Evaluation of Sixty-Day Drought Survival In San Antonio of Established Turfgrass Species and Cultivars

Final Report to Cooperators - February 2008

Submitted to:

The San Antonio Water System

and

The Turfgrass Producers of Texas

Submitted by:

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Introduction

This research evaluated turfgrass drought tolerance in San Antonio as related to the provisions of the San Antonio Water System's 2005 Conservation Ordinance. Treatments were designed to evaluate the turfgrasses commonly available in the San Antonio region. Equally important was to determine which turfgrasses might qualify for inclusion in the list of turfgrasses mentioned in item 3 below. Specific provisions in the ordinance with impact on turfgrass production and use are:

1. Turfgrass established or associated with new construction after January 1, 2006, shall have a minimum soil depth of 4-inches beneath the turfgrass.

2. Turfgrass established after January 1, 2007, shall have summer dormancy capabilities. "Summer dormancy" is defined as the ability of turfgrass to survive without water for a period of sixty consecutive days between the months of May through September.

3. Beginning January 1, 2007 SAWS will maintain a list of turfgrasses that have demonstrated summer dormancy capabilities.

Texas AgriLife Extension faculty in Soil and Crop Sciences and Agricultural Engineering entered into Memorandum of Agreements with the San Antonio Water System (SAWS) Conservation Program and the Turfgrass Producers of Texas for a two-year research project. The project evaluated the sixty-day drought survival of turfgrass species and cultivars in San Antonio over a 2 year period. Team members constructed the research site in cooperation with volunteers from the Turfgrass Producers of Texas. The research plots were sodded with 25 different turfgrasses in September 2005 for a summer 2006 60-day drought and September 2006 for a summer 2007 60-day drought. A 5,000 sq. ft. "drought simulator" rain shelter was constructed on the site. The drought simulator covered the plot area during times of rainfall to maintain the 60-day summer drought periods. Grasses were evaluated during 60-day summer drought periods in 2006 and 2007. Immediately following the drought period the grasses were allowed to recover with irrigation for 60 days and recovery from drought effects were measured. Additional spring recovery data was required in spring of 2007 to best gauge recovery from 2006 drought. No grasses survived the drought on the 4-inch soil depth in either 2006 or 2007. For that reason the data presented in this report will concentrate on the response of grasses planted on the unrestricted native soil. All grasses survived the 60-day drought period on the unrestricted native soil in both years.

Research Objectives:

- ☑ To identify which of the commonly grown and marketed warm-season turfgrasses in the San Antonio area are able to survive a 60-day drought without irrigation when grown on a locally occurring agricultural soil.
- ☑ To identify which of the commonly grown and marketed warm-season turfgrasses in the San Antonio area are able to withstand a 60-day drought without irrigation when grown on a shallow (4 inch deep) soil profile.

The Research Materials and Methods

This study involved the establishment of, 4 replications of 25 grasses on two soil depths, repeated on separate but similar test sites in successive years. Grasses were planted by sodding in September 2005 and 2006, established for 9 to 10 months and then subjected to a 60-day drought starting in July of the next year (2006 and 2007, respectively). The grasses studied were:

- ☑ bermudagrass (8) [Cynodon spp.]: Celebration; Common; GN-1; Grimes EXP; Premier; TexTurf; TifSport and Tifway (419)
- ☑ St. Augustinegrass (7) [Stenotaphrum secundatum]: Amerishade, Common, Delmar, Floratam, Palmetto, Raleigh, and Sapphire
- ☑ zoysiagrass (9) [Zoysia spp.]: Cavalier, El Toro, Emerald, Empire, Jamur, Palisades, Y-2, Zeon and Zorro)
- ☑ buffalograss (1) [Buchloe dactyloides]: 609

The experimental site was located on the Bladerunner Farm (approximately 3 miles south of San Antonio, TX) on an area of Lewisville silty clay (fine-silty, mixed, thermic Udic Calciustolls). A rectangular area approximately 100 ft wide by 500 ft long was selected for use. A 50 ft by 350 ft area within the cleared area was laser graded to provide a level 50 ft by 100 ft experimental area at each end of the 350 ft rectangle. The area between the two experimental areas was given a 1% slope toward the center. A trench (2 ft wide and 1.5 ft deep) was cut along each side of the area to accommodate construction of a concrete footer and wall on which the tracks for the rain shelter could be mounted.

Each experimental area was divided into 8 blocks each of which was 20 ft by 20 ft. Each of the 8 blocks was subdivided into 25 individual plots each of which was 4 feet by 4 ft. Blocks were separated by a 2 ft wide isle on all sides. The soil on four blocks was undisturbed other than some light tillage and hand raking and represented native soil with minimal restrictions to root growth. The remaining four blocks had the upper 4 inches of soil removed. The subgrade was then carefully graded by hand to provide a 0.5% slope from the center line to the outside and center drains. A 30 mil HDPE plastic sheet was placed over the subgrade and the 4 inches of removed topsoil was replaced. These blocks simulated lawns planted on shallow soil meeting the minimum requirements for new lawn construction in the San Antonio area.

A 4-inch diameter slotted ADS drain line bedded in washed ⅜ inch gravel to the surface was installed immediately inside and parallel to each concrete track wall. A third drain was installed down the center isle between the blocks. All three drains went to the center line where they joined into a center cross drain line, which exited through the wall and emptied into a 750 gallon underground concrete storage tank. The tank was equipped with a float activated pump that maintained a level of 50%-70% capacity. Excess water was discharged onto adjacent crop land.

Irrigation comprised a 2-zone automatic irrigation system controlled by an Irritrol Systems, KwikDial automatic sprinkler system controller that operated two 1-inch electric valves. One zone controlled irrigation to the four blocks having 4-inch soil depth while the second zone controlled irrigation to the four blocks with unrestricted soil depth. Each block was equipped with an irrigation head (Hunter Industries, San Marcos, CA, model PGJ-06 pop-up rotor spray head with a 2.0 gpm nozzle) at each corner, providing head to head coverage.

The 25 grasses were established from washed sod to minimize differences resulting from the soil on the sod. Grasses established well prior to drought treatment. The establishment period prior to drought was 10.2 months in 2005-06 and 9.5 months in 2006-07.

Table 1. Dates of planting, drought, and recovery for each drought year.

Drought year	Planting date	Drought started	Recovery started	60-Day Recovery end date	Extended Recovery date
2006	Sep 20, 2005	Jul 23, 2006	Sep 21, 2006	Nov 19, 2006	Jun 18, 2007
2007	Sep 22, 2006	Jul 5, 2007	Sep 3, 2007	Nov 1, 2007	Nov 19, 2007

The drought simulator ensured a 60-day drought for 25 grasses on two soil profiles. A 60-day irrigated drought recovery period followed the 60-day drought. The research plots were well established at the beginning of the study in both years. Data were collected for turfgrass quality, density, leaf firing due to moisture stress, and color as percent green turf cover.

Research Plot Management

Establishment Period: The research site was fertilized according to soil test results prior to sodding in September 2005 and 2006, respectively. Additional nitrogen applications were made in the spring and early summer for Year 1 and Year 2. Fungicides were applied preventatively for Brown Patch and Take-All Root Rot. The plots were mowed at 2.5 inches in 2006 and 2.25 inches in 2007; weekly or as needed. Irrigation was applied to prevent excess moisture stress and enhance establishment. The four-inch soil depth treatment was therefore irrigated more frequently as indicated by more frequent periodic wilting than those plots on native soil without restriction to rooting.

Drought Period: Plots were mowed up until the fifth week of the drought in 2006 and sixth week in 2007, when mowing was stopped, to prevent unnecessary stress, due to little or extremely slow growth. The drought simulator operated when the rainfall occurred during the 60-day drought treatments.

Recovery Period: The research plots were irrigated so water availability was not a limiting factor in turfgrass recovery. In 2006, plots were fertilized twice during recovery with a total of 1.5 lbs of actual nitrogen per 1000 sq. ft. In 2007, plots were fertilized once during recovery with a total of 1.0 lb of actual nitrogen per 1000 sq. ft. In 2006 mowing was begun at the start of the recovery period at a height of 2.75 inches. The mowing height was reduced to 2.25 inches two weeks into the recovery period. Lowering the mowing height caused scalping the bermudagrass cultivars and this is reflected in temporary decreases in recovery ground cover ratings (Figure 12a). In 2007 plots were mowed once at 1.25 inches in the first week of the recovery period to reduce competition from browned off leaf canopy, to encourage regrowth. They were then returned to the 2.25 inch mowing height.

Data Collection and Statistical Evaluation: Data were taken, every 7 to 10 days by D. Chalmers and K. Steinke during the 120 days of the drought and recovery periods. This is mentioned to verify that methods for data observations were according to turf protocol standards witnessed repeatedly and with consensus. During the establishment period, plots were evaluated monthly for percent cover and turf quality (data not shown). During the imposed drought, data (turf quality, turf uniformity, leaf firing) were collected every 7-10 days throughout the 60-day drought period. Digital photos of each plot were also taken for later evaluation. Leaf firing is a visual browning of leaves caused by excessive stress. Leaf firing was evaluated using a 1 to 9 visual rating scale, with 1 representing total leaf firing (browning), and 9 being no leaf firing. Soil samples were collected at 0, 20, 40 and 60 days of drought, from a selected entry of each species, at depths of 0-4, 4-8, 8-12, and 12-18 inches to measure gravimetric moisture content. Data were subjected to analysis of variance. Significant differences among treatment means were determined using Tukey's HSD test at $\propto$=0.05.

IMPORTANT NOTE: Throughout this final report figures have been used to illustrate the statistically analyzed data that is presented in data tables. The statistical groupings are only presented in the tables. Comparisons between grasses are only valid only when based upon statistical groupings in Tables and not on Figures. Grass performance data presented in table columns is not different if followed by the same letter.

Weather Station Data

An on-site weather station (manufactured by Campbell Scientific and configured by Dynamax Corp., Houston, TX) located 800 feet from the plot area recorded temperature, humidity, wind speed, wind direction, and solar radiation. Data were used to calculate potential evapotranspiration (PET) rate using the Pennman-Monteith equation (Monteith, 1965). PET, rainfall and other environmental data were collected, organized and published on the Texas ET web site (http://texaset.tamu.edu/) as the San Antonio South location.

Drought Simulator Operation

A 5,000 ft^2 movable drought simulator rain shelter was constructed by the Texas AgriLife Extension faculty in the Department of Biological and Agricultural Engineering. This drought simulator protected the plots from undesired rainfall during the drought period. On the north concrete beam, several 2-way micro-switches were used to monitor the location, control the speed, and stop the shelter's movement. All electrical components were located in an air-conditioned storage building. Two Campbell Scientific gauges were installed at the site to detect and record rainfall amounts. The rain shelter was programmed to automatically deploy and cover the research plots when either both rain gauges detected 0.01 inch of rain or when one gauge detected 0.02 inches of precipitation. Less than two minutes were required for the drought simulator to fully cover the research plots and protect them from unwanted rainfall. After 30 minutes without rainfall, the drought simulator returned to its center position. Thus, the drought simulator was only over the plots for minimal time periods necessary to protect the experimental area from rainfall events during the 60-day drought periods. Therefore, shading effects were not an issue. Runoff water from the rain shelter roof fell 1.5 ft outside the concrete track walls from which it drained onto adjacent crop land.

YEAR 1 (2006) Results: 60-Day Drought and Recovery from Drought

Photo caption: June 29, 2006. The Turfgrass Producers of Texas Field Day at the SAWS research site. Calvin Finch (left) from SAWS, John Cosper (center) from Turfgrass Producers of Texas, and David Chalmers (right) from the Texas AgriLife Extension Service were on hand to discuss the study with more than 40 producers .

Weather Conditions - 2006 Drought and Recovery

Drought period: Potential evapotranspiration (PET) totaled 13.61 inches during the drought period. If the PET was characterized every 20 days the PET for days 1-20, 21-40 and 41-60 was 5.03, 5.14 and 3.34 inches, respectively. Average daily high temperatures for days 1-20, 21-40 and 41-60 were 95.5, 97.9 and 89.1 degrees F, respectively. PET for the drought period is seen in Figure 1 while Figure 2 displays maximum and minimum temperatures during the drought. Figure 3 is a graph of PET during the recovery period while Figure 4 is a graph of maximum and minimum temperatures during the 60-day recovery.

Figure 1. Daily PET during the 60-day summer drought in 2006.

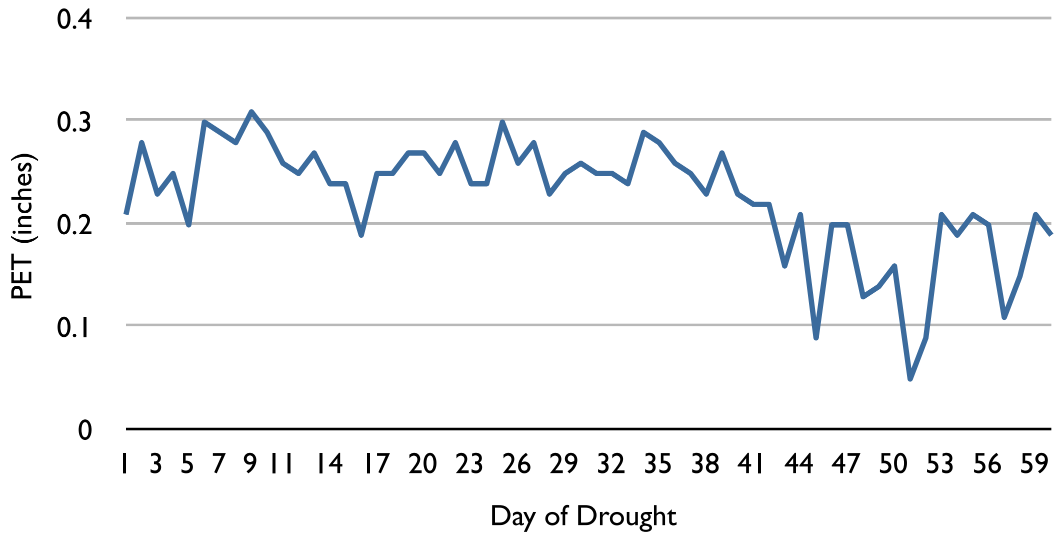


Figure 2. The 2006 daily maximum and minimum temperatures during summer drought.

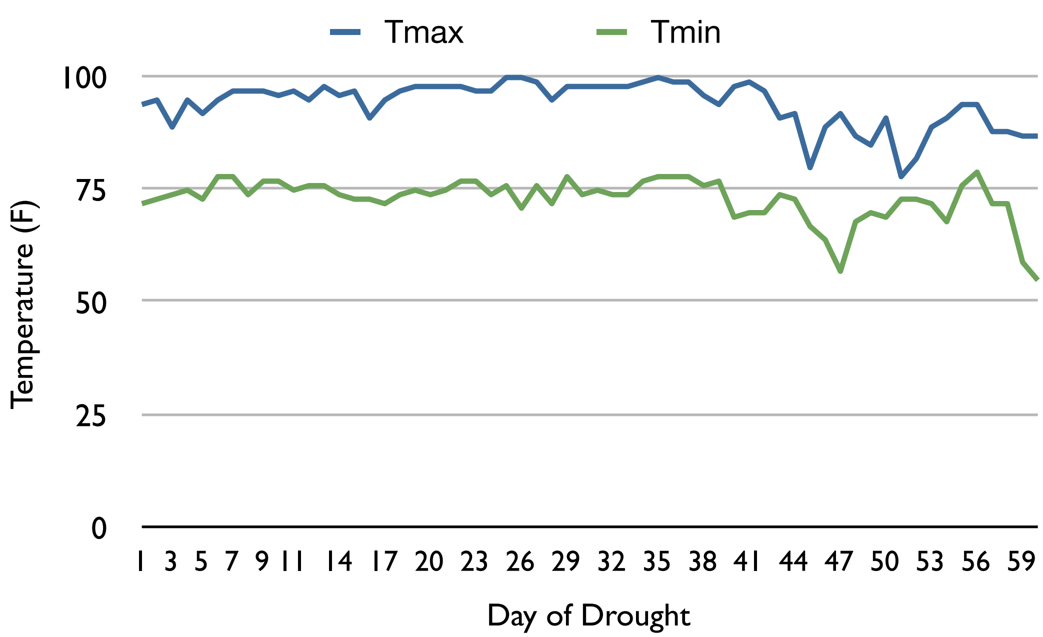


Figure 3. Daily potential evapotranspiration (PET) during the 2006 60-day drought recovery period.

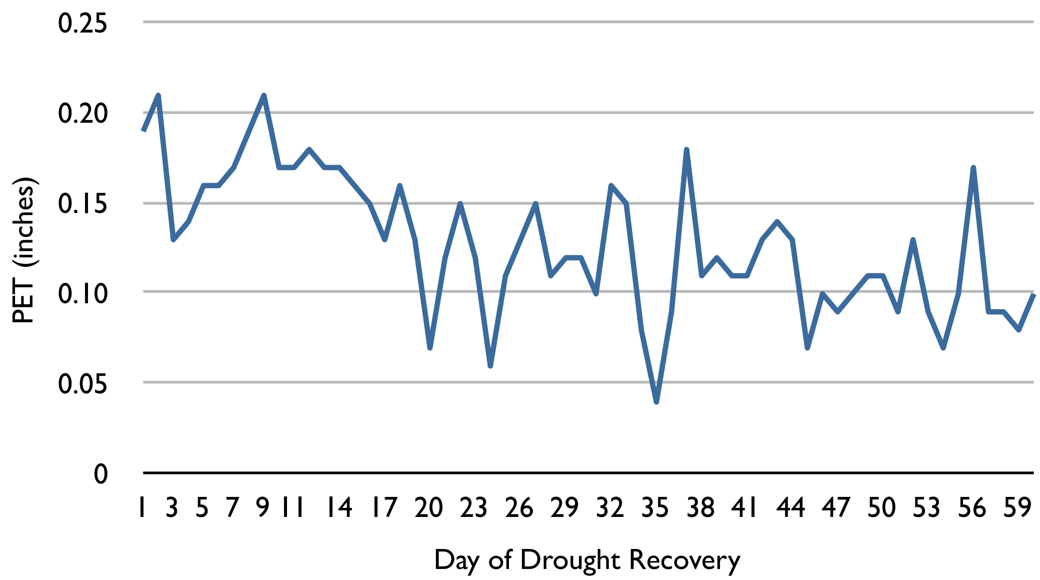


Figure 4. Maximum and minimum temperatures during the 2006 60-day drought recovery period.

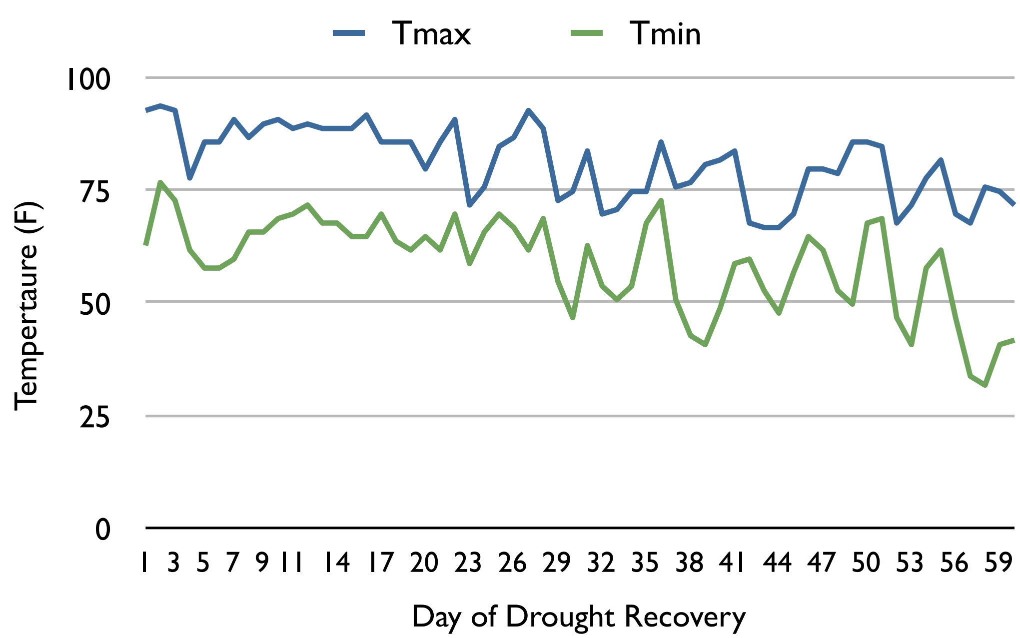


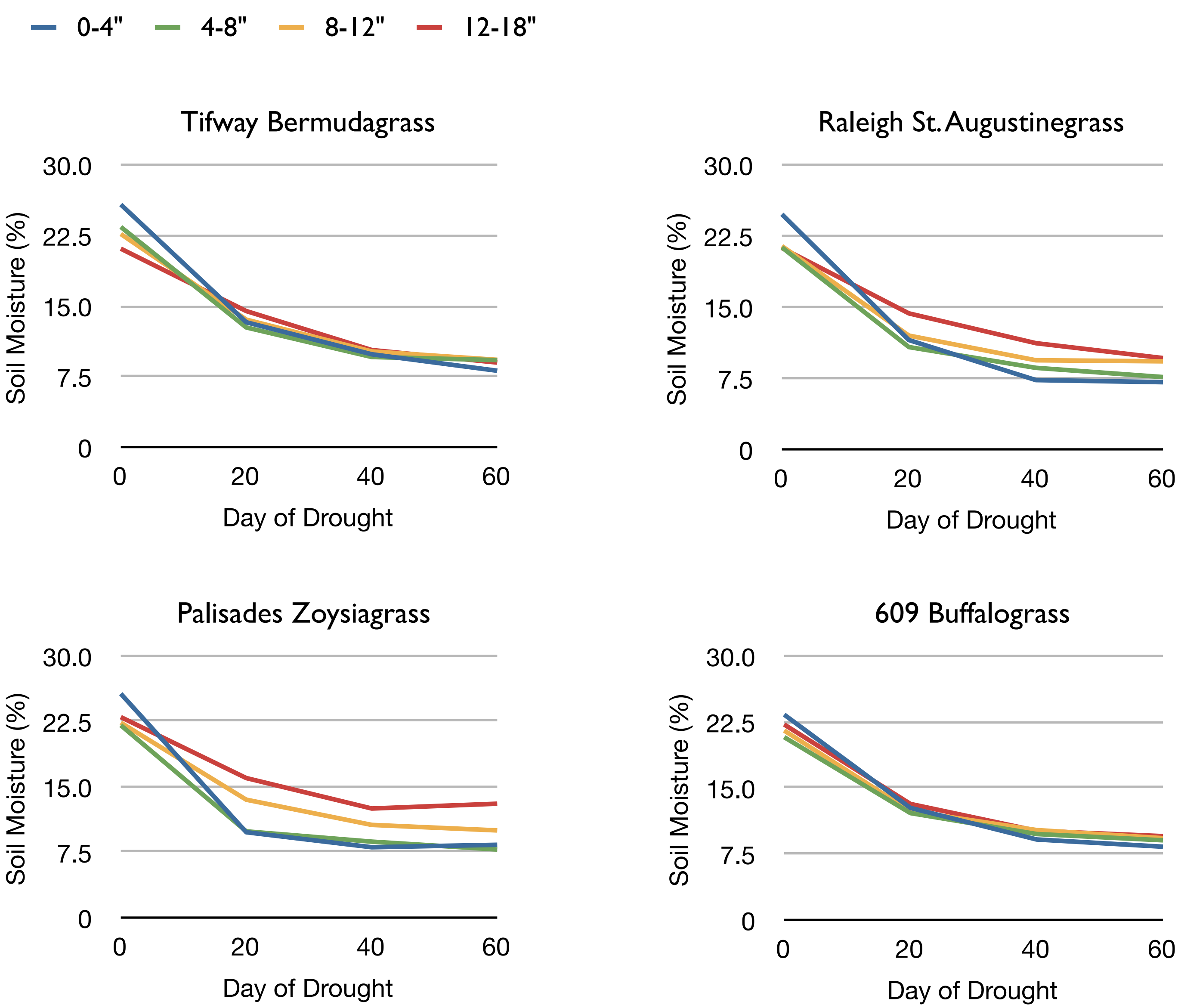
Figure 4 (above) shows how the minimum temperatures dropped below 60 degrees F in the latter half of the recovery period. In fact, 22 days had minimum temperatures below 60 degrees with 13 of those days having minimum temperatures near 50 degrees or below. Hence, the 23-day delay in beginning the drought waiting for the drought simulator to become operational, may have resulted in somewhat decreased turf recovery due to chilling night temperatures.

Soil Moisture Content With Soil Depth During 2006 Drought

The following four charts display the percent soil moisture from Raleigh St. Augustinegrass, Tifway bermudagrass, Palisades zoysiagrass and 609 buffalograss at four soil depths (0 to 4, 4 to 8, 8 to 12 and 12 to 18 inches). These samples were taken from the field plots after 0, 20, 40, and 60 days of drought. These data indicate soil moisture with depth during the duration of the drought.

Figure 5. Soil moisture profile with depth at 20 day intervals for a single variety from each of four grass species tested.

Legend:



Turfgrass Quality During Drought and Recovery - 2006

Quality is based on 9 being best and 1 being poorest. A rating of 6 or above is generally considered acceptable. A quality rating value of 9 is reserved for a perfect or ideal grass, but it also can reflect an absolutely outstanding treatment. Quality ratings varied based on turfgrass species, intensity of management and time of year. Quality ratings are relative within species but not among species. Quality ratings are not based on color alone, but on a combination of color, density, uniformity, texture, and disease or environmental stress (Morris & Shearman). Since this study is about grass drought survival and recovery, there should be great caution in the use of quality data for comparisons among grasses. This is especially important since all grasses were managed in a way to best gauge drought persistence and recovery and not to maximize quality.

Figure 6. Turfgrass quality for all species, comparing native soil depth with four-inch soil depth. Grasses planted on the four-inch soil profile did not recover from the 2006 60-day drought.

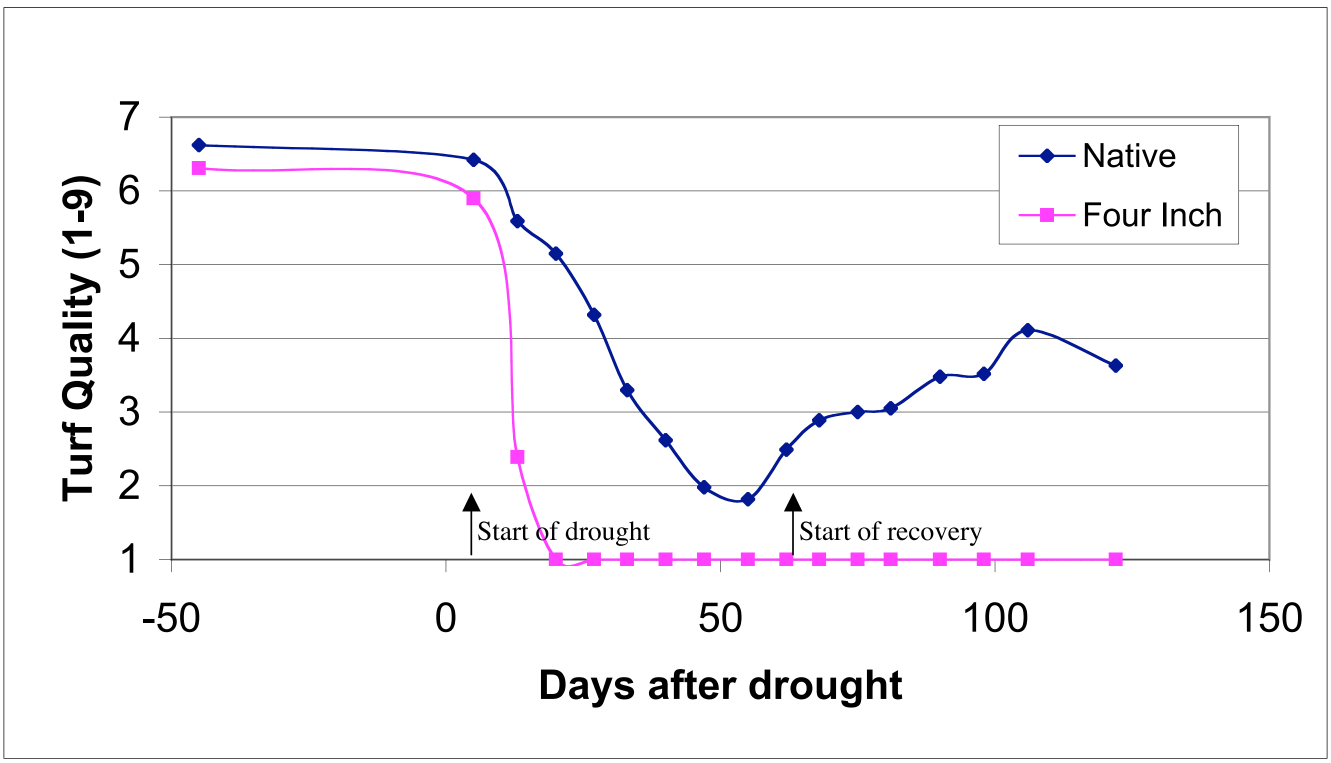


Table 2. Turfgrass quality (1-9=best) for species and cultivars growing on native soil depth during the 2006 drought. Data in columns followed by the same letter are not significantly different at the 0.05 level. *Note: Table heading includes the date the data were taken followed below by the day into the drought (0 to 60)*

	7/28	8/4	8/11	8/18	8/24	8/31	9/7	9/15
	Day of Drought							
Bermudagrass	5	13	20	27	33	40	47	55
Celebration	5.5 b	4.8 abc	6.0 abc	6.0 ab	7.0 a	6.8 a	5.3 a	3.8 ab
Common	5.5 b	4.8 abc	4.8 abcde	4.8 abcd	4.8 abcd	4.0 bcd	2.8 bcde	2.3 abcd
GN1	6.0 ab	5.3 abc	6.0 abc	5.5 abc	5.5 abc	5.5 abc	4.0 ab	3.0 abcd
Grimes EXP	6.0 ab	5.8 abc	6.8 a	5.3 abcd	4.5 bcde	4.0 bcd	2.5 bcde	2.3 abcd
Premier	6.3 ab	5.8 abc	4.0 bcde	3.0 de	3.0 defg	1.0 f	1.0 e	1.0 d
Tex Turf	6.5 ab	6.0 abc	5.8 abcd	5.8 abc	6.0 ab	6.3 ab	4.3 ab	4.3 a
TifSport	6.5 ab	5.8 abc	6.3 ab	6.0 ab	5.8 ab	4.8 abc	3.8 abc	2.8 abcd
Tifway 419	6.3 ab	6.3 ab	5.8 abcd	6.0 ab	6.0 ab	5.0 abc	3.5 abcd	3.0 abcd
St. Augustinegrass								
Amerishade	6.5 ab	6.5 a	5.5 abcd	4.8 abcd	3.3 cdefg	2.0 def	1.5 cde	1.5 cd
SA Common	7.0 a	5.5 abc	4.8 abcde	3.8 bcde	2.5 defg	1.5 ef	1.3 de	1.3 cd
Delmar	6.8 ab	6.0 abc	4.8 abcde	4.3 abcde	3.0 defg	2.3 def	1.5 cde	1.8 bcd
Floratam	6.5 ab	6.3 ab	6.3 ab	5.8 abc	4.0 bcdef	3.8 cde	2.3 bcde	2.8 abcd
Palmetto	6.3 ab	6.3 ab	4.8 abcde	4.3 abcde	3.0 defg	1.8 def	1.3 de	1.3 cd
Raleigh	6.5 ab	6.0 abc	4.5 abcde	4.3 abcde	2.3 efg	1.3 f	1.0 e	1.0 d
Sapphire	6.3 ab	5.8 abc	4.3 bcde	3.8 bcde	2.3 efg	1.3 f	1.3 de	1.3 cd
Zoysiagrass								
Cavalier	6.5 ab	5.3 abc	3.8 cde	3.0 de	1.0 g	1.0 f	1.0 e	1.0 d
El Toro	7.0 a	5.3 abc	3.5 de	3.5 cde	2.3 efg	1.0 f	1.0 e	1.0 d
Emerald	6.5 ab	5.8 abc	4.8 abcde	3.8 bcde	1.3 g	1.0 f	1.0 e	1.0 d
Empire	7.0 a	6.0 abc	3.8 cde	3.8 bcde	2.0 fg	1.3 f	1.0 e	1.3 cd
Jamur	6.8 ab	5.5 abc	3.5 de	3.5 cde	2.0 fg	1.0 f	1.0 e	1.0 d
Palisades	7.0 a	5.8 abc	4.0 bcde	4.0 abcde	1.8 fg	1.0 f	1.0 e	1.0 d
Y-2	6.3 ab	4.3 c	2.8 e	2.3 e	1.3 g	1.0 f	1.0 e	1.0 d
Zeon	6.3 ab	4.8 abc	3.5 de	3.0 de	1.3 g	1.0 f	1.0 e	1.0 d
Zorro	6.3 ab	4.5 bc	2.5 e	2.0 e	1.3 g	1.0 f	1.0 e	1.0 d
Buffalograss								
609	6.5 ab	6.3 ab	6.0 abc	6.3 a	5.8 ab	5.3 abc	3.5 abcd	3.3 abc

Figure 7a. Turfgrass Quality (2006) for buffalograss and bermudagrass cultivars during drought. Data reference is Table 2.

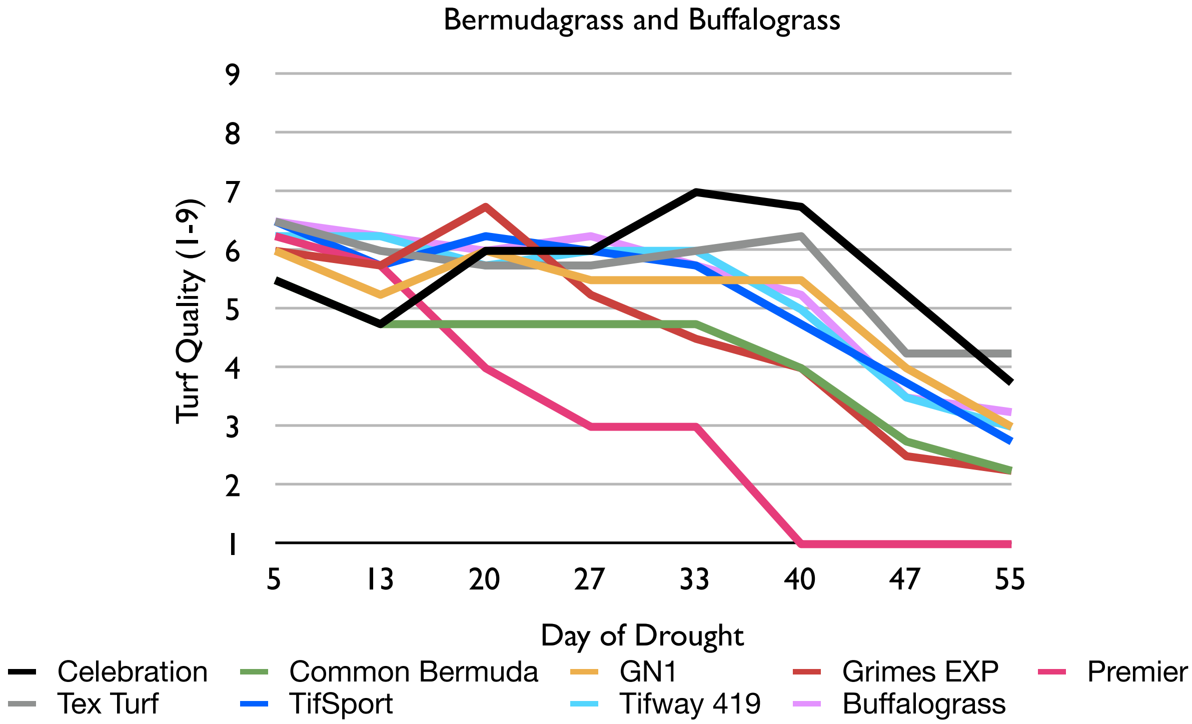


Figure 7b. Turfgrass Quality (2006) for St. Augustinegrass cultivars during drought period. Data reference is Table 2.

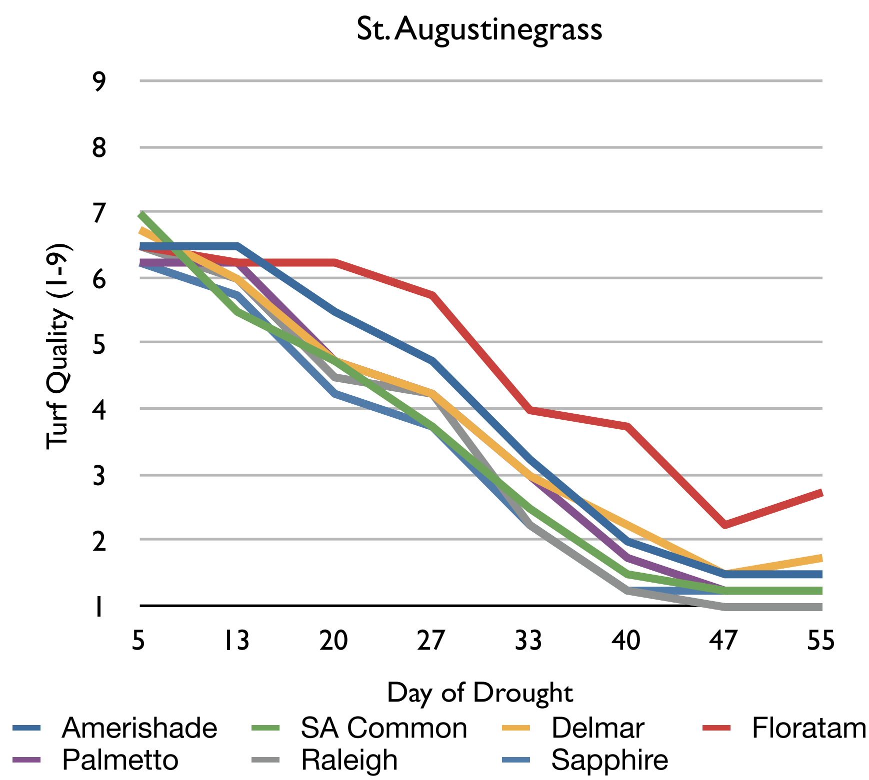
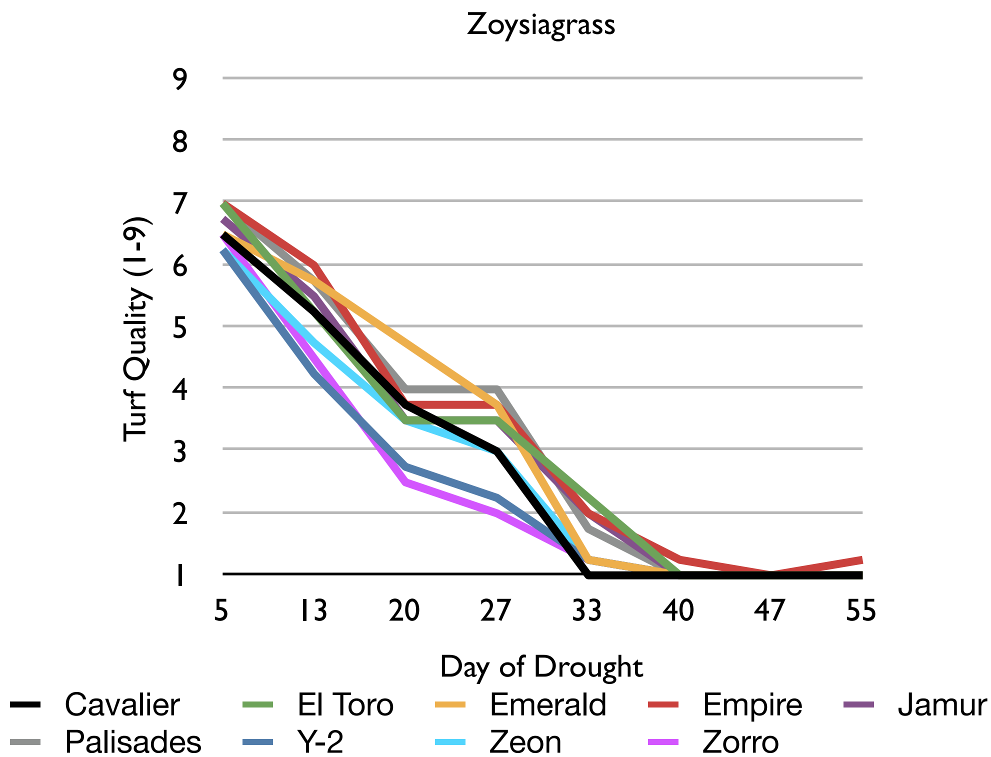


Figure 7c. Turfgrass Quality (2006) for zoysiagrass cultivars during the drought periods. Data reference is Table 2.



Color Ratings During 2006 Drought

Color retention ratings are a measure of overall plot color. The scale used is 1 to 9 scale with 1 being straw brown and 9 being dark green.

Table 3. Turfgrass color (1-9=best) for species and cultivars growing on native soil depth during the 2006 drought. Data in columns followed by the same letter are not significantly different at the 0.05 level. *Note: Table heading includes the date the data were taken followed below by the day into the drought (0 to 60).*

	8/4	8/11	8/18	8/24	8/31	9/7	9/15
	Day of Drought						
Bermudagrass	13	20	27	33	40	47	55
Celebration	6.5 abc	6.3 ab	6.5 a	7.3 a	5.8 a	5.3 a	2.8 abc
Common	4.8 cde	4.8 abcde	5.3 abcd	4.3 bcde	4.0 abc	2.8 bcdef	2.0 abc
GN1	6.3 abc	6.5 a	5.8 abc	5.8 abc	4.8 ab	3.3 abcde	2.5 abc
Grimes EXP	5.3 bcde	6.0 abc	5.8 abc	4.3 bcde	3.8 abcd	2.5 bcdef	2.3 abc
Premier	5.5 abcde	3.5 defg	3.0 efg	2.3 efg	1.0 d	1.0 f	1.0 c
Tex Turf	6.0 abcd	5.8 abc	6.0 ab	6.3 ab	6.0 a	4.5 ab	3.5 a
TifSport	6.8 ab	6.0 abc	6.0 ab	6.0 abc	5.3 a	3.5 abcd	3.0 ab
Tifway 419	6.8 ab	6.0 abc	6.0 ab	6.3 ab	5.3 a	3.3 abcde	2.5 abc
St. Augustine-grass							
Amerishade	7.3 a	5.5 abcd	4.5 bcde	3.0 defg	2.0 bcd	1.5 def	1.5 bc
SA Common	5.8 abcd	4.8 abcde	3.5 defg	2.3 efg	1.5 cd	1.3 ef	1.3 bc
Delmar	6.0 abcd	4.5 abcde	4.0 cdef	2.5 efg	2.0 bcd	1.5 def	1.3 bc
Floratam	6.5 abc	5.8 abc	5.3 abcd	3.8 cdef	3.5 abcd	2.3 cdef	2.3 abc
Palmetto	6.3 abc	4.8 abcde	3.8 defg	2.5 efg	2.0 bcd	1.3 ef	1.0 c
Raleigh	6.3 abc	4.0 cdefg	3.5 defg	2.3 efg	1.3 cd	1.0 f	1.0 c
Sapphire	5.8 abcd	4.5 abcde	3.8 defg	2.0 efg	1.3 cd	1.3 ef	1.0 c
Zoysiagrass							
Cavalier	4.8 cde	3.3 efg	2.5 fg	1.0 g	1.0 d	1.0 f	1.0 c
El Toro	5.5 abcde	3.0 efg	3.0 efg	1.5 fg	1.0 d	1.0 f	1.0 c
Emerald	6.3 abc	4.3 bcdef	3.5 defg	1.3 g	1.0 d	1.0 f	1.0 c
Empire	6.0 abcd	3.5 defg	3.3 efg	1.5 fg	1.3 cd	1.0 f	1.3 bc
Jamur	5.3 bcde	3.0 efg	2.8 efg	1.5 fg	1.0 d	1.0 f	1.0 c
Palisades	6.0 abcd	3.5 defg	3.3 efg	1.3 g	1.0 d	1.0 f	1.0 c
Y-2	3.8 e	2.0 g	2.0 g	1.0 g	1.0 d	1.0 f	1.0 c
Zeon	4.3 de	3.0 efg	2.3 fg	1.0 g	1.0 d	1.0 f	1.0 c
Zorro	4.3 de	2.3 fg	2.0 g	1.0 g	1.0 d	1.0 f	1.0 c
Buffalograss							
609	5.8 abcd	4.5 abcde	5.8 abc	5.3 abcd	5.5 a	3.8 abc	3.0 ab

Figure 8a. Turfgrass color for bermudagrass and buffalograss cultivars during the 2006 60-day drought. Data reference is Table 3.

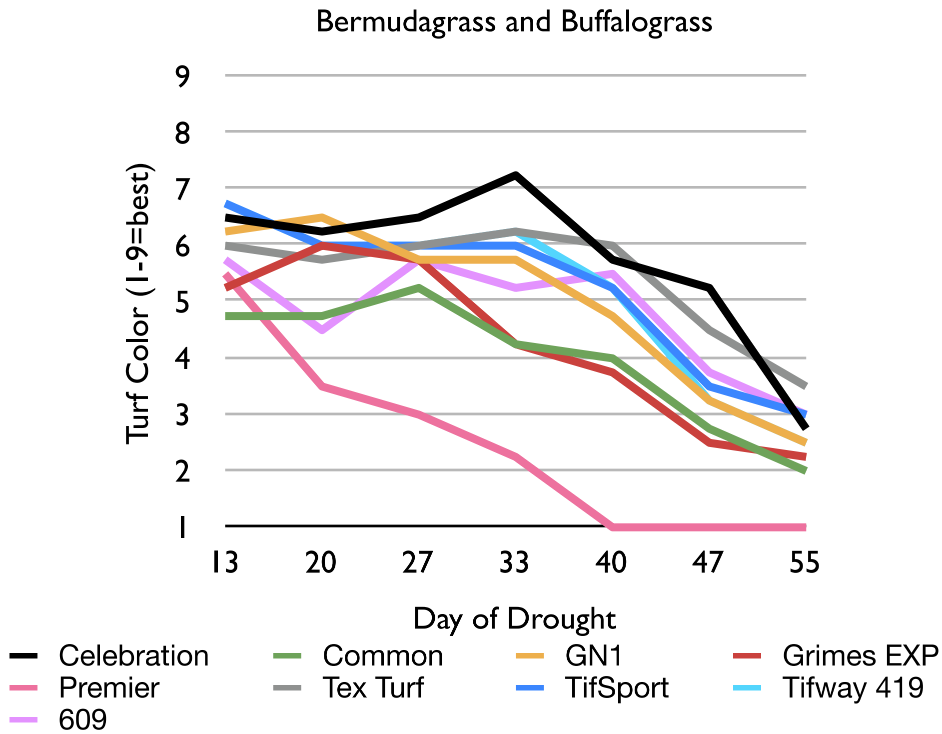


Figure 8b. Turfgrass color for St. Augustinegrass cultivars during the 2006 60-day drought. Data reference is Table 3.

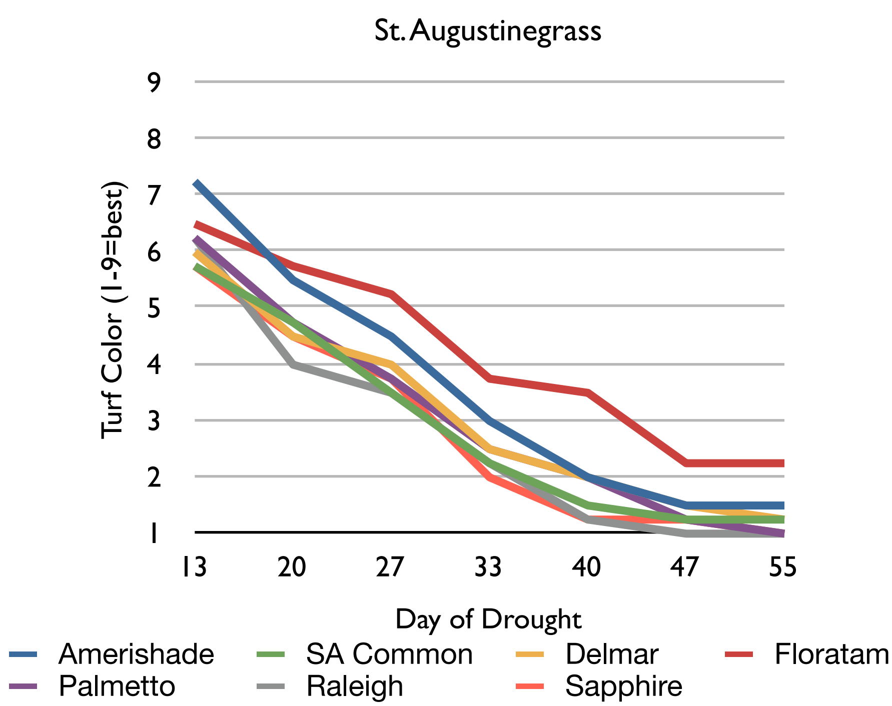
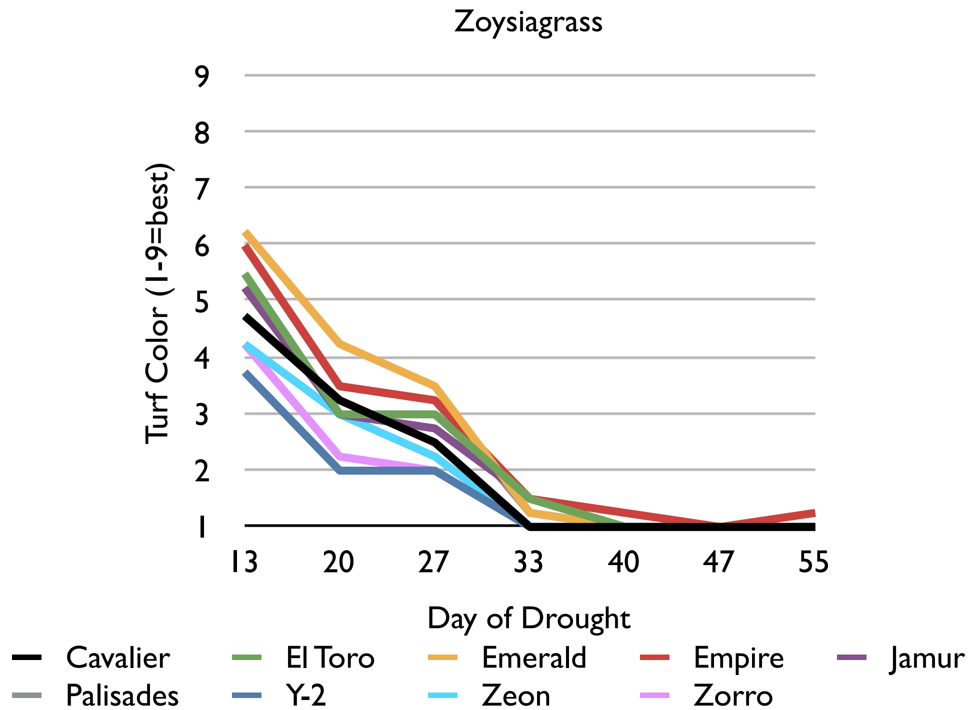


Figure 8c. Turfgrass color for zoysiagrass cultivars during the 2006 60-day drought. Data reference is Table 3.



The loss of turf color was seen during the 60-day drought. The trend for color loss mirrors the data on leaf firing ratings during the drought. Comparisons between grasses within species are only valid using the mean separation order from Table 4.

Leaf Firing During Drought

Leaf firing is used to indicate drought stress resistance. Leaf firing is a visual browning of leaves due to a loss of chlorophyll, the green pigment in plants, that is caused by excessive stress. Leaf firing is a visual rating that is used to evaluate plant stress. A 1 to 9 visual rating scale is used with 1 being 100% leaf firing, complete dormancy or no plant recovery; and 9 being no leaf firing or 100% green-no dormancy. The image to the left was taken 20 days into the drought period. The browned off large blocks are where the grasses were planted over the 4-inches of soil. Those plots have completely fired. This is a time when the zoysiagrass plots are beginning to brown off first. The data from leaf firing during the 2006 drought period is in Table 4.

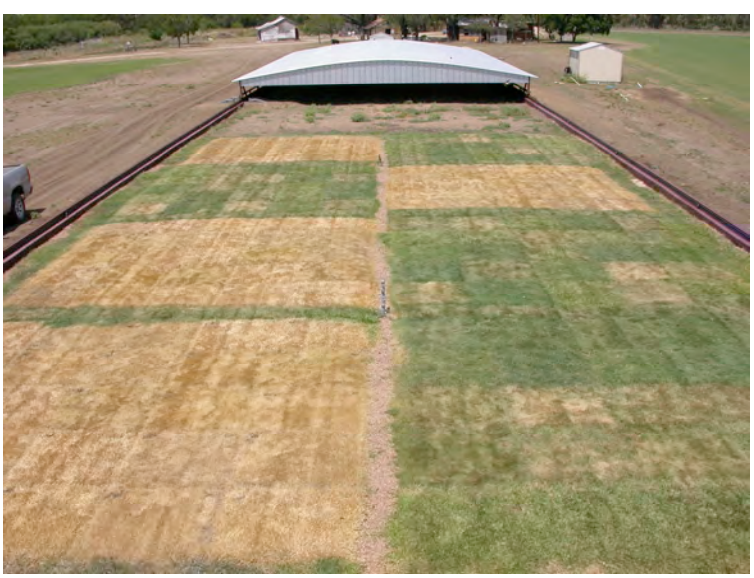


Table 4. Turfgrass leaf firing (1 to 9, where 9 equals no firing) for species and cultivars on native soil depth during the 2006 drought. Data in columns followed by the same letter are not significantly different at the 0.05 level. *Note: Table heading includes the date the data were taken followed below by the day into the drought.*

	8/4	8/11	8/18	8/24	8/31	9/7	9/15
	Day of Drought						
Bermudagrass	13	20	27	33	40	47	55
Celebration	9.0 a	8.0 ab	8.0 a	8.8 a	7.5 a	7.0 a	3.8 ab
Common	9.0 a	7.5 abcd	6.5 abcd	6.0 abcd	5.0 bc	3.8 bcdef	2.3 bc
GN1	9.0 a	8.0 ab	7.3 abc	7.0 abc	5.8 abc	4.8 abcde	3.3 abc
Grimes EXP	9.0 a	7.8 abc	6.5 abcd	5.8 bcd	5.0 bc	3.5 bcdef	2.8 abc
Premier	8.8 a	5.0 efgh	4.0 efgh	2.0 f	2.0 de	1.0 e	1.0 c
Tex Turf	9.0 a	7.8 abc	7.5 ab	7.8 abc	7.0 ab	6.3 ab	5.0 a
TifSport	9.0 a	7.8 abc	7.3 abc	8.0 ab	6.5 ab	5.0 abcd	4.3 ab
Tifway 419	9.0 a	8.0 ab	7.8 ab	7.8 abc	6.3 ab	4.8 abcde	4.0 ab
St. Augustine-grass							
Amerishade	8.5 a	6.8 abcde	5.5 bcdef	3.5 def	2.5 de	1.5 e	1.3 c
SA Common	8.0 a	5.8 cdef	4.5 defgh	2.5 ef	2.0 de	1.8 ef	1.0 c
Delmar	8.5 a	5.5 def	4.8 defg	2.8 ef	2.3 de	2.0 def	1.3 c
Floratam	8.8 a	6.5 abcdef	6.3 abcde	5.0 cde	3.8 cd	3.0 cdef	2.3 bc
Palmetto	8.8 a	6.0 bcdef	4.8 defg	2.8 ef	2.0 de	1.8 ef	1.0 c
Raleigh	7.8 a	5.8 cdef	4.5 defgh	2.8 ef	2.0 de	1.3 e	1.0 c
Sapphire	8.5 a	5.5 def	4.5 defgh	2.3 ef	2.0 de	1.3 e	1.0 c
Zoysiagrass							
Cavalier	7.5 a	4.5 fgh	3.5 fgh	1.0 f	1.0 e	1.0 e	1.0 c
El Toro	7.3 a	4.5 fgh	4.0 efgh	1.8 f	1.5 de	1.0 e	1.0 c
Emerald	8.5 a	6.5 abcdef	5.0 cdef	1.3 f	1.0 e	1.0 e	1.0 c
Empire	8.3 a	5.3 efg	4.0 efgh	1.5 f	1.3 e	1.0 e	1.0 c
Jamur	8.0 a	4.5 fgh	3.8 fgh	1.5 f	1.5 de	1.0 e	1.0 c
Palisades	8.0 a	5.0 efgh	4.3 defgh	1.8 f	1.3 e	1.0 e	1.0 c
Y-2	6.3 a	3.0 h	2.5 gh	1.0 f	1.0 e	1.0 e	1.0 c
Zeon	6.8 a	5.0 efgh	3.5 fgh	1.0 f	1.0 e	1.0 e	1.0 c
Zorro	7.0 a	3.3 gh	2.3 h	1.0 f	1.0 e	1.0 e	1.0 c
Buffalograss							
609	7.0 a	8.3 a	7.5 ab	6.8 abc	6.0 abc	5.3 abc	3.8 ab

Figure 9a. Turfgrass leaf firing graphed for bermudagrass cultivars during 2006 drought. Data reference is Table 4.

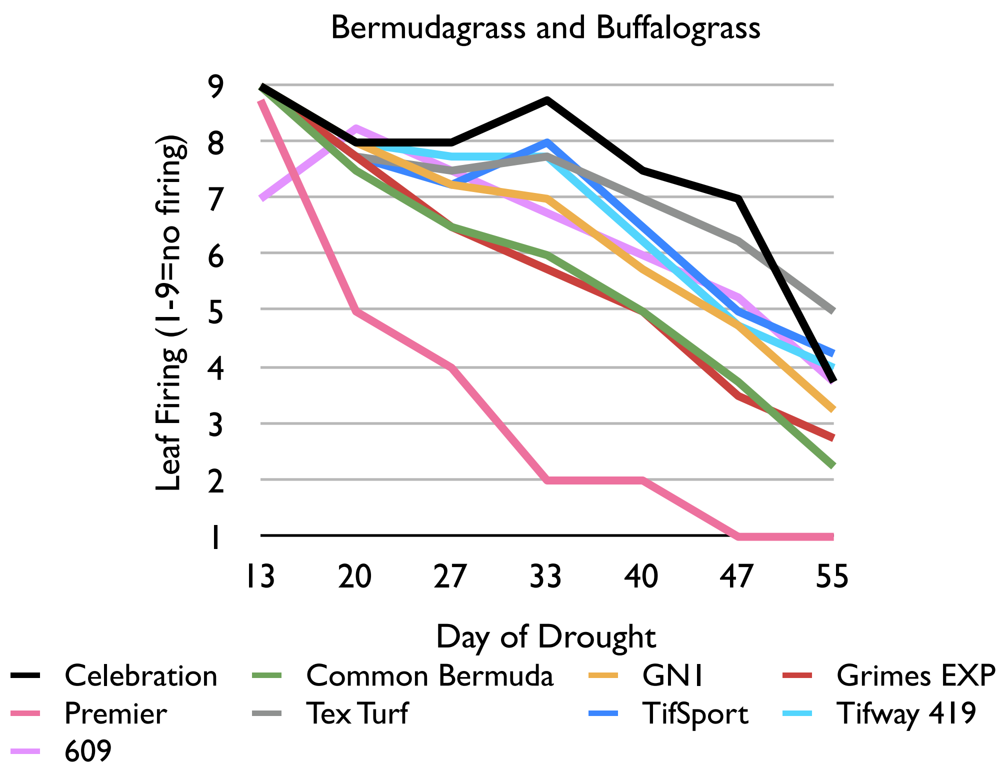


Figure 9b. Turfgrass leaf firing graphed for St. Augustinegrass cultivars during 2006 drought. Data reference is Table 4.

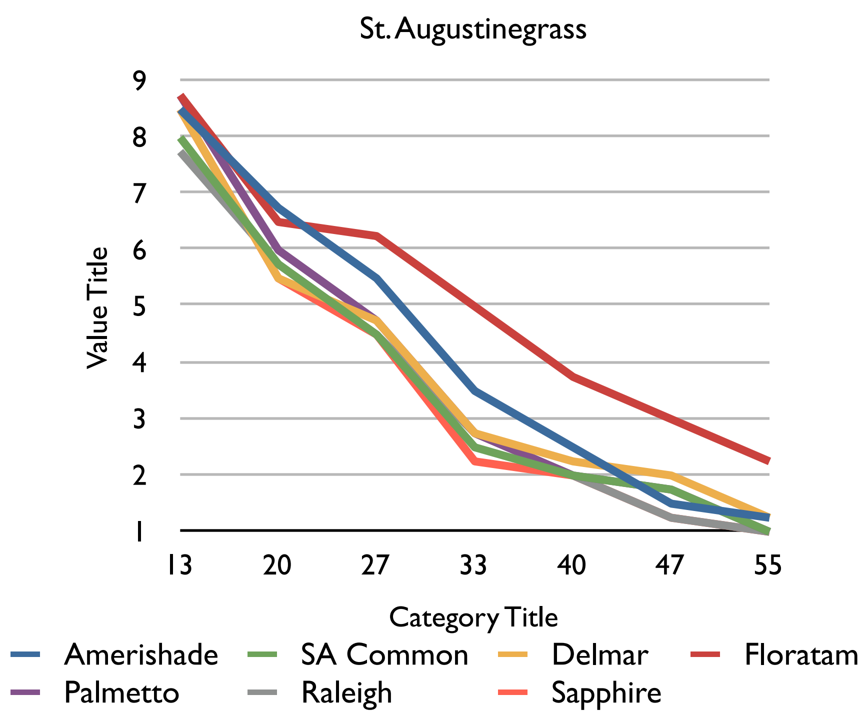


Figure 9c. Turfgrass leaf firing graphed for zoysiagrass cultivars during 2006 drought. Data reference is Table 4.

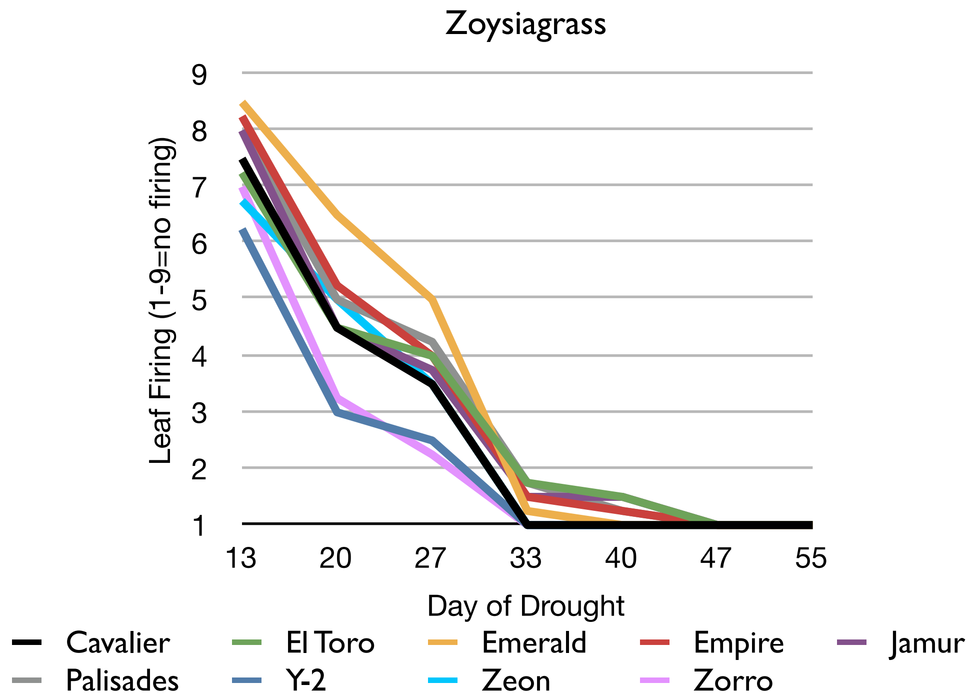
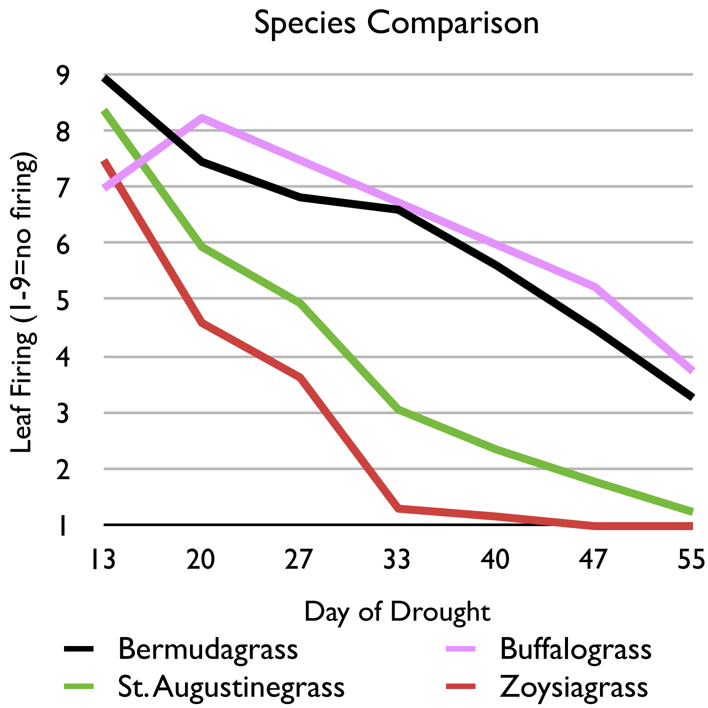


Table 5. Leaf firing data (using a scale of 1 to 9, where 9 equals no leaf firing and 1 equals complete firing) summarized by species for observation dates during 2006 drought. Data in columns followed by the same letter are not significantly different at the 0.05 level. *Note: Table heading includes the date the data were taken followed below by the day into the 60-day drought.*

Native Soil Only	8/4	8/11	8/18	8/24	8/31	9/7	9/15
	Day of Drought						
	13	20	27	33	40	47	55
Bermudagrass	9.0 a	7.5 a	6.8 a	6.6 a	5.6 a	4.5 a	3.3 a
Buffalograss	7.0 b	8.3 a	7.5 a	6.8 a	6.0 a	5.3 a	3.8 a
St. Augustinegrass	8.4 a	6.0 b	5.0 b	3.1 b	2.4 b	1.8 b	1.3 b
Zoysiagrass	7.5 b	4.6 c	3.6 c	1.3 c	1.2 b	1.0 b	1.0 b

Figure 10. Leaf firing data summarized by species for observation dates during 2006 drought. Data reference is Table 5.



60-Day Drought Recovery (2006) - Turfgrass Quality

During the recovery period the data collection focused upon turf quality (Table 6, and Figures 11a, 11b, and 11c) and percent living ground cover (Table 7, and Figures 12 a, 12b, and 12c and Table 8). Data collection occurred approximately every 7 days during the recovery period. The one exception was the period of time between the second to last and final data collection. The final data collection included uniformity of plot recovery. Recovery may have been impaired by the 23-day delay in starting the drought. Figure 4 shows the frequency with which the daily minimum temperature dropped below 60 degrees F during the last half of the recovery period, which may have slowed recovery.

Photo caption: The Second Day of a 60-Day Recovery Period is pictured here on September 22, 2006.

Table 6. Turfgrass quality (1-9=best) for species and cultivars growing on native soil depth during the 2006 recovery. Data in columns followed by the same letter are not significantly different at the 0.05 level. *Note: Table heading includes the date the data were taken followed below by the day into the 60-day recovery period.*

	9/22	9/28	10/5	10/11	10/20	10/28	11/5	11/21
	Day of Recovery							
Bermudagrass	2	8	15	21	30	38	46	62
Celebration	4.5 ab	6.3 a	6.5 a	3.0 bcd	4.8 abc	4.5 bcd	6.0 ab	3.5 cdef
Common	2.8 abcde	3.3 bcdefg	4.5 abc	4.3 ab	4.3 bcd	4.5 bcd	5.8 abc	4.5 bcd
GN1	3.5 abcd	4.3 abcdef	4.0 bcd	3.0 bcd	4.0 bcde	4.3 bcde	5.8 abc	3.8 bcdef
Grimes EXP	3.8 abc	4.3 abcdef	5.5 ab	4.3 ab	5.3 ab	5.0 abc	6.3 a	4.0 bcde
Premier	2.0 cde	2.0 efg	1.3 e	2.5 cd	3.0 def	3.3 cdefg	3.3 efghi	3.0 cdef
Tex Turf	4.8 a	5.5 ab	5.5 ab	3.5 bcd	4.0 bcde	4.0 bcdef	6.3 a	4.5 bcd
TifSport	3.8 abc	4.8 abcd	4.5 abc	3.8 bc	4.3 bcd	4.3 bcde	6.0 ab	4.5 bcd
Tifway 419	4.0 abc	4.5 abcde	4.5 abc	3.3 bcd	4.3 bcd	4.3 bcde	6.0 ab	5.3 abc
St. Augustinegrass								
Amerishade	2.0 cde	2.5 cdefg	2.5 cde	2.8 bcd	3.0 def	2.8 defg	2.8 fghi	3.3 cdef
SA Common	2.0 cde	2.3 defg	2.5 cde	3.0 bcd	3.5 cdef	3.3 cdefg	3.8 efgh	4.0 bcde
Delmar	2.3 bcde	2.5 cdefg	2.5 cde	3.0 bcd	3.0 def	3.0 defg	3.0 efghi	3.3 cdef
Floratam	3.3 abcde	4.3 abcdef	4.0 bcd	4.3 ab	5.3 ab	5.8 ab	5.5 abcd	6.0 ab
Palmetto	2.0 cde	2.3 defg	2.5 cde	2.5 cd	3.3 cdef	3.0 defg	3.3 efghi	3.5 cdef
Raleigh	1.8 cde	2.0 efg	2.0 de	2.5 cd	2.5 ef	2.5 efg	2.5 ghi	2.5 def
Sapphire	2.0 cde	2.0 efg	2.0 de	2.3 cd	2.3 f	2.3 fg	2.3 hi	1.8 ef
Zoysiagrass								
Cavalier	1.0 e	1.5 g	1.3 e	2.0 d	2.0 f	2.5 efg	2.5 ghi	2.3 def
El Toro	2.0 cde	2.0 efg	2.3 de	3.0 bcd	3.5 cdef	3.5 cdefg	4.0 defg	3.5 cdef
Emerald	1.0 e	1.0 g	1.0 e	2.0 d	2.0 f	2.0 g	2.0 i	2.3 def
Empire	1.8 cde	2.3 defg	2.3 de	3.3 bcd	3.5 cdef	3.3 cdefg	4.3 cdef	4.0 bcde
Jamur	2.0 cde	2.0 efg	2.5 cde	3.0 bcd	3.5 cdef	3.8 cdefg	4.5 bcde	4.0 bcde
Palisades	2.0 cde	2.0 efg	2.3 de	3.3 bcd	3.5 cdef	3.5 cdefg	4.3 cdef	4.5 bcd
Y-2	1.3 de	1.3 g	1.0 e	2.0 d	2.0 f	2.0 g	1.8 i	1.5 f
Zeon	2.0 cde	1.8 fg	1.3 e	2.3 cd	2.3 f	2.3 fg	2.3 hi	2.0 ef
Zorro	1.0 e	1.0 g	1.0 e	2.0 d	2.0 f	2.3 fg	2.0 i	2.5 def
Buffalograss								
609	4.0 abc	5.0 abc	6.0 ab	5.8 a	6.3 a	6.5 a	7.0 a	7.0 a

Figure 11a. Turfgrass Quality (2006) for buffalograss and bermudagrass cultivars during 60-day recovery period. Data reference is Table 6.

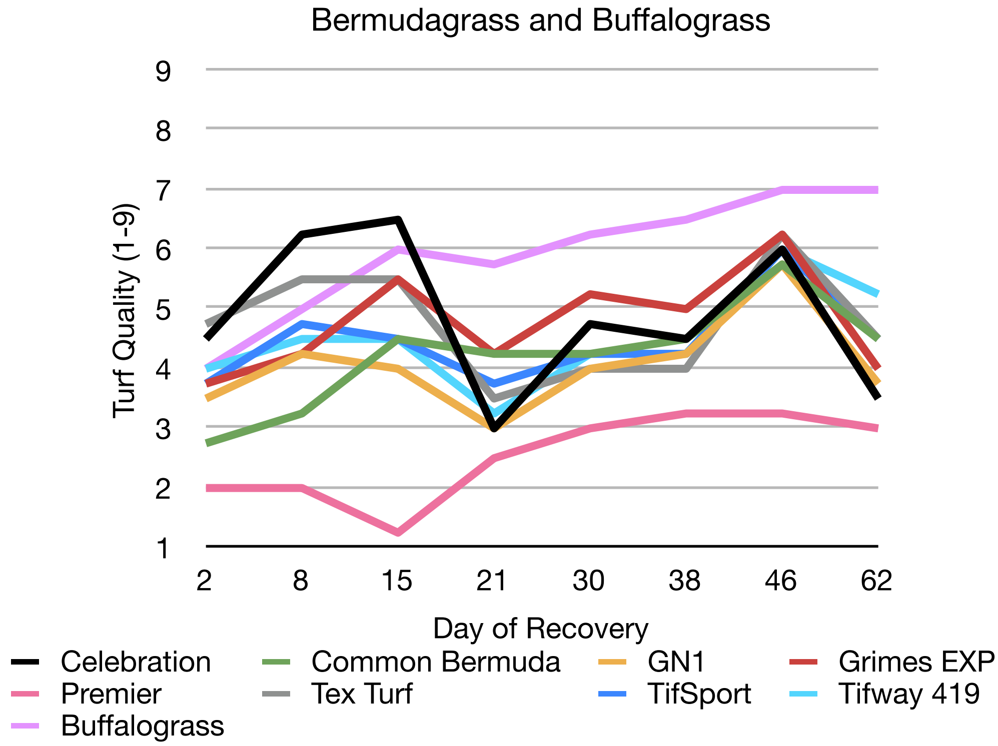


Figure 11b. Turfgrass Quality (2006) for St. Augustinegrass cultivars during the recovery periods. Data reference is Table 6.

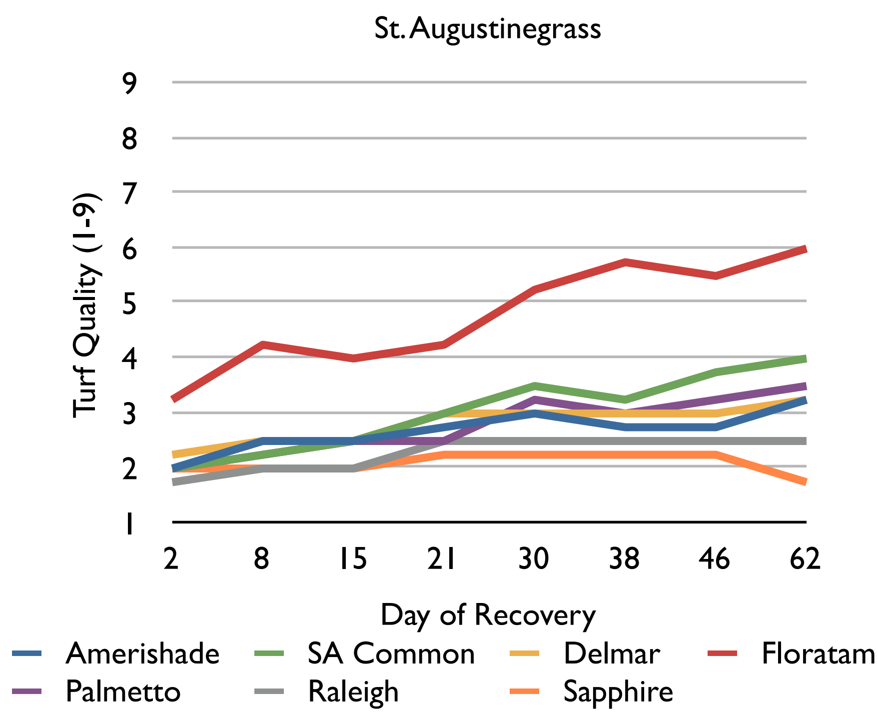
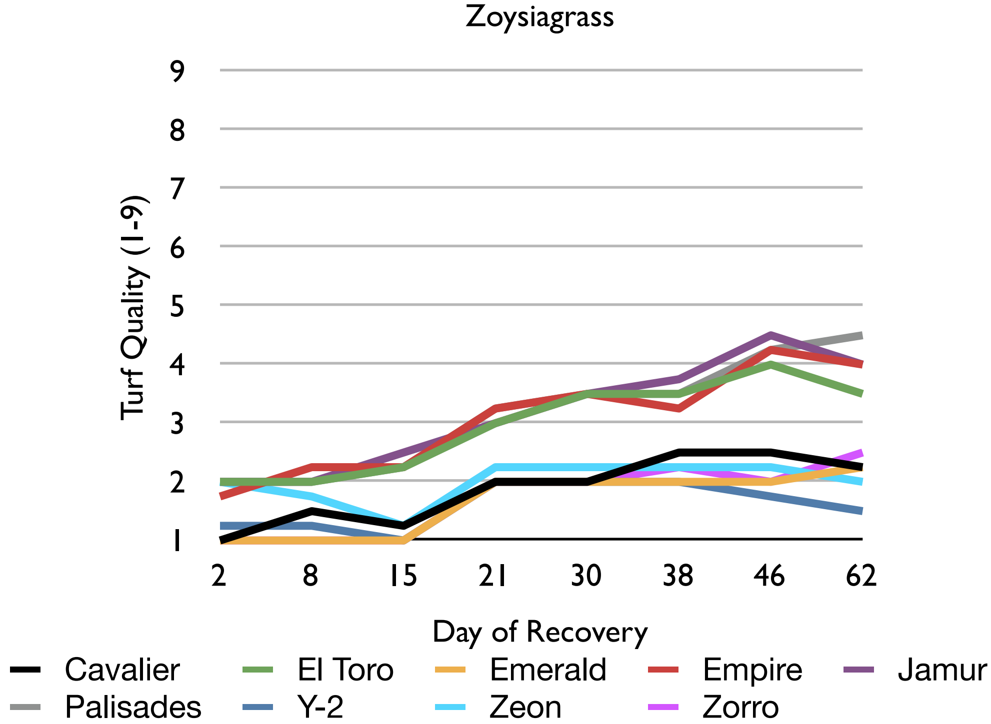


Figure 11c. Turfgrass Quality (2006) for zoysiagrass cultivars during the recovery period. Data reference is Table 6.



60-Day Drought Recovery (2006) - Percent Living Ground Cover and Uniformity

Table 7. Turfgrass percent living ground cover ratings on native soil depth during 2006 60-day recovery. Data in columns followed by the same letter are not significantly different at the 0.05 level. *Note:Table heading includes the date the data were taken followed below by the day into the recovery period.*

	9/22		9/28		10/5		10/11		10/20		10/28		11/5		11/21	
	Day of Drought															
	2		8		15		21		30		38		46		62	
Bermudagrass	% Living Green Ground Cover															
Celebration	71	a	91	a	95	a	28	bcde	74	ab	86	a	93	a	100	a
Common	16	bcde	38	bcdef	80	ab	50	b	60	ab	84	a	88	ab	99	ab
GN1	30	abcde	50	abcde	54	b	20	cdef	51	bc	79	a	88	ab	99	ab
Grimes EXP	41	abcde	53	abcd	78	ab	48	b	71	ab	90	a	94	a	100	a
Premier	1	de	3	f	4	d	6	ef	16	d	29	cde	38	def	58	bcdefgh
Tex Turf	69	a	86	a	90	a	34	bcd	55	ab	81	a	93	a	98	ab
TifSport	49	abc	61	ab	78	ab	29	bcde	66	ab	80	a	94	a	98	ab
Tifway 419	50	ab	56	abc	69	ab	34	bcd	66	ab	84	a	93	a	99	ab
St. Augustinegrass																
Amerishade	8	cde	14	def	14	cd	15	def	26	cd	21	cde	25	defg	43	efghij
SA Common	4	de	9	ef	10	d	16	def	23	d	21	cde	30	defg	55	cdefghi
Delmar	11	bcde	16	cdef	14	cd	15	def	21	d	21	cde	25	defg	38	efghij
Floratam	20	bcde	40	bcdef	46	bc	44	bc	69	ab	73	ab	78	abc	89	abcd
Palmetto	4	de	9	ef	10	d	14	def	18	d	19	cde	28	defg	51	defghi
Raleigh	2	de	5	f	6	d	8	ef	9	d	11	de	13	fg	25	ghij
Sapphire	3	de	5	f	6	d	6	ef	7	d	10	de	11	fg	18	hij
Zoysiagrass																
Cavalier	0	e	2	f	2	d	4	f	6	d	9	de	15	efg	28	fghij
El Toro	1	de	8	f	14	cd	15	def	21	d	35	cd	48	cde	63	abcdefg
Emerald	0	e	1	f	1	d	3	f	4	d	5	de	8	fg	25	ghij
Empire	2	de	9	ef	13	cd	18	def	26	cd	31	cde	49	cd	71	abcde
Jamur	2	de	8	f	10	d	16	def	21	d	43	bc	55	bcd	69	abcdef
Palisades	1	de	5	f	10	d	18	def	24	d	35	cd	49	cd	71	abcde
Y-2	1	de	2	f	2	d	3	f	2	d	4	e	2	g	4	j
Zeon	7	cde	1	f	1	d	3	f	6	d	6	de	6	fg	18	hij
Zorro	0	e	1	f	2	d	2	f	5	d	5	de	5	fg	15	ij
Buffalograss																
609	43	abcd	66	ab	80	ab	83	a	80	a	90	a	94	a	95	abc

Figure 12a. Living ground cover ratings for bermudagrass and buffalograss cultivars during the 60-day recovery period following the 60-day 2006 drought. Data reference is Table 7. Note: the downward "dip" in ground cover was due to lowering the mowing height, which scalped the bermudagrasses.

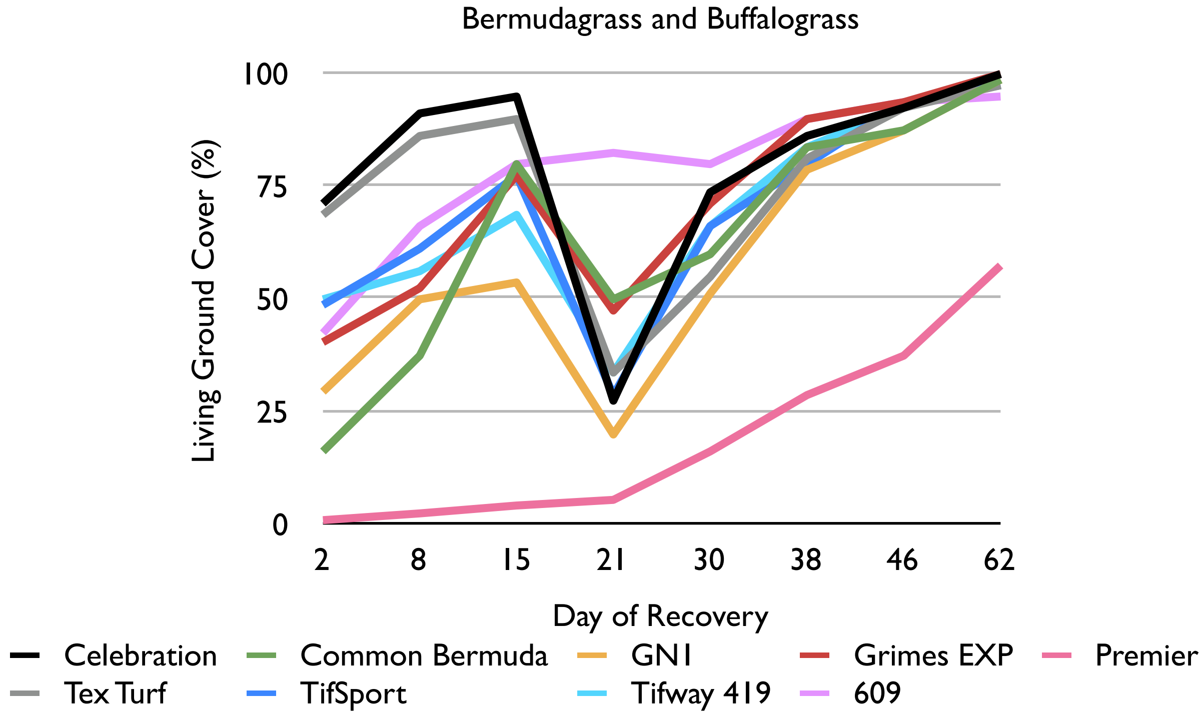


Figure 12b. Living ground cover ratings for St. Augustinegrass cultivars during the 2006 60-day recovery period following the 60-day drought. Data reference is Table 7.

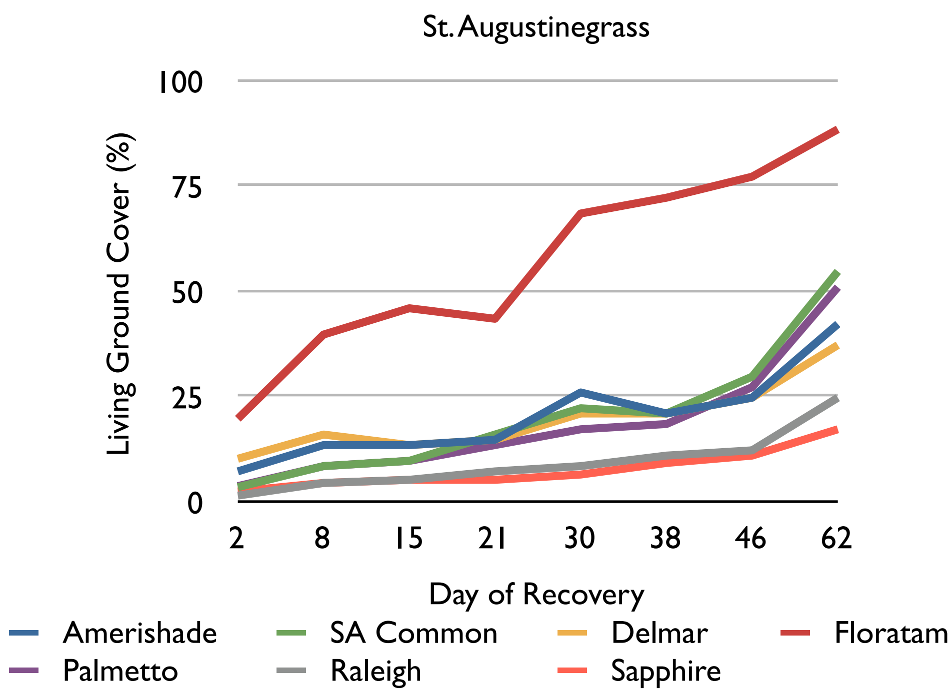
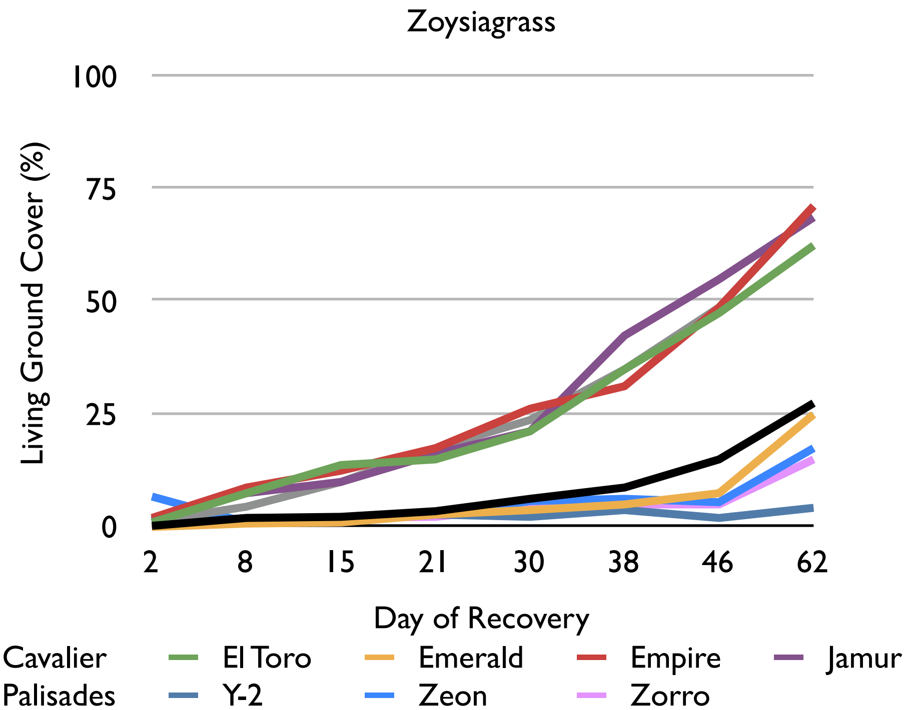


Figure 12c. Living ground cover ratings for zoysiagrass cultivars during the 2006 60-day recovery period following the 60-day drought. Data reference is Table 7.



Drought Recovery Following the 2006 60-Day Drought

One end product of the Year 1 experiment was that all grasses were unable to survive 2006 drought conditions when grown on the 4-inch soil depth. However, all grasses survived on the native, unrestricted soil depth. Yet, differences in survival on native soil did exist between grasses. Cultivar survival ranged from just over 4 percent for Y-2 zoysiagrass to 100 percent for two bermudagrass cultivars (Table 7 and Table 8). The percent recovery resulted in large statistical groupings of grasses. For example, the recovery of Y-2 zoyziagrass is not statistically different from the grasses in ascending order through Amerishade St. Augstinegrass at 42.5% living ground cover. Another example, in descending order, groups the grass cultivar having 95% recovery as similar to grass cultivars with equal to or greater than 55% recovery living ground cover.

At the end of the recovery period data was also taken on uniformity of plot recovery. How a grass recovers as far as density of active growth centers can greatly impact its ability to repopulate a turfed area. The data under the heading "Uniformity" in Table 7 represents how well each cultivar had recovered throughout the planted area. These data might provide insight into how grasses might recover; 1) if the grass exhibits a true physiological dormancy mechanism to shut down growth under prolonged moisture stress, 2) that it may be drought tolerant in the absence of a dormancy mechanism, or 3) that it might escape drought by finding channels in a shrink-swell soil to allow for deeper rooting. The grouping associated with the top uniformity ranking of 9 is similar in recovery uniformity in descending order to include grasses ranked 6 or higher. Throughout the study, the bermudagrass and buffalograss cultivars did well in resisting drought and recovering from the drought. Floratam St. Augustinegrass, when compared to other St. Augustinegrass cultivars, persisted well into the drought and was in the top grouping for drought recovery. This clearly demonstrates that grass cultivars within a species can indeed perform differently than others in the group. Recent examples of municipalities wanting to "ban" or "outlaw" all St. Augustinegrasses in efforts at water conservation would lose an important cultivar in the case of St. Augustinegrass. Shade tolerance, a characteristic of St. Augustinegrass, is desirable and cannot be overlooked in selecting grasses for shaded Texas landscapes.

Table 8. Percent living ground cover and recovery uniformity (scale of 1 to 9, with 9 equalling greatest recovery uniformity) at the end of the 60 day recovery period in 2006. Data in columns followed by the same letter are not significantly different at the 0.05 level.

	Nov 22, 2006	
Bermudagrass	% Living Ground Cover	Uniformity
Celebration	100 a	9.0 a
Common	99 ab	9.0 a
GN1	99 ab	9.0 a
Grimes EXP	100 a	9.0 a
Premier	58 bcdefgh	7.3 ab
Tex Turf	98 ab	9.0 a
TifSport	98 ab	9.0 a
Tifway 419	99 ab	9.0 a
St. Augustinegrass		
Amerishade	43 efghij	4.5 bc
SA Common	55 cdefghi	6.0 abc
Delmar	38 efghij	4.8 bc
Floratam	89 abdc	8.5 a
Palmetto	51 defghi	4.8 bc
Raleigh	25 ghij	4.5 bc
Sapphire	18 hij	3.0 c
Zoysiagrass		
Cavalier	28 fghij	6.8 ab
El Toro	63 abcdefg	8.5 a
Emerald	25 ghij	7.3 ab
Empire	71 abcde	8.5 a
Jamur	69 abcdef	8.3 a
Palisades	71 abcde	8.5 a
Y-2	4 j	3.0 c
Zeon	18 hij	6.8 ab
Zorro	15 ij	6.0 abc
Buffalograss		
609	95 abc	9.0 a

Another observation is related to the zoysiagrass cultivars. Even though they fired sooner than most bermudagrass cultivars and appeared to enter dormancy or a quiescent state, the coarser textured zoysiagrass cultivars (Empire, El Toro, Jamur and Palisades) recovered to greater living ground cover than did the finer textured zoyiasgrasses. The fine textured zoysiagrasses have a characteristically dense canopy. The 2.25 inch mowing height was significantly higher than normal for these grasses. That may have put them at a disadvantage for timely recovery since their canopies did not break down during drought or the recovery period. Their residual canopies were partially removed, by hand with rakes, 5 weeks into recovery. Therefore the dense canopy associated with these grasses may, to some extent, be self-limiting during recovery from dormancy.

Extended Recovery Period Through June 2007

Late season 60-day recovery, in 2006, favored grasses that declined least during the 60-day drought, namely most bermudagrasses and buffalograss. All zoysiagrasses had to recover from a completely browned off dormant/quiescence state. The 60-day data convinced the San Antonio Water System to include Floratam on their list of drought tolerant grasses for new home construction and reinforces that grass varieties can vary greatly in their ability to survive and recover from drought stress. When the grasses were evaluated for further recovery in spring of 2007, a good number of grasses exhibited very acceptable recovery ratings by June 19, 2007 (Table 9). This was especially true for the fine textured zoysiagrasses; namely Zorro, Zeon, Cavalier, Emerald and Y-2. Therefore, the arbitrary 60-day recovery period was inadequate due to cool night time air temperatures (often between 41°F and 59°F) in November 2006 (Figures 4 and 13), which likely inhibited recovery growth.

Prior to this study, municipalities in Central Texas were of the opinion that St. Augustinegrasses were not drought tolerant and should not be planted on newly constructed urban landscapes. Floratam St. Augustinegrass exhibited good post drought recovery (Table 7). It compared favorably with the species traditionally accepted as being more drought tolerant. The percent ground cover for each of the twenty-five grasses, at the end of the 60-day drought which was the beginning of the 60-day recovery period, is observed for September 22 in Figures 14a, 14b, and 14c. These graphs represent the drought recovery profiles after 60 days recovery, through June 19, 2007, grouped by species.

Table 9. Percent living ground cover at the end of the 60 day recovery period in 2006 and extended recovery data into spring 2007. Data in columns followed by the same letter are not significantly different at the 0.05 level.

	11/22/06		4/13/07		5/18/07		6/19/07	
Bermudagrass	% Living Green Ground Cover							
Celebration	100	a	93	ab	91	ab	100	a
Common	99	a	84	ab	80	ab	98	a
GN1	99	a	83	ab	75	abcd	98	a
Grimes EXP	100	a	99	a	99	a	100	a
Premier	58	bcde	73	abc	88	ab	100	a
TexTurf	98	a	100	a	99	a	100	a
TifSport	98	a	96	ab	90	ab	100	a
Tifway 419	99	a	99	a	93	ab	100	a
St. Augustinegrass								
Amerishade	43	defgh	24	fgh	36	cde	44	b
Common	55	cdef	66	bcde	81	ab	90	a
Delmar	38	defgh	34	fgh	54	abcde	63	ab
Floratam	89	abc	76	abc	94	ab	100	a
Palmetto	51	cdefg	39	defg	63	abcd	63	ab
Raleigh	25	efgh	35	fgh	50	bcde	73	ab
Sapphire	18	fgh	7	h	19	e	44	b
Zoysiagrass								
Cavalier	28	efgh	38	efgh	70	abcd	95	a
El Toro	63	abcde	49	cdef	79	abc	99	a
Emerald	25	efgh	15	gh	34	de	79	ab
Empire	71	abcd	50	cdef	86	ab	100	a
Jamur	69	abcd	69	abcd	83	ab	100	a
Palisades	71	abdc	70	abc	94	ab	98	a
Y-2	4	h	6	h	18	e	63	ab
Zeon	18	fgh	29	fgh	59	abcde	96	a
Zorro	15	gh	25	fgh	55	abcde	98	a
Buffalograss								
609	95	ab	100	a	100	a	100	a

Figure 13. 2006-07 seasonal temperatures during recovery from drought.

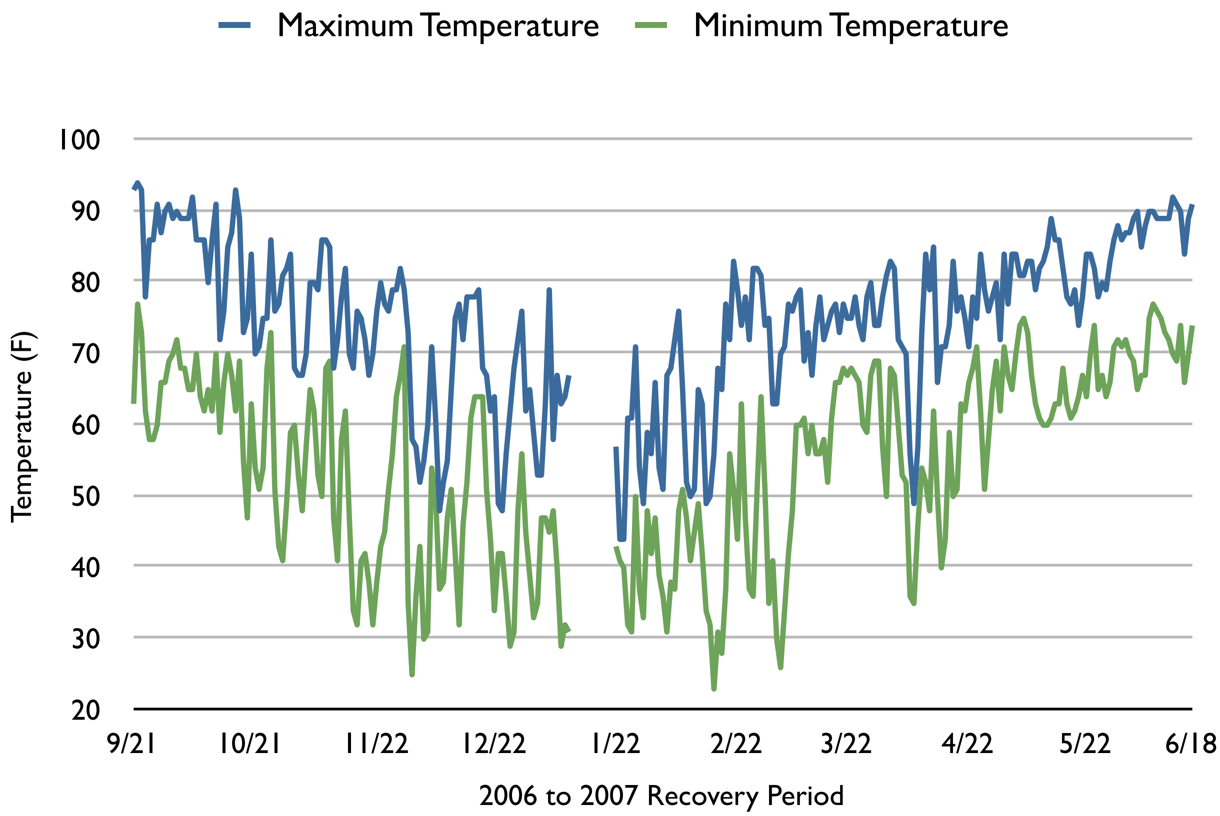


Figure 14a. Late season through next spring drought recovery profiles for bermudagrass and buffalograss following a 60-day drought that ended on September 20, 2006. Data reference is Table 9.

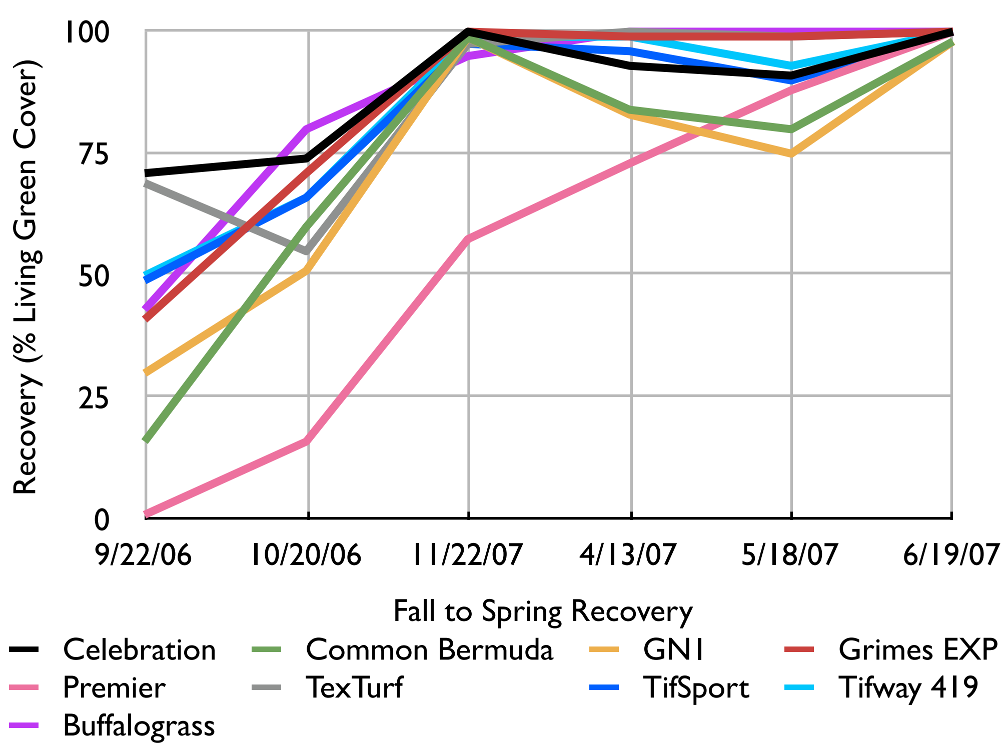


Figure 14b. Late season through next spring drought recovery profiles for St. Augustinegrasses following a 60-day drought that ended on September 20, 2006. Data reference is Table 9.

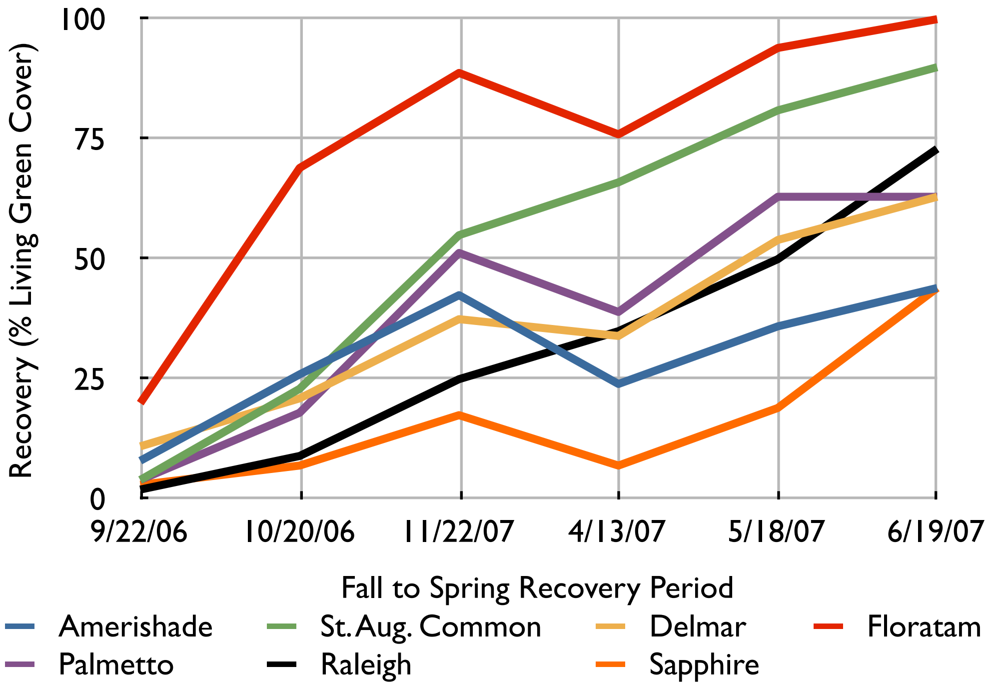
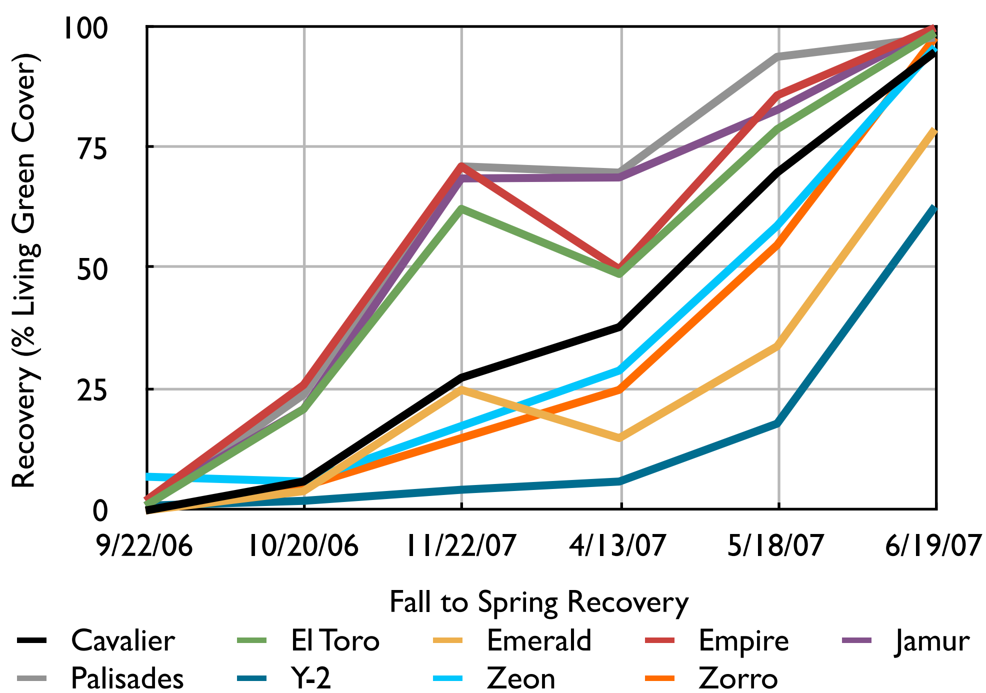


Figure 14c. Late season through next spring drought recovery profiles for zoysiagrasses following a 60-day drought that ended on September 20, 2006. Data reference is Table 9.



Summary for 2006-2007 Recovery Period

Evaluating grasses for recovery from drought stress must allow for a period of recovery that enables turfgrasses to reflect the true characteristics of not only the species but the individual varieties as well. To restrict decisions based upon an arbitrary 60-day recovery period, especially in light of poor growing conditions during the period, ignores data that truly reflect the characteristics of grass cultivars.

Summary for Year 1 (2006)

1. Shallow soils (4 inch) contribute to an inability of turfgrasses to survive extended drought.

2. Turfgrasses exhibited survival ability to extended drought on a deep soil with minimal root restrictions.

3. Recovery from drought is strongly influenced by post-drought environmental conditions, grass species and variety, and inherent plant dormancy mechanisms.

YEAR 2 (2007) Results: 60-Day Drought and Recovery from Drought

Photo caption: The Year 2 (2007) site planting on September 22, 2006, at the opposite end of the drought simulator.

Introduction

The Year 2 plot area was constructed on a separate site at the opposite end of the drought simulator and planted September 22, 2006. The same set of grasses were evaluated for 60-day drought survival in 2007 that had been evaluated in 2006. The drought simulator again covered the plot area during times of rainfall in 2007 to maintain a 60-day summer drought period. Grasses were evaluated during the drought period (July 5 through September 2, 2007) for the same characteristics measured in 2006. The 4-inch soil depth plots again fired quickly, as in 2006, while those on native soil depth again fired more gradually. There were differences on how grass cultivars fired in response to the drought but the extent of drought injury was less in 2007. Immediately following the 60-day drought period the grasses were allowed to recover with irrigation for 60 days (September 3 through November 1, 2007).

As in 2006, no grasses survived the 2007 drought on the 4-inch soil depth. For that reason the data presented for 2007 will address the response of only grasses planted on the unrestricted native soil. All grasses survived the 60-day drought period. The recovery, from drought ranged from from 69 to 99 percent living ground cover after 47 days recovery and 98 to 100 percent living ground cover after 78 days recovery.

Weather Conditions - 2007 Drought and Recovery

Drought period: Potential evapotranspiration (PET) totaled 9.44 inches during the drought period. If the PET was characterized every 20 days the PET for days 1-20, 21-40 and 41-55 (data collection error occurred on days 56-60) was 3.12, 3.6 and 2.72 inches, respectively. Average daily high temperatures for days 1-20, 21-40 and 41-55 were 86.9, 90 and 90 degrees F, respectively. PET for the drought period is seen in Figure 15 while Figure 16 displays maximum and minimum temperatures during the drought. Figure 17 is a graph of PET during the recovery period while Figure 18 is a graph of maximum and minimum temperatures during the 60-day recovery.

Figure 15. Daily PET during the 60-day summer drought in 2007. No data for day 55-60.

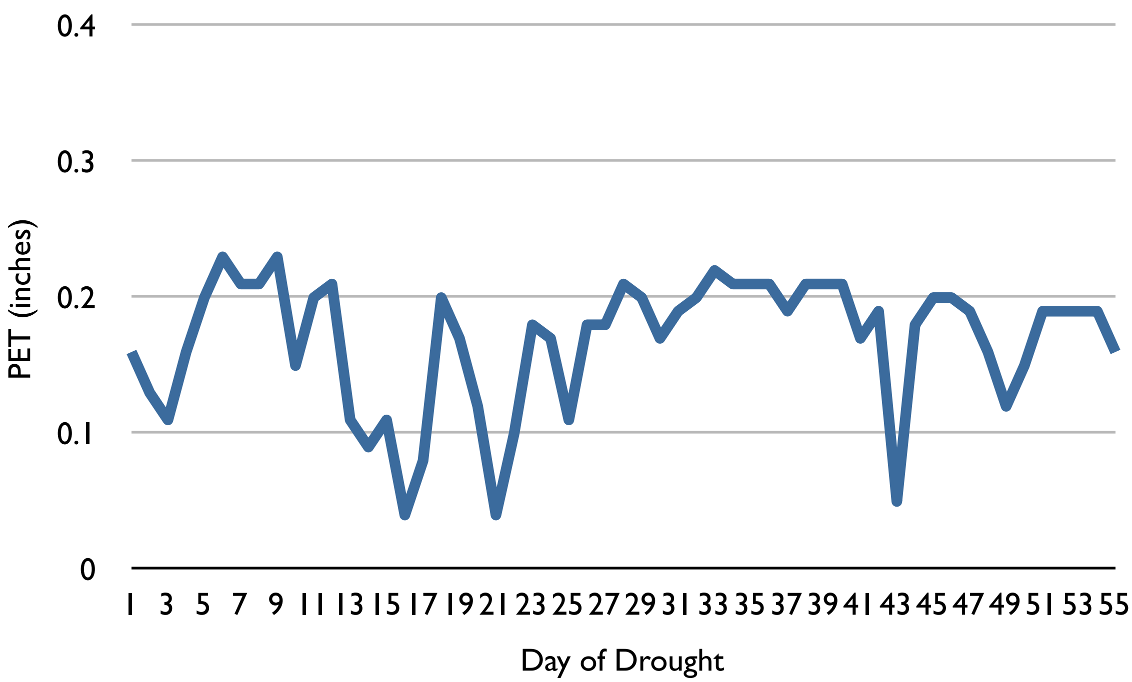


Figure 16. The 2007 daily maximum and minimum temperatures during summer drought.No data day 55-60.

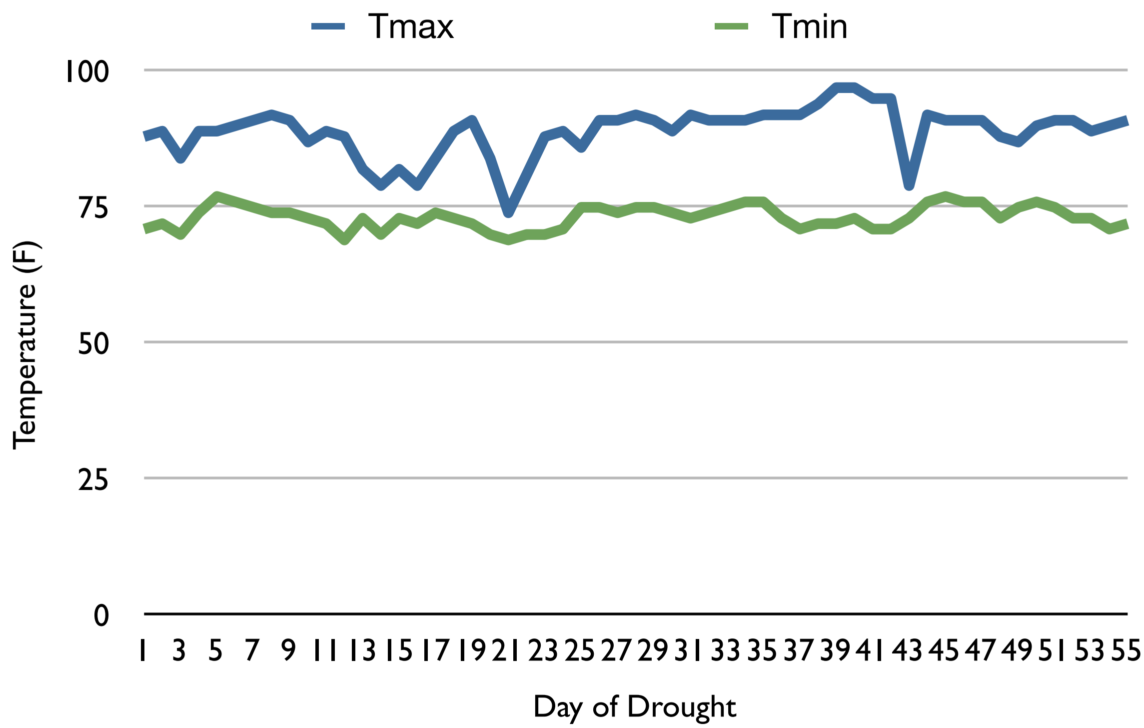


Figure 17. Daily potential evapotranspiration (PET) during the 2007 60-day drought recovery period.

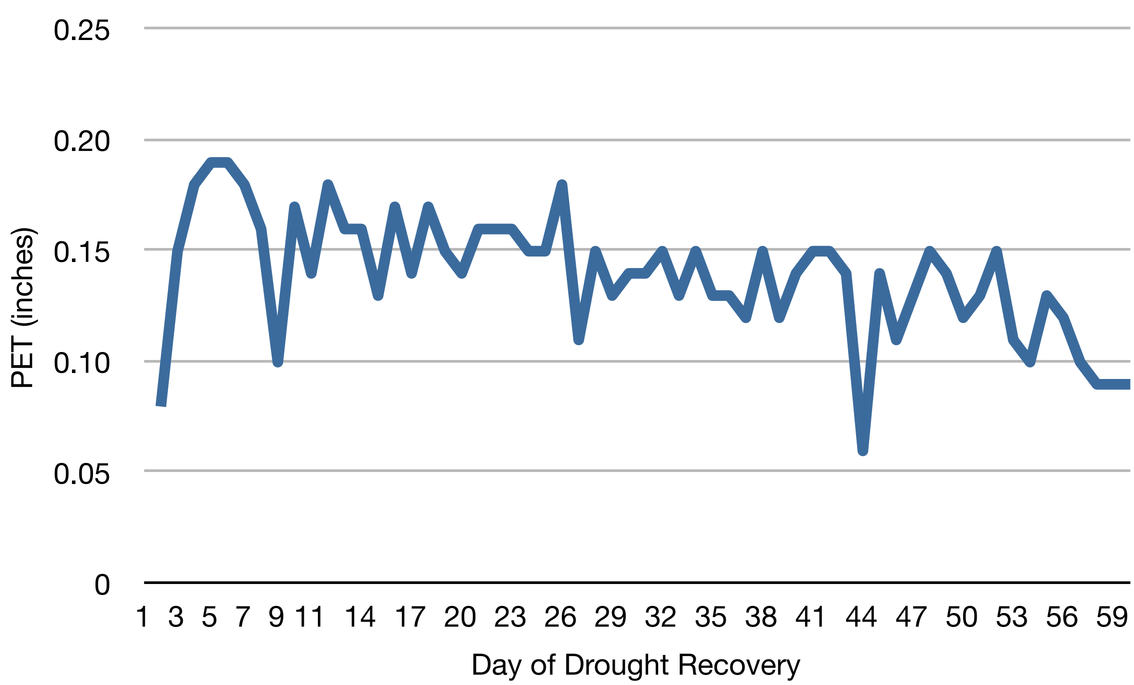
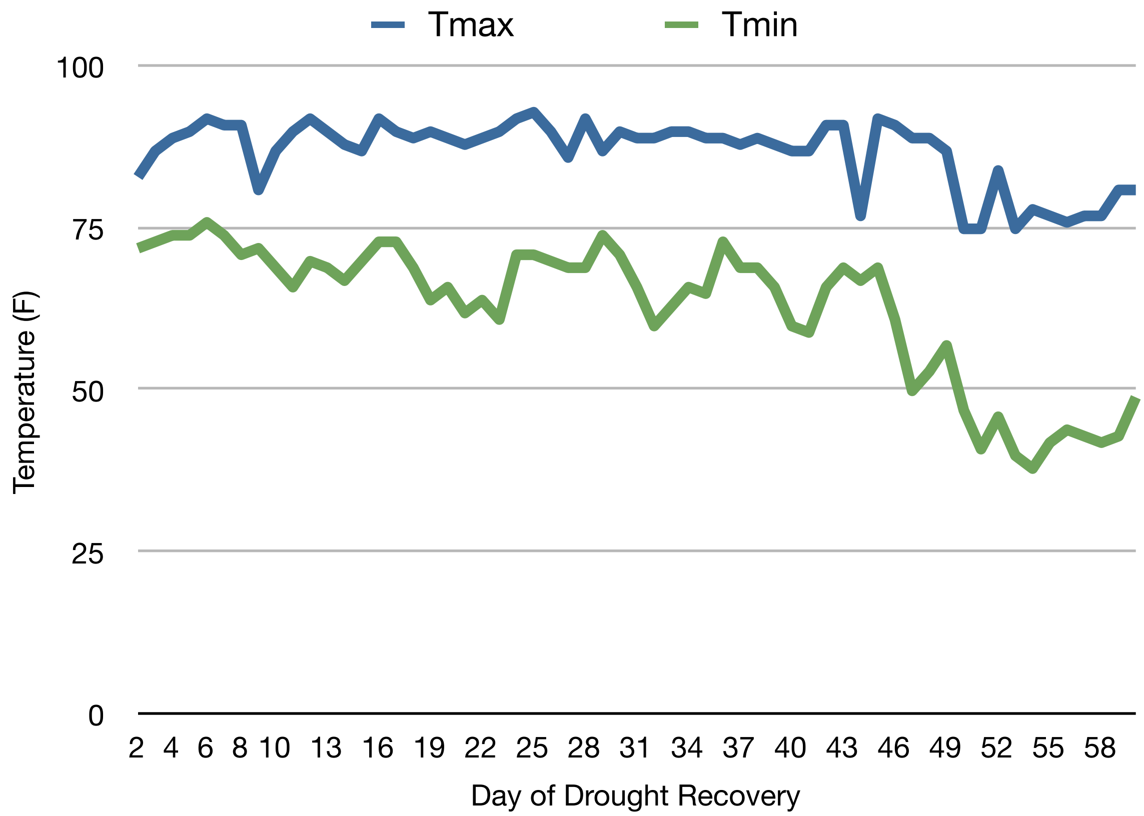


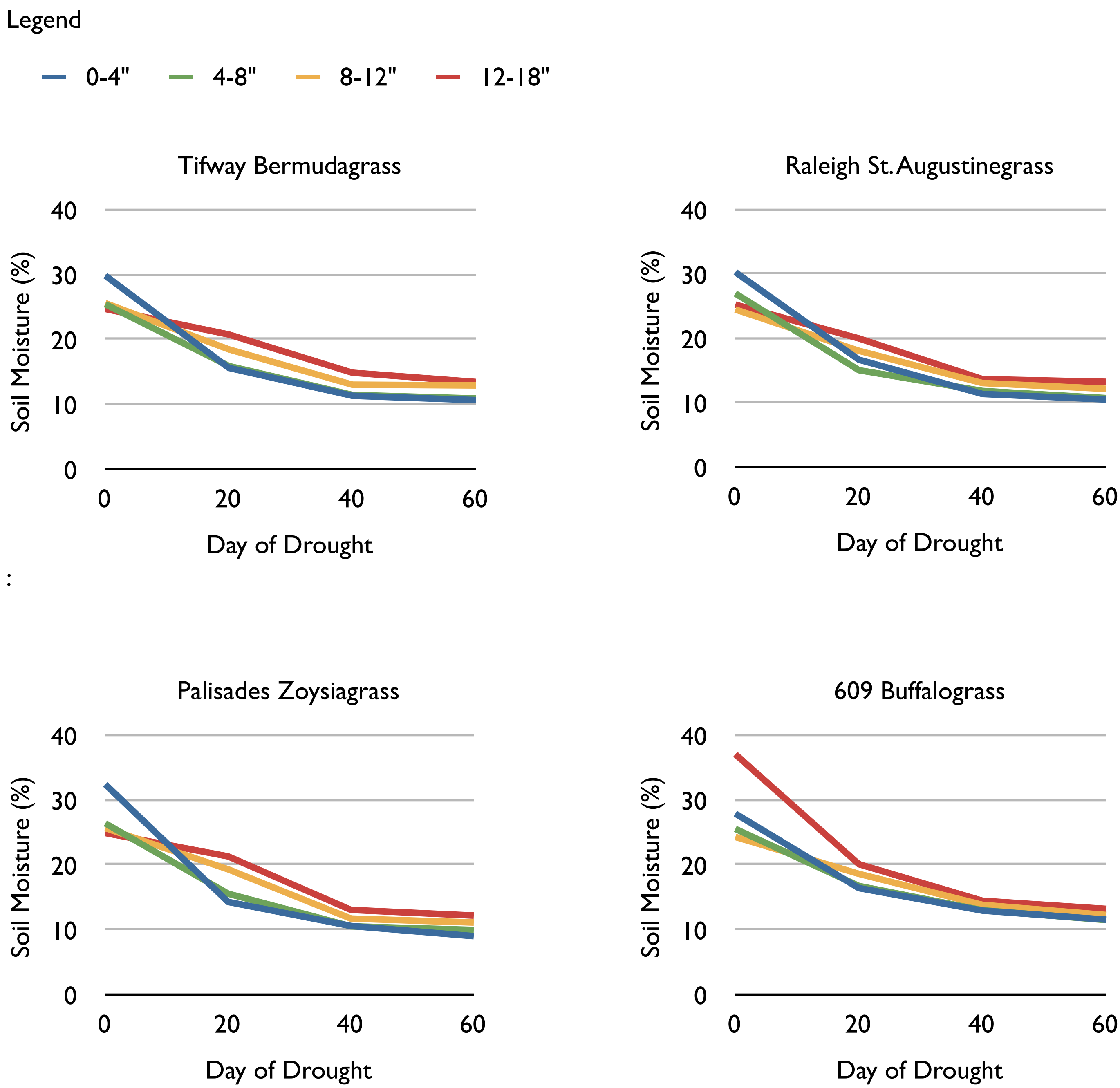
Figure 18. Maximum and minimum temperatures during the 2007 60-day drought recovery period.



Soil Moisture Content With Soil Depth During 2007 Drought

The following four charts (Figure 19) display the percent soil moisture on Raleigh St. Augustinegrass, Tifway bermudagrass, Palisades zoysiagrass and 609 buffalograss at four soil depths (0 to 4, 4 to 8, 8 to 12 and 12 to 18 inches). These samples were taken from the field plots after 0, 20, 40, and 60 days of drought. These data indicate soil moisture with depth during the duration of the drought.

Figure 19. Soil moisture profile with depth at 20 day intervals for a single variety from each of four grass species tested in 2007.



Results - Leaf Firing During the 2007 60-Day Drought

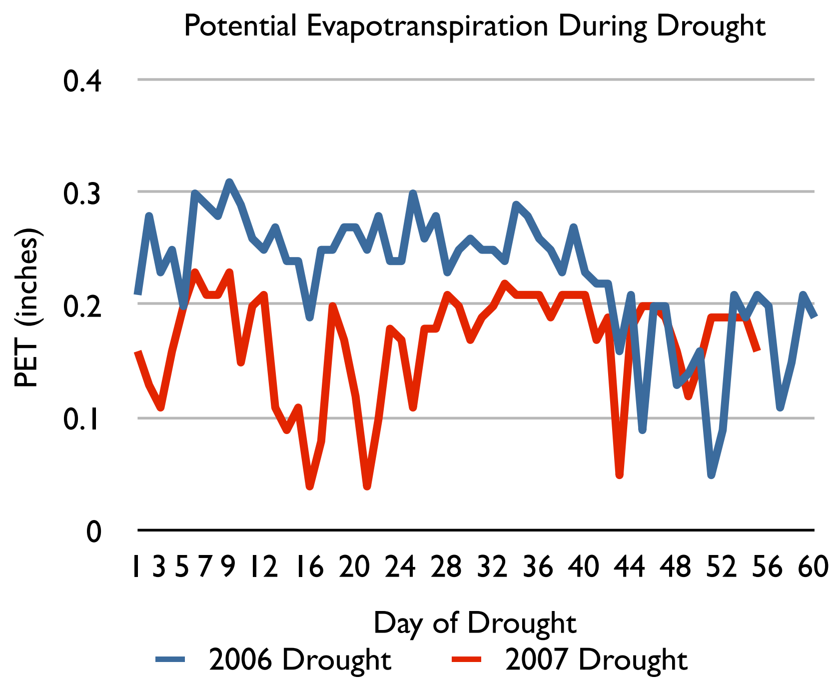
Grasses on the 4 inch soil depth browned off rapidly and completely in 6 to 12 days in 2006 and over a slightly longer period in 2007. Therefore, the leaf firing data are only presented from the native unrestricted soil, which exhibited more gradual turfgrass decline and significant differences between grasses. Data for leaf firing, as the droughts progressed in 2007, are compared in Table 10.

Table 10. Comparative leaf firing for 25 turfgrasses in response to 2007 60-day drought. Note: means in columns, in the above table, followed by the same letter are not significantly different (∝=.05). Ratings on a 1 to 9 scale where 9 = no leaf firing and 1 = completely browned-off turf.

	7/18	7/22	8/3	8/13	8/24	9/3
	Day of Drought					
Bermudagrass	14	19	30	40	51	60
Celebration	8.3 ab	9.0 a	9.0 a	9.0 a	9.0 a	8.0 a
Common	8.0 ab	9.0 a	9.0 a	9.0 a	8.8 a	7.3 abc
GN1	7.8 b	9.0 a	8.8 a	8.5 a	9.0 a	6.8 abcd
Grimes EXP	8.3 ab	9.0 a	9.0 a	8.8 a	8.8 a	7.3 abc
Premier	7.8 b	9.0 a	8.5 a	3.8 ef	2.8 def	2.0 e
Tex Turf	8.3 ab	9.0 a	9.0 a	8.5 a	8.8 a	7.0 abc
TifSport	8.0 ab	9.0 a	9.0 a	8.3 ab	9.0 a	7.5 ab
Tifway 419	8.0 ab	9.0 a	8.8 a	8.5 a	9.0 a	6.8 abcd
St. Augustinegrass						
Amerishade	8.3 ab	8.7 ab	8.3 a	7.0 abc	5.0 bcdef	4.0 de
SA Common	9.0 a	9.0 a	8.7 a	7.0 abc	5.7 abcde	4.0 de
Delmar	9.0 a	9.0 a	8.5 a	6.5 abcd	4.8 bcdef	3.8 e
Floratam	9.0 a	9.0 a	8.5 a	7.3 abc	7.5 abc	7.0 abc
Palmetto	9.0 a	9.0 a	8.8 a	6.5 abcd	4.5 cdef	4.0 de
Raleigh	9.0 a	9.0 a	7.7 abc	6.3 abcd	4.0 cdef	3.3 e
Sapphire	9.0 a	9.0 a	9.0 a	7.3 abc	6.0 abcd	4.7 bcde
Zoysiagrass						
Cavalier	8.0 ab	8.3 ab	5.8 bcd	3.5 ef	2.3 ef	2.0 e
El Toro	8.7 ab	8.3 ab	6.7 abcd	4.0 def	3.7 def	3.3 e
Emerald	8.3 ab	9.0 a	8.0 ab	6.3 abcd	4.0 cdef	3.7 e
Empire	8.8 ab	8.5 ab	6.8 abcd	4.8 cdef	4.5 cdef	4.0 de
Jamur	8.7 ab	8.7 ab	7.0 abcd	5.7 bcde	3.7 def	3.3 e
Palisades	9.0 a	9.0 a	7.8 abc	5.0 cdef	4.3 cdef	4.5 cde
Y-2	8.0 ab	8.0 ab	5.8 bcd	3.3 ef	2.0 e	2.3 e
Zeon	8.0 ab	8.3 ab	5.5 cd	3.3 ef	3.0 def	2.5 e
Zorro	8.0 ab	7.8 b	5.3 d	3.0 e	2.5 def	2.0 e
Buffalograss						
609	8.0 ab	8.5 ab	8.5 a	8.8 a	8.0 ab	6.8 abcd

Drought conditions were more severe in 2006 than in 2007 based upon comparative potential evapotranspiration (PET) between years (Figure 20). Leaf firing for all species was delayed and less severe in 2007 (Table 10).

Figure 20. PET differences during 2006 and 2007 summer 60-day droughts.



Complete leaf firing data are graphed by species (bermudagrass + buffalograss, St. Augustinegrass and zoysiagrass) for 2007 (Figures 21a, 21b, and 21c). The July to September 60-day drought in 2006 resulted in greater turfgrass leaf firing (Table 4 and figures 9a, 9b and 9c) than the 60-day drought in 2007 (Table 10 and Figures 21a, 21b, and 21c). In 2006, zoysiagrass and St. Augustinegrass varieties lost color and browned off sooner and to a much greater extent than most bermudagrass or buffalograss varieties . The leaf firing profile for Premier bermudagrass was more similar to that of zoysiagrass and St. Augustinegrass varieties than it was to other bermudagrasses in both 2006 and 2007. Most bermudagrass varieties and 609 buffalograss delayed leaf firing longer into the 2006 drought. Bermudagrass leaf firing in 2007 was less severe than 2006 and again delayed compared to most St Augustinegrass and zoysiagrass varieties.

Figure 21a. Bermudagrass and buffalograss leaf firing during drought in 2007. Data reference is Table 10.

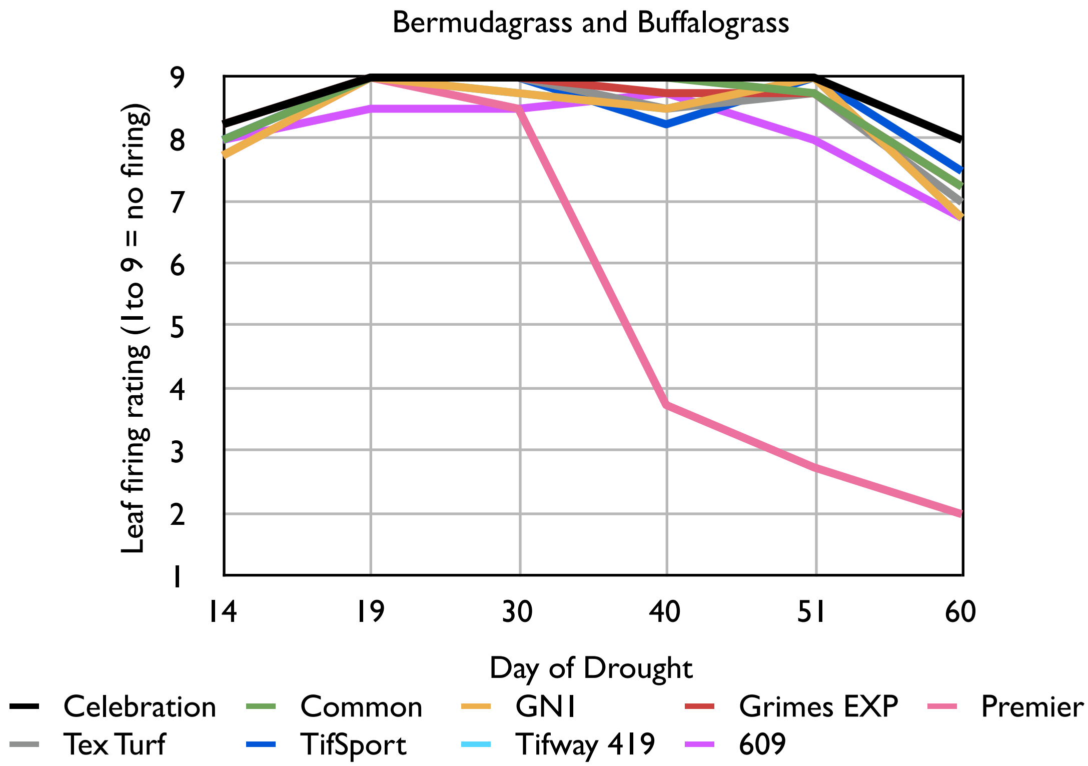


Figure 21b. St. Augustinegrass leaf firing during drought in 2007. Data reference is Table 10.

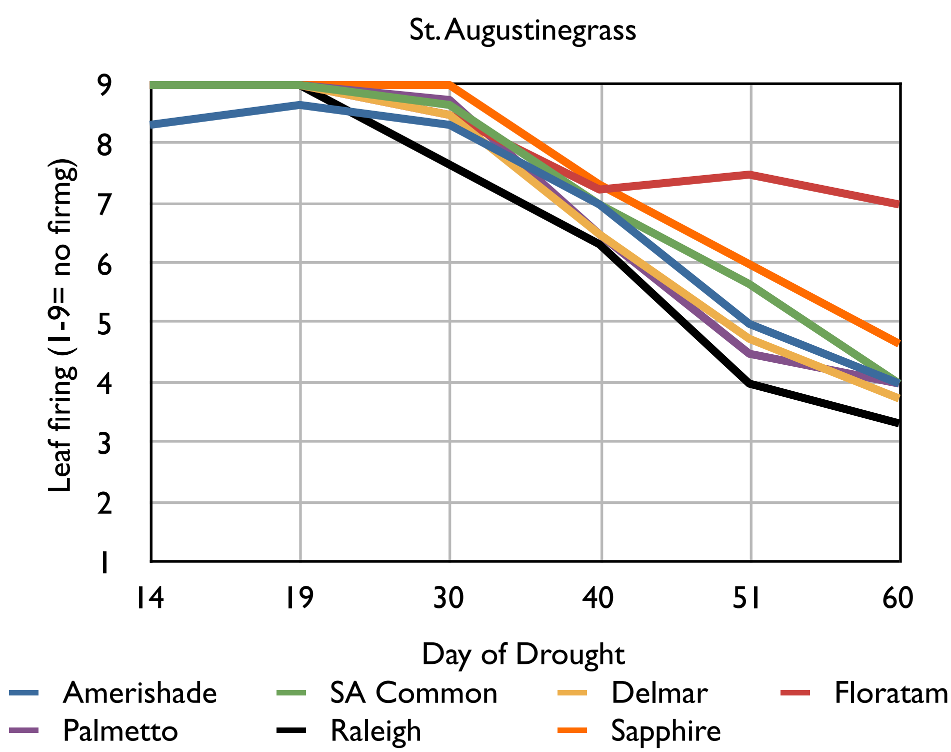
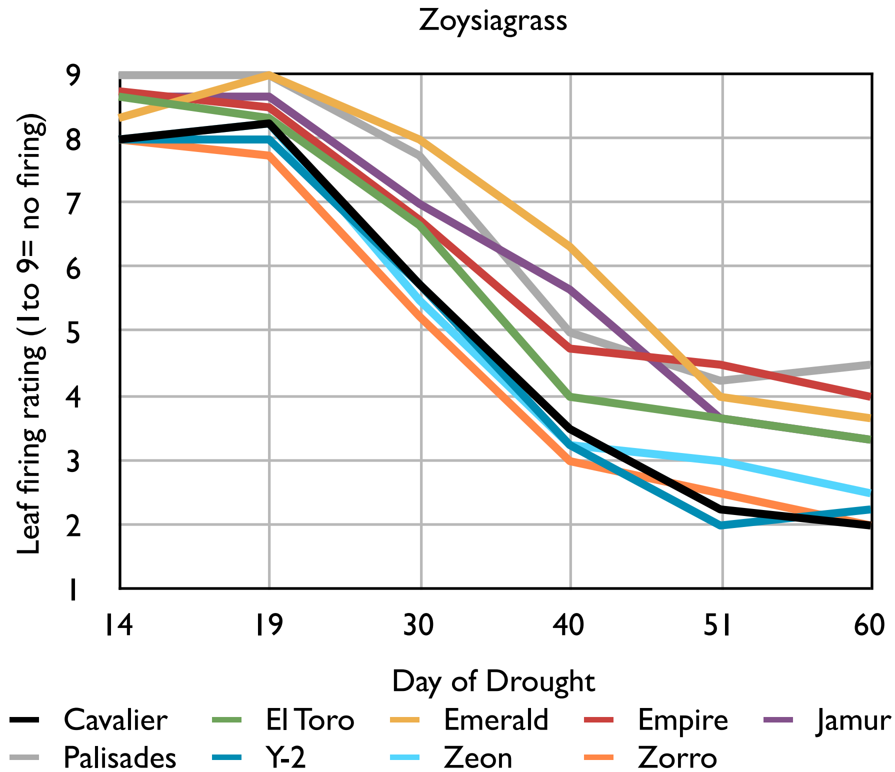


Figure 21c. Zoysiagrass leaf firing during drought in 2007. Data reference is Table 10.



Summary - Leaf Firing 2006 & 2007

The leaf firing profile for Premier bermudagrass followed a similar pattern in both 2006 and 2007 as it was more similar to that of zoysiagrass and St. Augustinegrass varieties than it was to other bermudagrasses. Firing response of Premier was significantly greater than other bermudagrasses in both years of testing. Floratam St. Augustinegrass seemed to resist firing more than other St. Augustinegrass varieties in both years although it was most significant in 2007. The similar "position" of Premier and Floratam respective to other grasses in their species provides some validation in the methods used to evaluate turfgrass response to drought. Most bermudagrass varieties and 609 buffalograss delayed leaf firing longer into the 2006 drought compared to St. Augustinegrass and zoysiagrass. Bermudagrass leaf firing in 2007 was less severe than 2006 and again delayed compared to most St Augustinegrass and zosiagrass varieties.

The differences in PET between 2006 and 2007 suggest drought stress and progression to a summer dormant/quiescent state or drought damage will vary by grass species/variety and climatic conditions during drought. Therefore, developing a field tested profile of turfgrass quality during prolonged drought stress, and any potential for recovery, should consider not only drought but also environmental variables and soil characteristics. The 4 inch soil depth constructed for this study was not capable of supporting turf through a 60-day drought while grasses on native soil depth survived but varied in extent of recovery. These comparative results also provide perspective as to grasses that might "trigger" irrigation to offset poor quality due to an early leaf firing tendency, especially on shallow soils.

Quality During Drought - 2007

Quality is based on 9 being best and 1 being poorest. A rating of 6 or above is generally considered acceptable. A quality rating value of 9 is reserved for a perfect or ideal grass, but it also can reflect an absolutely outstanding treatment. Quality ratings will vary based on turfgrass species, intensity of management and time of year. Quality ratings are relative within species but not among species. Quality ratings are not based on color alone, but on a combination of color, density, uniformity, texture, and disease or environmental stress.

Since this study is about grass drought survival and recovery, there should be great caution in the use of quality data for comparisons between grasses. This is especially important in when considering that all grasses were managed in a way to best gauge comparative drought persistence and recovery in one combined research study.

The quality data will first be presented, accompanied by statistical analysis, in Table 11. Individual varieties are presented graphically within species, with the exception where bermudagrass and buffalograss have been combined. The graphs follow the Table 11 as Figures 22a (bermudagrass and buffalograss), 22b (St. Augustinegrass), and Figure 22c (zoysiagrass).

Table 11. Turfgrass quality ratings during the 60-day drought in 2007. Note: data means in columns, in the table, followed by the same letter are not significantly different.

	7/5		7/12		7/18		7/23		8/3		8/13		8/24		9/3	
	Day of Drought															
	1		8		14		19		30		40		51		61	
Bermudagrass	---------- Turfgrass Quality (1 to 9 = Best) ----------															
Celebration	5.0	efg	5.5	bcdef	4.4	abcd	3.8	abcd	3.8	a	3.6	a	3.5	a	3.5	a
Common Bermuda	4.0	f	4.4	e	3.9	bcd	3.3	bcd	2.9	abcdef	2.5	bcd	2.5	bcdef	2.9	abcd
GN1	4.1	f	4.5	ef	3.6	d	3.1	cd	3.0	abcdef	2.8	abc	3.1	ab	2.8	abcd
Grimes EXP	4.9	fg	5.0	def	3.8	cd	3.3	bcd	3.0	abcdef	2.4	bcd	2.8	abcd	2.6	abcde
Premier	5.8	cdef	6.0	abcd	4.1	abcd	3.0	d	2.9	abcdef	2.0	cd	1.5	g	1.5	g
TexTurf	4.9	fg	5.3	cdef	4.5	abcd	3.5	abcd	3.1	abcdef	2.9	abc	3.0	abc	2.9	abcd
Tifsport	5.6	def	5.9	abcde	4.5	abcd	3.9	abcd	3.1	abcdef	2.9	abc	3.1	ab	3.1	abc
Tifway	5.8	cdef	5.8	abcdef	4.5	abcd	3.4	abcd	3.4	abcd	2.6	bcd	3.1	ab	2.8	abcd
St. Augustinegrass																
Amerishade	6.8	abcd	6.4	abcd	5.4	abc	4.3	abcd	3.6	ab	2.9	abc	2.6	abcde	2.8	abcd
SA Common	6.3	abcde	6.1	abcd	5.6	a	4.6	ab	3.5	abc	2.6	bcd	2.8	abcd	2.6	abcde
Delmar	6.4	abcd	6.1	abcd	5.5	ab	4.8	a	3.5	abc	2.4	bcd	2.4	bcdefg	2.3	cdefg
Floratam	6.1	abcdef	6.1	abcd	5.6	a	4.6	ab	3.6	ab	2.8	abc	3.0	abc	3.4	ab
Palmetto	6.1	abcdef	6.4	abcd	5.8	a	4.5	abc	3.5	abc	2.5	bcd	2.1	cdefg	2.1	defg
Raleigh	6.1	abcdef	6.1	abcd	5.8	a	4.8	a	3.3	abcde	2.3	cd	2.4	bcdefg	2.5	bcdef
Sapphire	5.8	cdef	6.1	abcd	5.6	a	4.4	abcd	3.8	a	2.5	bcd	2.8	abcd	2.8	abcd
Zoysiagrass																
Cavalier	7.4	a	6.5	abcd	5.1	abcd	4.3	abcd	2.8	bcdef	2.0	cd	1.6	fg	1.5	g
El Toro	6.6	abcd	6.3	abcd	4.9	abcd	3.6	abcd	2.4	ef	2.1	cd	1.7	efg	2.0	defg
Emerald	7.4	a	7.1	a	4.6	abcd	4.4	abc	3.0	abcdef	2.4	bcd	2.1	cdefg	1.7	efg
Empire	6.5	abcd	6.4	abcd	5.4	abc	4.0	abcd	2.5	def	2.3	cd	2.0	defg	2.1	defg
Jamur	5.7	cdef	5.6	bcdef	5.0	abcd	4.1	abcd	2.3	f	2.3	bcd	1.9	defg	2.0	defg
Palisades	7.1	ab	6.3	abcd	5.6	a	4.5	abc	3.1	abcdef	2.6	bcd	2.1	cdefg	2.3	cdefg
Y-2	7.1	ab	6.5	abcd	5.4	abc	4.3	abcd	2.4	ef	2.0	cd	1.6	fg	1.6	fg
Zeon	7.1	ab	7.0	ab	5.0	abcd	4.0	abcd	2.6	cdef	2.1	cd	1.6	fg	1.8	efg
Zorro	7.0	abc	6.7	abc	5.3	abcd	4.0	abcd	2.6	def	1.7	d	1.6	fg	1.3	g
Buffalograss																
609	5.9	bcdef	5.0	def	4.8	abcd	3.9	abcd	3.5	abc	3.3	ab	3.1	ab	3.5	a

Figure 22a. Bermudagrass and Buffalograss quality during 2007 drought. Data reference is Table 11.

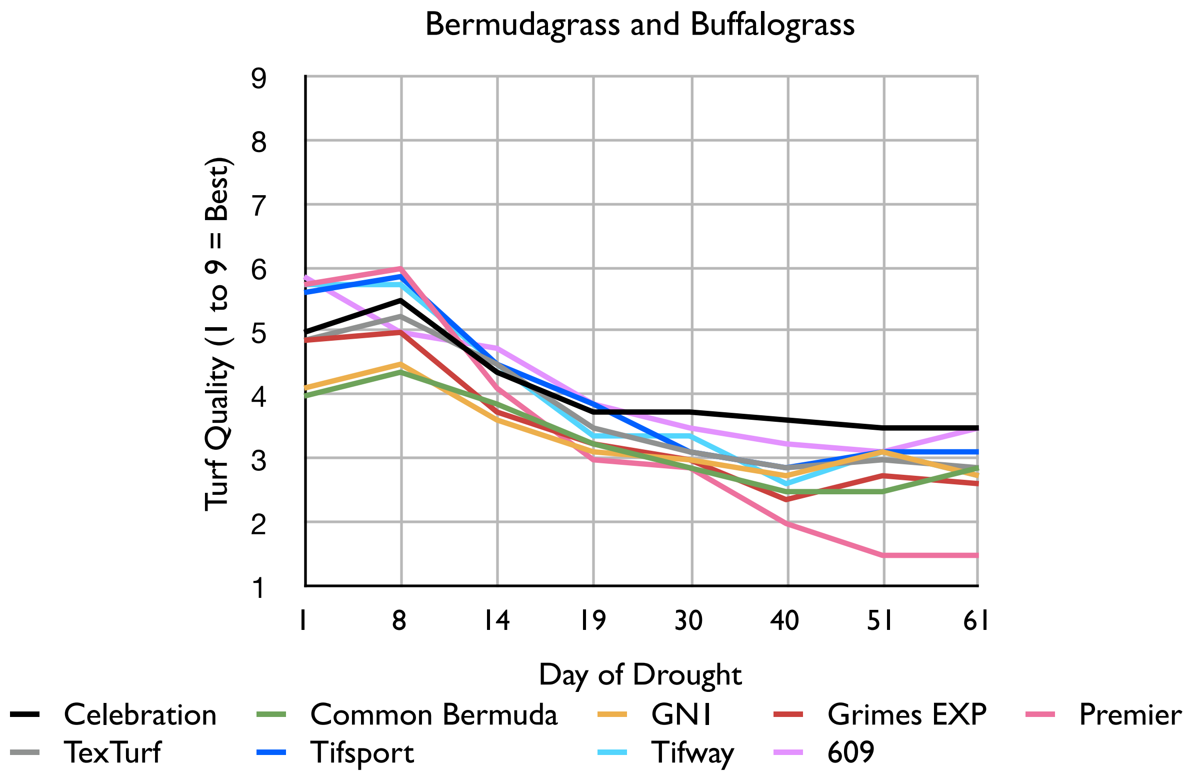


Figure 21b. St. Augustinegrass quality during 2007 drought. Data reference is Table 11.

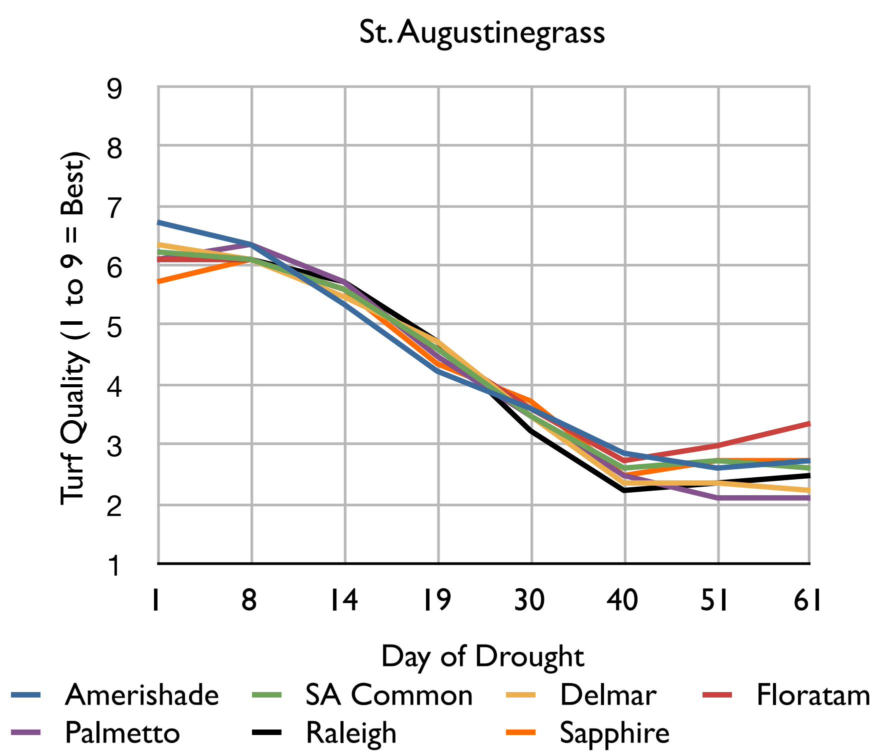
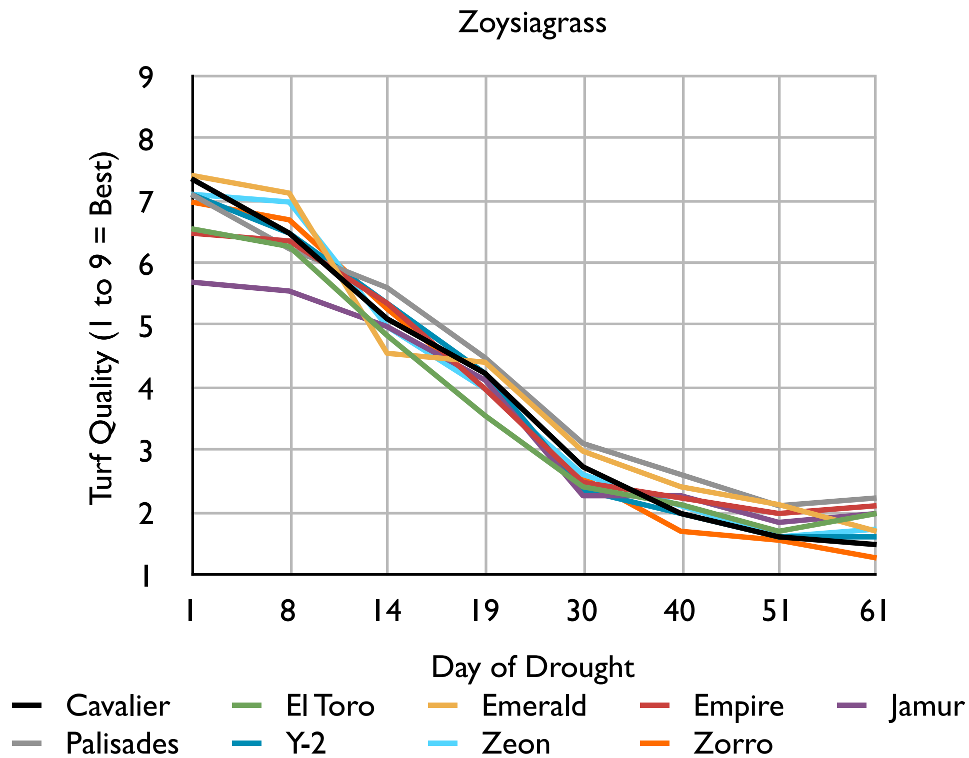


Figure 21c. Zoysiagrass quality during 2007 drought. Data reference is Table 11.



Turfgrass Recovery from 60 Day Drought - 2007

Recovery, as percent living green ground cover, is presented in Table 12 accompanied by statistical analysis and mean comparison groupings. Individual varieties are presented graphically within species, with the exception that bermudagrass and buffalograss have been combined (Figures 23a, 23b, and 23c). The severity of drought injury, as indicated by leaf firing data demonstrates the absence of turf injury from the 2007 drought. The climatic conditions observed during the 2007 60-day drought resulted in less total stress, which accounts for delayed and less leaf firing than in 2006. Lower temperatures and higher humidity resulted in less evapotranspiration during the 60-day drought. Less injury during the 60-day drought period resulted in much quicker recovery during the 60-day recovery period. All grasses recovered quickly from the 2007 drought. Drought conditions were more severe in 2006 than in 2007 based upon comparative potential evapotranspiration (PET) data. Results suggest drought induced summer dormancy, quiescence and/or injury are impacted by grass species/variety and climatic conditions during drought. Therefore, developing a field-tested profile of turfgrass drought performance should consider not only drought but also environmental variables and soil characteristics.

Table 12. Recovery of 25 turfgrass varieties following the 2007 60-day drought as indicated by recovery growth assessed as percent living green ground cover. *Note: means in columns, in the table below, followed by the same letter are not significantly different (∝=0.05).*

	9/14		9/21		9/25		10/4		10/12		10/19		11/19	
	Day of Recovery													
	12		19		23		32		40		47		78	
Bermudagrass	--------------- % Living Green Ground Cover ----------------													
Celebration	29	a	88	a	94	ab	98	a	99	a	99	a	100	a
Common Bermuda	19	a	88	a	86	abc	89	abc	93	a	69	a	99	a
GN1	15	a	73	abc	86	abc	91	ab	91	a	94	a	99	a
Grimes EXP	28	a	86	a	91	ab	90	abc	91	a	90	a	100	a
Premier	10	a	40	abcde	50	abcde	75	abcdef	91	a	96	a	100	a
TexTurf	5	a	74	ab	80	abcd	91	ab	94	a	95	a	100	a
Tifsport	18	a	80	a	91	ab	89	abc	98	a	99	a	100	a
Tifway	28	a	84	a	95	a	93	ab	96	a	98	a	100	a
St. Augustinegrass														
Amerishade	45	a	63	abcd	69	abcde	90	abc	79	ab	75	a	99	a
SA Common	40	a	74	ab	65	abcde	93	ab	84	ab	89	a	100	a
Delmar	40	a	60	abcde	63	abcde	85	abcd	79	ab	81	a	100	a
Floratam	31	a	46	abcde	45	bcde	80	abcde	88	a	85	a	100	a
Palmetto	29	a	65	abcd	74	abcde	92	ab	91	a	90	a	100	a
Raleigh	39	a	53	abcde	55	abcde	80	abcde	85	ab	90	a	100	a
Sapphire	50	a	65	abcd	70	abcde	85	abcd	57	b	76	a	100	a
Zoysiagrass														
Cavalier	4	a	13	e	30	e	50	ef	76	ab	85	a	100	a
El Toro	12	a	32	bcde	47	abcde	60	cdef	83	ab	90	a	100	a
Emerald	35	a	50	abcde	62	abcde	73	abcdef	90	a	93	a	100	a
Empire	11	a	31	bcde	50	abcde	68	abcdef	81	ab	90	a	100	a
Jamur	15	a	45	abcde	57	abcde	70	abcdef	83	ab	92	a	100	a
Palisades	25	a	55	abcde	58	abcde	73	abcdef	88	a	94	a	100	a
Y-2	23	a	31	bcde	38	dcde	48	f	76	ab	86	a	100	a
Zeon	17	a	24	de	30	e	58	def	80	ab	86	a	100	a
Zorro	15	a	25	cde	33	de	65	bcdef	80	ab	93	a	100	a
Buffalograss														
609	33	a	55	abcde	63	abcde	73	abcdef	81	ab	85	a	98	a

It should be noted that early recovery ratings may have been influenced by the severe defoliation of the plots immediately following the 60-day drought. At that time all plots were mowed to a height of 1.25 inches to reduce the impact that existing canopy densities might have on recovery. This practice probably impacted St. Augustinegrass varieties the least, while removing a good bit of the green canopy of the bermudagrasses and the browned off canopy of the zoysiagrasses. Our observations indicate that it had only a temporary impact and did not negatively affect recovery. Grass health at the end of the 60-day drought is best represented by leaf firing data in Table 10 and Figures 21a,21b, and 21c. It is also observed as turfgrass quality data in Table 11. That being said, the recovery data in Table 12 demonstrates how rapidly the grasses recovered in 2007.

Again, the data in Table 12 is graphically presented in Figures 23a, 23b, and 23c to demonstrate the speed and extent of recovery from the 2007 drought.

Figure 23a. Living ground cover ratings for bermudagrass and buffalograss cultivars during the 2007 60-day recovery period following the 60-day drought. Data reference is Table 12.

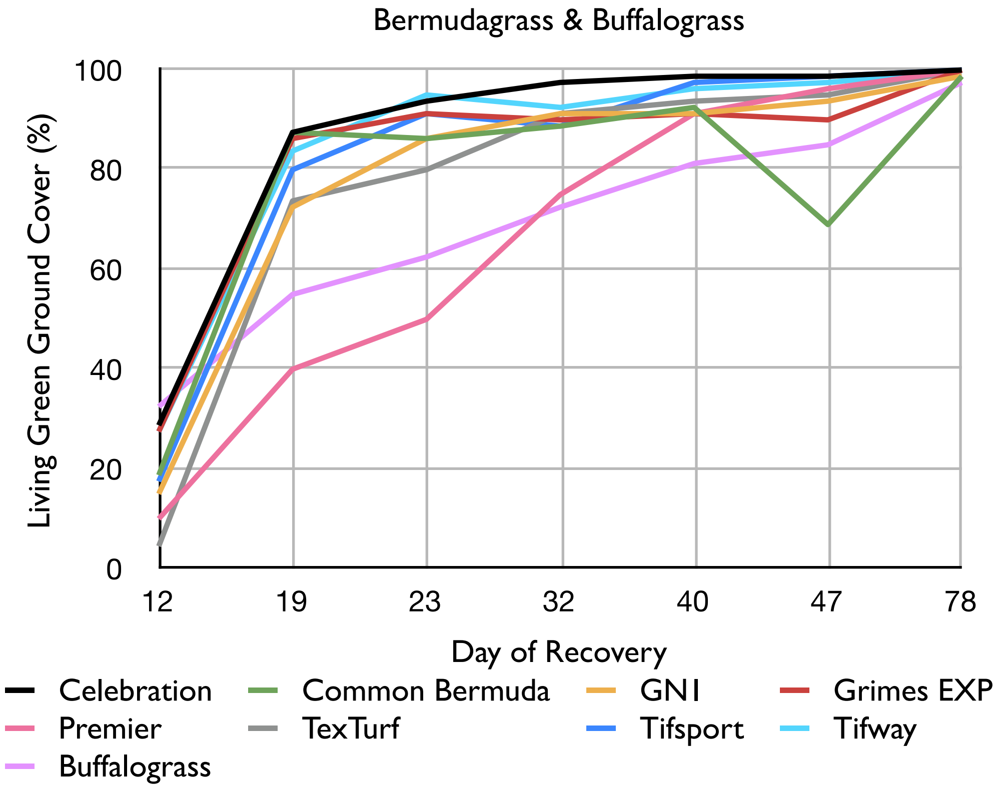


Figure 23b. Living ground cover ratings for St. Augustiegrass cultivars during the 2007 60-day recovery period following the 60-day drought. Data reference is Table 12.

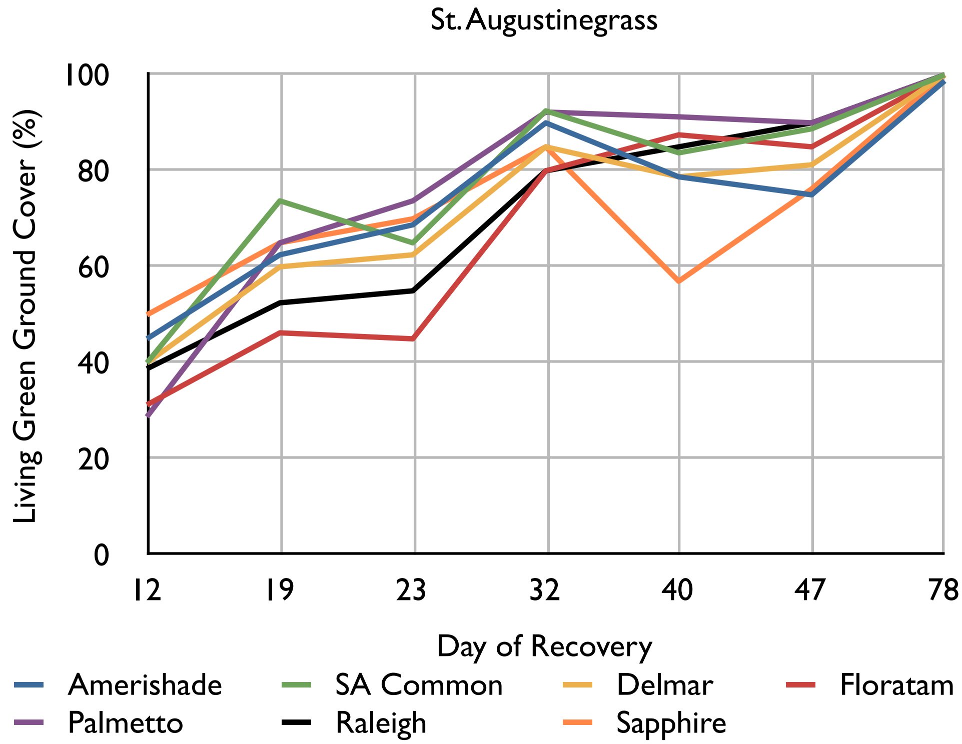
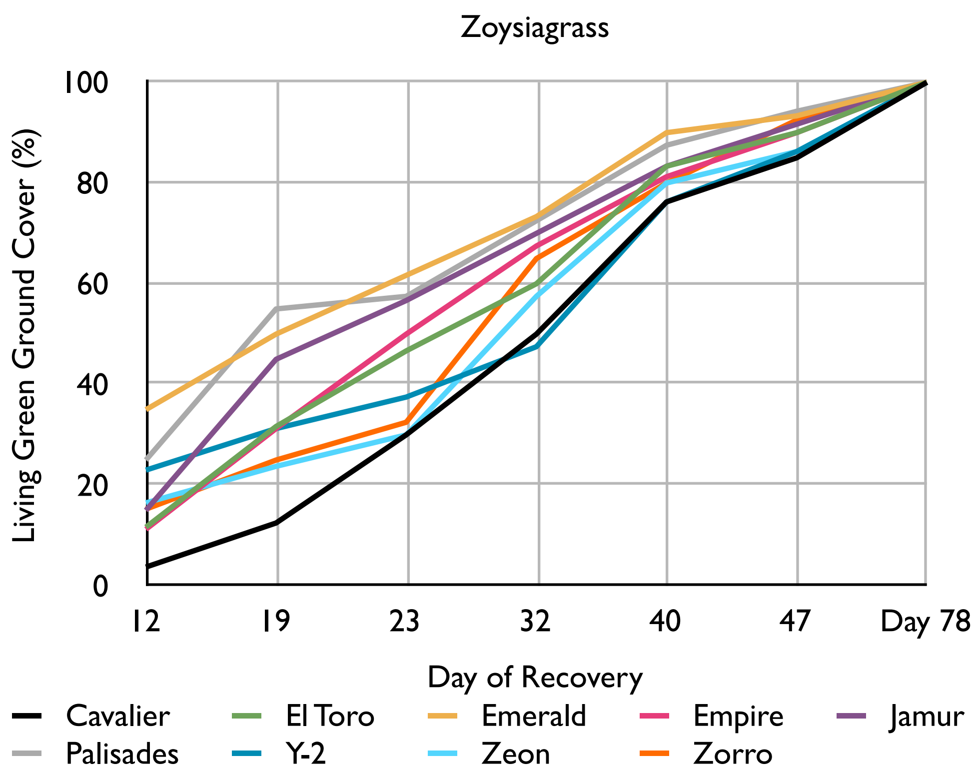


Figure 23c. Living ground cover ratings for zoysiagrass cultivars during the 2007 60-day recovery period following the 60-day drought. Data reference is Table 12.



Drought Recovery Uniformity - 2007

During the recovery period the data collection also focused upon uniformity of plot recovery. How a grass recovers as far as density of active growth centers can greatly impact its ability to repopulate a turfed area. This combined with other items that might impact re-growth (extent of leaf firing, extent of additional injury to drought, and inherent growth rate from rhizomes and/or stolons). Uniformity did not vary as greatly between grasses in 2007 compared to 2006. In addition, as grasses recovered it was evident that each did so with a high degree of uniform recovery (Table 13).

Table 13. 2007 drought recovery uniformity of 25 turfgrass varieties. *Note: means in columns, in the table below, followed by the same letter are not significantly (n.s.) different (∝=0.05).*

	9/14		9/21		9/25		10/4	
	Day of Recovery							
	12		19		23		32	
Bermudagrass	Post-Drought Recovery Uniformity (1 to 9 = Best)							
Celebration	7.8	n.s.	9.0	a	9.0	n.s.	9.0	a
Common Bermuda	7.0		9.0	a	9.0		9.0	a
GN1	6.3		9.0	a	9.0		9.0	a
Grimes EXP	8.3		9.0	a	9.0		9.0	a
Premier	5.0		7.8	ab	9.0		9.0	a
TexTurf	5.3		9.0	a	8.8		9.0	a
Tifsport	6.8		9.0	a	9.0		9.0	a
Tifway	7.0		9.0	a	9.0		9.0	a
St. Augustinegrass								
Amerishade	6.8		8.8	a	9.0		9.0	a
SA Common	8.3		9.0	a	9.0		9.0	a
Delmar	7.8		8.8	a	9.0		9.0	a
Floratam	8.3		9.0	a	8.8		9.0	a
Palmetto	7.0		9.0	a	9.0		9.0	a
Raleigh	8.0		8.8	a	9.0		9.0	a
Sapphire	8.5		9.0	a	9.0		9.0	a
Zoysiagrass								
Cavalier	4.0		7.3	b	8.5		9.0	a
El Toro	6.7		8.0	ab	8.7		9.0	a
Emerald	8.3		8.7	ab	8.7		9.0	a
Empire	5.8		8.3	ab	9.0		9.0	a
Jamur	7.0		8.3	ab	9.0		8.7	b
Palisades	7.8		9.0	a	9.0		9.0	a
Y-2	6.5		7.8	ab	8.8		9.0	a
Zeon	5.5		7.8	ab	9.0		9.0	a
Zorro	6.8		8.0	ab	9.0		9.0	a
Buffalograss								
609	8.5		9.0	a	9.0		9.0	a

Table 14. Turfgrass quality ratings during the post-drought recovery period in 2007. *Note: means in columns followed by the same letter are not significantly different (∝=0.05).*

	9/14		9/21		10/4		10/12		10/19		11/19	
	Day of Recovery											
	12		19		32		40		47		78	
Bermudagrass	--------------- Turf Quality Rating (1 to 9 = best) -----------------											
Celebration	3.3	abc	6.5	a	7.3	a	7.5	a	8.0	a	5.0	abcd
Com. Bermuda	3.3	abc	6.5	a	5.8	abcd	6.3	abc	6.0	bcde	3.3	d
GN1	3.0	abc	5.5	ab	6.0	abcd	7.0	bc	6.5	abcd	3.5	cd
Grimes EXP	3.8	abc	5.8	ab	6.5	abc	6.8	abc	5.8	cde	3.8	bcd
Premier	2.5	bc	4.0	ab	5.5	abcde	7.0	bc	6.8	abcd	4.0	abcd
TexTurf	2.3	c	5.5	ab	6.8	ab	7.3	bc	7.8	ab	5.0	abcd
Tifsport	2.5	bc	5.8	ab	7.3	a	7.3	bc	7.8	ab	5.5	abcd
Tifway	3.5	abc	6.0	ab	7.3	a	7.3	bc	7.5	abc	6.3	a
St. Augustinegrass												
Amerishade	4.3	abc	5.5	ab	5.5	abcde	5.5	bc	4.5	e	4.5	abcd
SA Common	4.5	abc	6.0	ab	5.5	abcde	5.8	abc	5.8	cde	4.8	abcd
Delmar	4.8	ab	5.8	ab	5.5	abcde	6.0	abc	5.3	de	5.3	abcd
Floratam	3.8	abc	4.8	ab	5.3	bcde	6.0	abc	5.5	de	5.5	abcd
Palmetto	4.0	abc	6.3	ab	6.0	abcd	6.3	abc	6.3	abcde	5.8	abc
Raleigh	4.8	ab	5.5	ab	5.5	abcde	6.5	abc	6.0	bcde	4.8	abcd
Sapphire	5.0	a	6.3	ab	5.5	abcde	5.0	c	4.5	e	4.5	abcd
Zoysiagrass												
Cavalier	2.3	c	3.5	b	3.8	e	6.3	abc	6.0	bcde	5.8	abc
El Toro	2.7	abc	4.3	ab	4.7	cde	6.3	abc	7.0	abcd	5.0	abcd
Emerald	4.3	abc	4.7	ab	5.0	bcde	6.0	abc	5.7	cde	6.0	ab
Empire	2.5	bc	4.8	ab	5.0	bcde	6.0	abc	6.0	bcde	5.3	abcd
Jamur	3.3	abc	5.0	ab	5.3	abcde	6.0	abc	7.0	abcd	5.7	abcd
Palisades	3.8	abc	5.5	ab	5.5	abcde	6.3	abc	7.0	abcd	6.0	ab
Y-2	2.8	abc	4.3	ab	4.5	de	6.0	abc	7.0	abcd	6.0	ab
Zeon	2.8	abc	4.0	ab	4.3	de	6.5	abc	6.5	abcd	5.8	abc
Zorro	2.8	abc	4.3	ab	4.5	de	6.0	abc	6.8	abcd	6.3	a
Buffalograss												
609	4.3	abc	6.3	ab	5.3	bcde	6.8	abc	7.0	abcd	4.3	abcd

The recovery turf quality data are presented in Table 14 accompanied by statistical analysis and mean comparison groupings. Individual varieties are presented graphically within species, with the exception that bermudagrass and buffalograss have been combined. The graphs follow as Figure 24a (bermudagrass and buffalograss), Figure 24b (St. Augustinegrass), and Figure 24c (zoysiagrass).

Figure 24a. Turfgrass quality for bermudagrass and buffalograss cultivars during the 2007 drought recovery period. Data reference is Table 14.

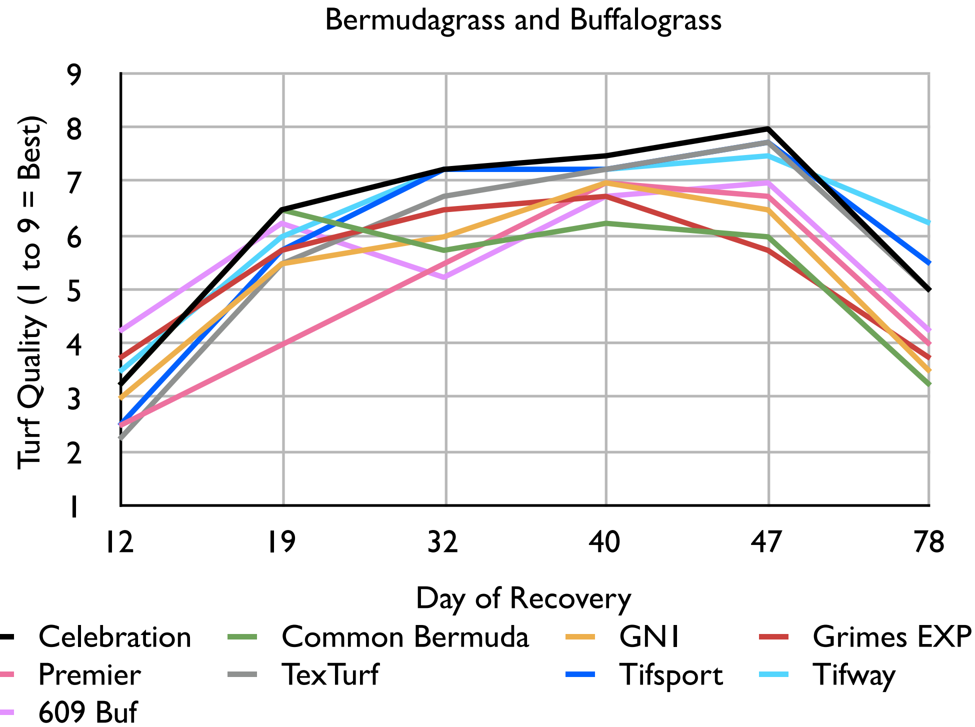


Figure 24b. Turfgrass quality for St. Augustinegrass cultivars during the 2007 drought recovery period. Data reference is Table 14.

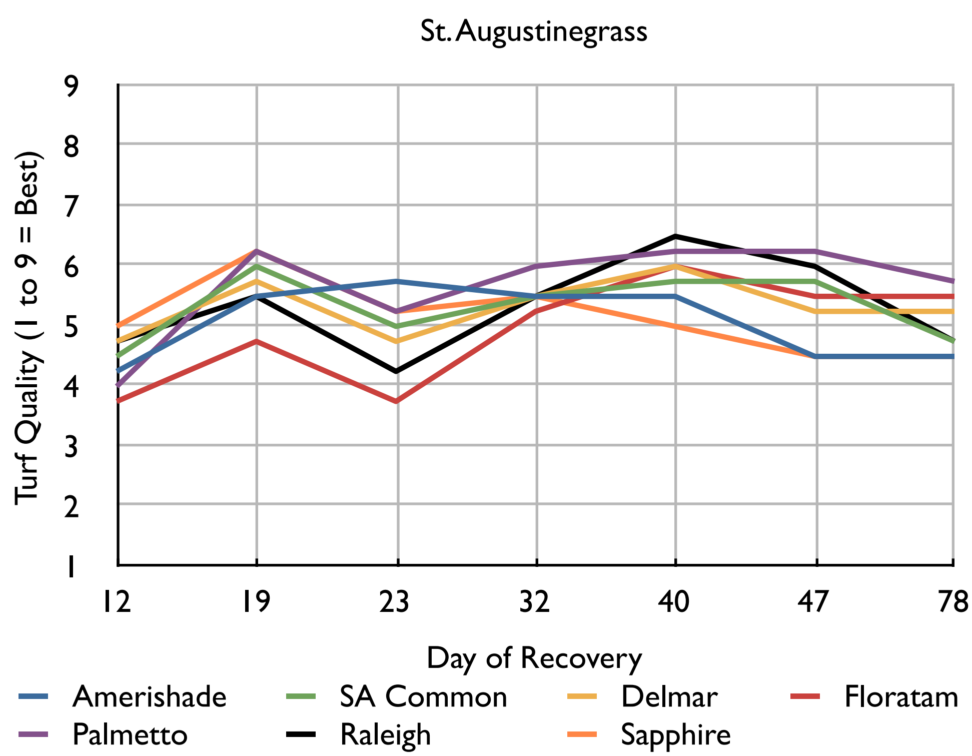


Figure 24c. Turfgrass quality for zoysiagrass cultivars during the 2007 drought recovery period. Data reference is Table 14.

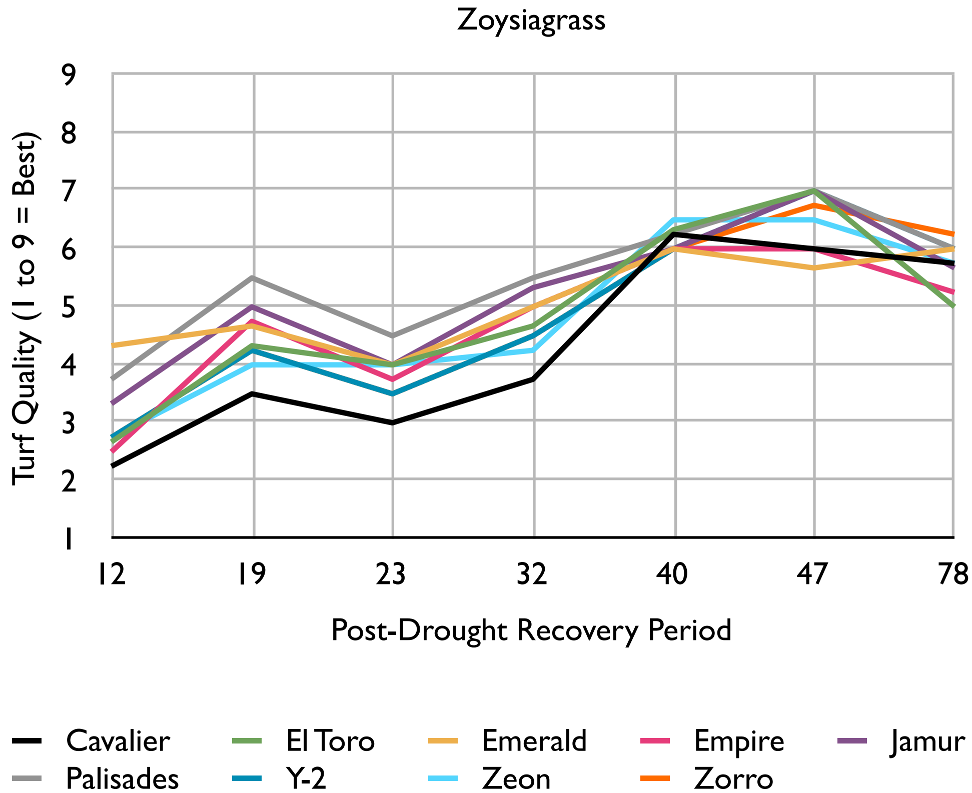


Figure 25. The Year 2 study appearance after 47 days of recovery from the 2007 summer drought.

Summary for Year 2 (2007)

Year 2 repeated the 2006 study and confirmed that during a less stressful year a 4-inch soil depth is incapable of supporting turfgrass water needs during an extended drought.

Year 2 also confirmed the ability of numerous turfgrass varieties, including St. Augustinegrass, to survive an extended drought on deep soils with minimal restriction to rooting.

Summary Observations Impacting Research Conclusions

- No grass was able to survive a 60-day drought on a 4-inch soil media in either 2006 (with significant heat stress, low humidity, and high PET) or 2007 (with less heat stress, higher humidities, and less PET).
- All grasses survived the 60-day drought, in both years, when planted on the native agricultural soil without restriction to rooting depth.
- The 2006 drought period resulted in excessive heat that also impacted turfgrass response in addition to withholding water for 60 days. The question exists as to the impact of heat stress compounding the turfgrass response to soil drying.
- Recovery from drought in 2006 was delayed due to cooler temperatures in the designated arbitrary 60-day recovery period. Extending the recovery period through mid-June 2007 provided the opportunity to more realistically assess turfgrass variety and specie recovery potential.
- The arbitrary nature of the 60-day recovery period, even though it was a starting point in the research protocol, must be looked at objectively to make certain environmental conditions over the period do indeed favor plant growth and recovery. Not much can be learned about turfgrass drought tolerance and potential for recovery if artificial limits are imposed as to how plants recover from drought and other summer stresses.
- The 2007 drought period really never threatened the ability of the grasses to survive and recover, which they accomplished quite well after 40 days of recovery under favorable temperatures. Therefore, the 2007 results could reflect more of a direct drought stress response. Daily maximum temperatures and relative humidity for the drought periods are reported in Appendix I and II, respectively.
- Turfgrass variety and specie survival of drought should be evaluated at early and late season stages of seasonal growth to better categorize potential drought resistance and recovery potential under diverse environmental conditions.
- This research did not validate any mechanisms (dormancy, osmotic adjustment, etc) grasses may use to persist in the absence of water from precipitation or irrigation. Even though some grasses experience leaf firing response sooner than other grasses, this does not indicate a grass is less tolerant

to drought. Grasses that enter such a quiescent state may or may not be actually dormant. Appendix III describes turfgrass responses to moisture stress conditions.

- The 60-day drought injury was greater in 2006 than 2007, likely due to the presence or absence of additional stresses. Yet, additional stresses are not commonly inventoried, reported and included in sometimes specious discussions pertaining to understanding of drought tolerant mechanisms in grasses as they relate to water conservation strategies.
- Relative soil depth impact on drought stress needs to be better quantified. The methods of constructing the 4-inch soil depth used in this study may or may not be consistent with landscaped sites.
- Conditions inherent to the San Antonio research site, namely soil type, and the research protocol should be considered before extrapolating these results to other locations.

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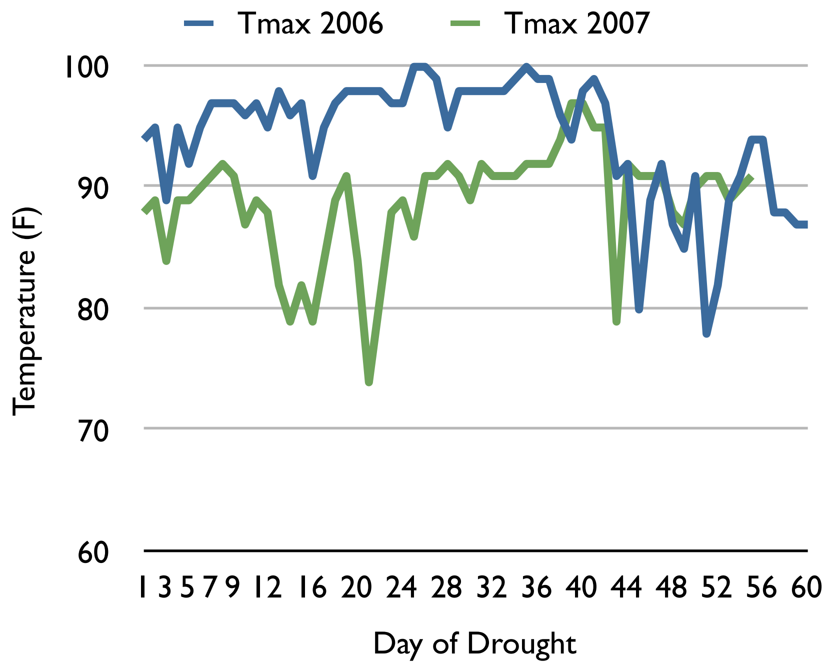
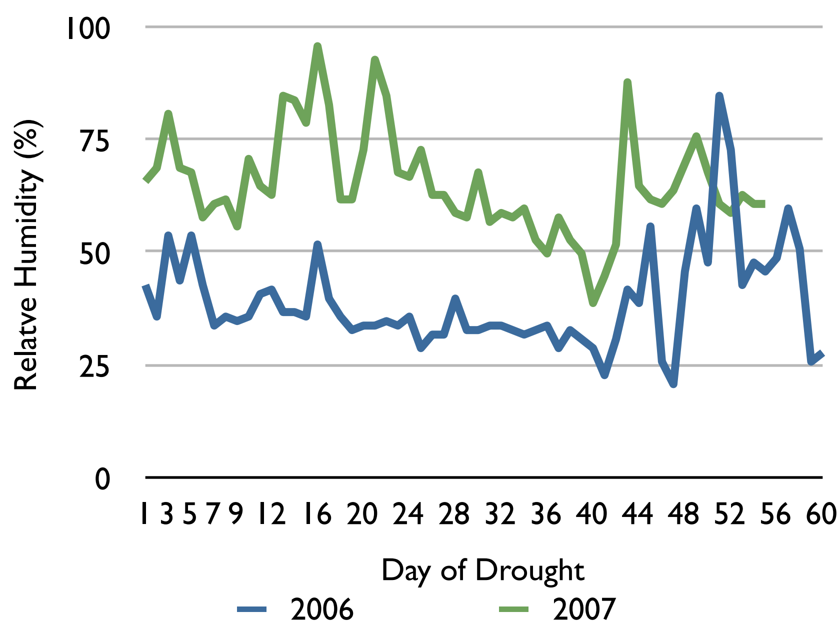
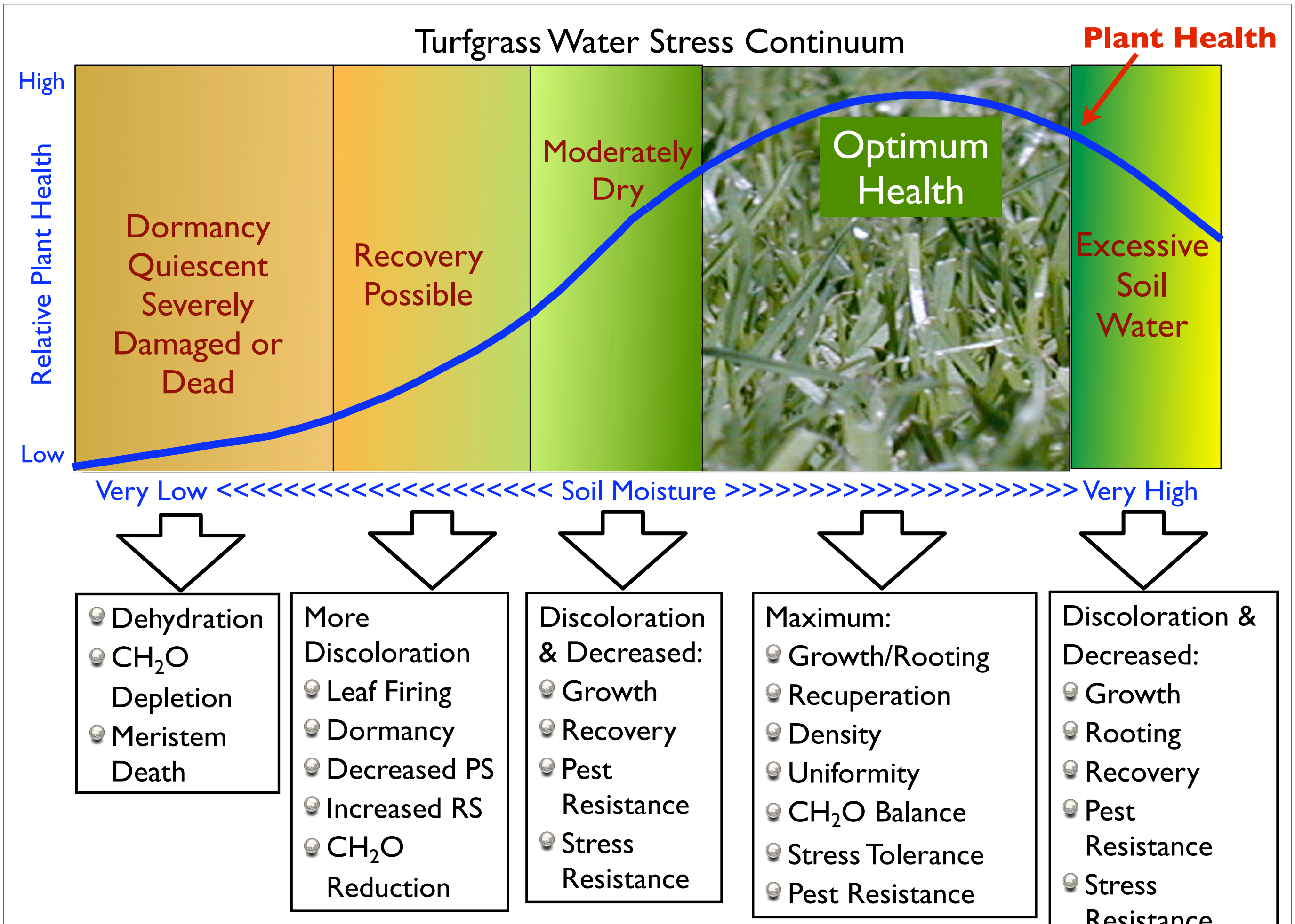
Appendix I. Daily maximum temperatures during drought in 2006 and 2007.



Appendix II. Relative humidity during drought in 2006 and 2007.



Appendix III. Turfgrass responses to soil moisture levels.



Credit: Dr. Richard White - Texas A&M University