.

Motulsky, H.J., and A. Christopoulos. 2003. Fitting models to biological data using linear and nonlinear regression: A practical guide to curvefitting. GraphPad Software, San Diego, CA.

Richardson, M.D., D.E. Karcher, K. Hignight, and D. Rush. 2008. Drought tolerance and rooting capacity of Kentucky bluegrass cultivars. Crop Sci. 48:2429–2436.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888.

San Antonio Water System. 2007. Drought-tolerant grass. Available at http://www.saws.org/conservation/ordinance/turfgrass/(verified 2 June 2010).

Steinke, K., and D.R. Chalmers. 2010. Refining qualitative turfgrass canopy stress measurements during drought. Acta Hortic. (ISHS) (in press).

Steinke, K., D.R. Chalmers, J.C. Thomas, and R.H. White. 2009. Summer drought effects on warm-season turfgrass canopy temperatures. Online. Appl. Turfgrass Sci. doi:10.1094/ATS-2009-0303-01-RS.

Su, K., D.J. Bremer, S.J. Keeley, and J.D. Fry. 2007. Effects of high temperature and drought on a hybrid bluegrass compared with Kentucky bluegrass and tall fescue. Crop Sci. 47:2152–2161.