# Evaluation of Turfgrass Species and Varieties for Drought Tolerance in a Renovated Linear Gradient Irrigation System

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***Background***

Rapidly growing urban population and demands on water supplies have placed increased scrutiny on turfgrass irrigation. Municipal and federal guidelines have been imposed to limit the amount of water that can be applied to turfgrass in the landscape, creating new challenges for homeowners. Thus, drought has become the issue of critical importance to producers, consumers, turf managers, and researchers. Research that identifies 1- drought tolerant turfgrass varieties, 2- minimal water requirements needed to achieve acceptable quality throughout a growing season, and 3- cultural management programs to enhance turfgrass drought tolerance are more important than ever. To address these challenges, a 3-year field study was undertaken at Texas AgriLife Research and Extension Urban Solutions Center in Dallas. This progress report contains a summary of some of the key results from year 3 of this project.

***LGIS Establishment, Design, and Experimental Treatments***

This study involves a series of large turfgrass research plots encompassing an area of 2.5-acres. In the fall of 2007, the site was planted to 20 turfgrass varieties, with four replicate plots per variety, representing five major turfgrass species, namely, zoysiagrass, St. Augustinegrass, bermudagrass, buffalograss, and tall fescue. Also included in the study were one St. Augustinegrass variety and one bermudagrass variety of unknown identity. These turfgrasses were delivered to the site and labeled as 'Floratam' and 'TexTurf10' during the fall of 2007 and were sodded into the designated plot areas. However, as these entries regained normal appearance during establishment, it became clear that morphological characteristics of these two entries did not match known markers associated with Floratam and TexTurf10. Therefore, data from these two varieties are not included.

Research plots were established in 2007, with the following spring of 2008 designated as the pretreatment phase of the study (i.e., prior to imposing treatments). During this pretreatment phase, the irrigation system was set to evenly water entire plots to allow them to establish uniformly. Once establishment was complete, the sole source of irrigation to plots became the linear gradient irrigation system (LGIS) that intersects the large field study.

LGIS creates a linear gradient of water availability through supplement water application such that the inner section of each plot (closest to the irrigation line) is well watered and the outer section (furthest from the irrigation line) receives no supplemental water. From April through October of each year, plots have been irrigated twice weekly to coincide with 2-day per week municipal water restrictions commonly imposed on landscapes throughout the region. Water application rates are calculated from reference evapotranspiration ($ET_o$) estimates generated from an on-site weather station, with appropriate corrections made to account for rainfall events. Irrigation amount as a function of distance from the center line has been closely monitored using plastic catch cups to ascertain that all irrigation heads are functioning properly and that a linear gradient of drought stress is being imposed. Figure 1 shows the irrigation distribution as a % of $ET_o$ as measured over 11 sampling dates for seven collection points within each plot. As expected based on the principle of the linear gradient irrigation system, irrigation amount is inversely correlated to the distance from the center line. Irrigation is supplied at 120% of $ET_o$ for the area along the center line with diminishing amounts supplied as one moves towards the outer edge of the gradient, at which point only supplemental rainfall is received. Data contained within tables of this report will refer to 'wet', 'semi-wet', 'semi-dry', and 'dry' zones within plots. Figure 1 illustrates the specific irrigation amounts supplied across these plot zones to be as follows: 'Wet' = 80% of $ET_o$, 'Semi-Wet' = 35% of $ET_o$, 'Semi-Dry' = Interface of irrigated/non-irrigated, and 'Dry' = no supplemental irrigation.

In addition to the irrigation treatment levels, each of the main turf plots is broken into subplots mowed weekly at different heights and fertilized between April and September with different levels of nitrogen (Table 1). Each entry is mowed at a 2-inch height and one alternative height. Depending on the entry's intended use, the alternate mowing height is either 0.5 inch, 1 inch or 3 inches. The 2008 pretreatment phase allowed subplots to be "trained" to their final mowing height and for fertility treatments to take effect.

***The 2010 Season***

Relative to previous seasons, 2010 was ushered in with one of the coldest winters on record for our area. The Dallas Center research site experienced ~72 hours of continual near-below-freezing temperatures in late December 2009, followed by an intensely cold winter (Figure 2). During the spring transition period, it became evident that the St. Augustinegrass plots within LGIS had sustained substantial winterkill, even though these plots had gone into the winter with acceptable quality across the majority of the plots. The most severe injury was associated with outer areas of plots that had received less than ~50% of $ET_o$, and these areas failed to recover over the course of the 2010 season. Inner zones of St. Augustinegrass plots that had received sufficient irrigation (>50% $ET_o$) the prior seasons, while slow to recover, resumed acceptable quality. Of the remaining species, none sustained serious injury, but all appeared delayed in emerging from dormancy relative to previous seasons.

An extremely hot summer followed a cool, wet spring. During the summer of 2010, two distinct drought periods were encountered in which no significant rainfall was received for 3-6 week periods (Figure 3). The first of these was a ~3 week period occurring in the latter half of May through mid-June, and following some brief rains in early July, the next occurred over a more prolonged 6-week period from late July until September. During this later drought period, temperatures exceeding 100º F combined to produce excessively high ET rates that approach 0.4 inches/ day (Figure 4). When combined with the extreme temperatures, both periods challenged the turfgrasses in the study and provided excellent conditions in which to evaluate the impact of cultural management on the drought tolerance of these varieties.

***Turfgrass Quality***

Early-season turfgrass quality within plots may have been more a function of cold tolerance and/or recovery following the previous winter than drought tolerance, per se. During a late spring rating date (May, Table 2) St. Augustinegrass quality was poor in all treatment plots, due to winter injury. Buffalograss exhibited minimally acceptable levels of quality that did not change across irrigation levels, with ‘609’ showing superior quality to ‘Prairie’ at all irrigation levels. In wet zones within plots, ‘Jamur’ and ‘Palisades’ zoysiagrass had the highest quality of the *Japonica* type zoysiagrases, with Jamur maintaining acceptable quality even into dry zones. The *matrella* type zoysiagrasses exhibited the highest quality of all other species at this point in the season, with acceptable quality extending even into non-irrigated plots. Within the *matrellas*, ‘Zorro’ and ‘Zeon’ outperformed other varieties in wet, semi-wet, and semi-dry zones of plots. The sports-type bermudagrasses exhibited much better early season quality than the lawn-type bermudagrasses in the May rating period. "Tifsport' and 'Tifway 419' had acceptable quality across all irrigation levels while 'Celebration' had significantly lower quality than the other three sports-type varieties, and was only of acceptable quality in the more heavily irrigated zones. Tall fescue quality was also acceptable only within wet zones of plots, which is not surprising given its presumably higher water use rate as a $C_3$ species, and given that this area of plots (15 feet from irrigation line) received only ~80% $ET_o$ (Figure 1).

A variety-by-cutting height-by N fertility interaction occurred in the May sampling date (Table 3). While grasses generally had improved quality at the high N rate, increased N had no discernable effect on quality of buffalograss or St. Augustinegrass. 'Jamur', 'Zeon', and 'Zorro' zoysiagrasses also showed no response to increased N rate in the late spring. Within the sports-type bermudagrasses, N rate had no influence on quality at the low mowing height.

By early July, plots had been through their first extended drought period in which no rainfall had occurred for much of June. As a result, only a few varieties continued to show acceptable quality into semi-dry and dry zones, which equate to irrigation levels below 35% $ET_o$ (Table 4). Varieties that stood out during this mid-summer period included '609' buffalograss, which continued to exhibit acceptable quality into dry zones receiving no irrigation. 'Tifsport' and 'Tifway 419' bermudagrass had the highest quality of all varieties in dry zones receiving no irrigation. Also, by July, St. Augustinegrass had finally recovered to acceptable levels within wet zones of plots, which received 80% $ET_o$.

The August quality evaluation occurred during the second and most severe drought period of the entire season. As previously mentioned, ET rates during this time approached 0.4 inches/day, and plots became extremely stressed, even into 'semi-wet' zones that received irrigation at 35% of $ET_o$. Unlike earlier sampling dates, no species were able to maintain acceptable levels of quality into semi-dry or dry zones. The only species that maintained acceptable quality in semi-wet zones were the *japonica* type zoysiagrasses 'Empire' and 'Palisades' and sports type bermudagrasses 'Celebration', 'Tifsport', and 'Tifway 419'(Table 5). Even the 80% $ET_o$ irrigation level in the wet zone was not sufficient to achieve acceptable quality in tall fescue or 'Prairie' buffalograss during this period. While the response of the cool-season species tall fescue is not surprising, the poor quality of 'Prairie' is not consistent with its performance in previous years, and suggests that a factor other than drought may be attributed to its lower-than-expected performance.

***Wilt Line Distance Data***

Wilt line distance data collected in the study represent the distance from the center irrigation line to the interface between acceptable/unacceptable quality during the most stressful period of the day. Therefore, these data, although not identical to, tell a similar story to that provided through quality ratings. While the previous quality data provide a more permanent evaluation that encompasses density, color, and texture, wilt line data offer a point-in-time value that can be used to support quality data in determining minimal water requirements. As with the quality data in this report, early, mid, and late summer data are presented.

In the early summer wilt line ratings, all varieties of bermudagrass and buffalograss showed excellent drought tolerance across the entire 60 foot plots (June, Table 6). St. Augustinegrass, zoysiagrass, and tall fescue groups showed relatively similar drought tolerance with wilt lines in the ~30 ft. distance range. 'Empire' zoysiagrass stood out among the *japonica* type zoysiagrasses with a high wilt line distance. Generally, mowing height had no influence on wilt line distance, however 'Cavalier' zoysiagrass and common St. Augustinegrass each had greater wilt line distances at lower mowing heights, perhaps attributed to lower ET rates associated with less leaf area at the shorter height of cut.

In the mid-summer rating period (August, Table 7), wilt lines were clearly visible in all varieties, generally in the 25-35 foot range, which corresponds to ~35% $ET_o$. Two notable exceptions to this included 'Grimes EXP' bermudagrass, which had a 41 ft. wilt line suggestive of superior drought tolerance, and tall fescue, which had a 21 foot wilt line, indicating an inability to meet evapotranspirational demand by this species relative to others. Also, mowing height again had no effect on wilt line distance, with the exception of 'Grimes EXP' which had greater wilt line distance at the taller mowing height.

Late summer evaluation of wilt line took place near the end of the intense August drought (Table 8). Whereas species differences were apparent in earlier ratings of the season, little difference now existed between the zoysiagrasses, bermudagrasses, buffalograsses and St. Augustinegrasses, with all ranging between ~27-35 ft. One notable exception to this was common bermudagrass, which showed a 43 ft. wilt line at the tall mowing height. '609' buffalograss had greater wilt line distances than 'Prairie' at both mowing heights. Within the lawn bermudagrasses, common bermudagrass at the tall mowing height had the greatest wilt line distance, and ‘Tifsport’ bermudagrass had the greatest wilt line distance among the sports-types. Tall fescue had the shortest wilt line of 16 feet, near the 80% $ET_o$ point. Nitrogen rate did not significantly impact wilt line distance in any variety.

***Canopy and Soil Temperatures***

Increasing irrigation deficits had noticeable effects on reflective heat loads generated from turf canopies, but had no influence on soil temperatures (data not shown). Measurements taken early summer (May, Table 9) revealed canopy temperatures in wet zones slightly greater than ambient air temperatures, but gradually increasing when moving into dryer zones of plots receiving less irrigation. Buffalograsses and bermudagrasses generally had lower temperatures than zoysiagrasses and St. Augustinegrass in dry zones of plots, suggesting adequate green cover and sustained transpiration rates in these areas. Tall fescue’s noticeably lower temperatures in wet zones are reflective of its higher water use rate relative to the warm-season grasses. Very little difference in temperature could be detected from wet to dry areas in buffalograss and ‘Celebration’ bermudagrass, suggesting these turf varieties were able to sustain growth and transpiration levels across plots, regardless of irrigation level. This also may suggest that these varieties possess relatively deep root systems and/or lower inherent consumptive water use rates.

Whereas some species had shown little or no temperature increases from wet to dry zones in May, all had significantly greater temperatures in dry zones in June (June, Table 10). Again, zoysiagrasses and St. Augustinegrass exhibited noticeably greater temperatures in dry zones, nearly 10-15 degrees warmer than in buffalograsses or bermudagrasses. Within the bermudagrasses, ‘Celebration’ maintained a considerably lower canopy temperature than other varieties even into dry zones.

Mid-July canopy temperatures showed a similar trend to that of the previous month, but with slightly lower heat loads, likely due to prior rain events that provided moisture to dryer zones of plots (July, Table 11). Again, bermudagrasses and buffalograss appeared to generate less heat load relative to other warm-season varieties. ‘Celebration’ maintained cooler canopy temperatures than all other varieties except ‘609’ buffalograss across all zones. Remarkably, ‘Celebration’ temperatures in dry zones were similar to those of many other varieties in wet zones.

***Soil Volumetric Water Content***

Volumetric water content of plots was obtained throughout the season for the 0-2 inch depth using a hand-held SM 200 Theta Probe (Dynamax, Inc., Houston TX). As one would expect, water content of soils gradually decreased from wet zones to dry zones of plots (Table 12). Wet plots generally held from ~40-45% water by volume. Dry zones ranged from ~10-14% by volume, all of which was likely plant unavailable. No discernable influence of N rate or mowing height on soil water content was found. No further interactions occurred on other sampling dates, and similar overall trends existed with respect to irrigation level, so no further water content data have been presented.

***Weed Incidence***

Weed pressure for the 2010 season was generally low throughout much of the irrigated plots of LGIS. Generally, weed pressure within plots was minimal within wet and semi wet zones, with low to moderate pressure resulting in dry plot zones due to low density and exposure of bare soil. The most vulnerable areas that developed moderate to severe weed pressure were semi-dry and dry zones of St. Augustinegrass, due to winter injury. Tall fescue plots also harbored weeds in these areas receiving little or no irrigation, primarily due to the low density of these plots (data not shown). Prostrate spurge and common bermudagrass were the most common weeds that arose.

***Conclusions***

The 2010 season has been ideal for meeting the objectives of the LGIS study. The multiple periods of drought and extreme temperatures have provided us with a more detailed understanding of which turfgrass varieties are best able to cope with the extreme Texas summers. Somewhat surprisingly, while differences in mowing height and N fertility affected quality, they had little influence on drought tolerance of these varieties. The severely cold winter also allowed us to evaluate impacts of our cultural practices on susceptibility to and recovery from winter injury, particularly in St. Augustinegrass. These 2010 results appear to confirm that these species do differ with respect to their minimal water requirements, an observation that did not come out as clearly in the previous season, perhaps due to more favorable 2009 conditions. These minimal requirements also can change rapidly. Once 2010 data collection and analysis has been fully completed, we will also be able to better understand how genetic rooting potential of the species and varieties may have contributed to the relative drought tolerance (or lack thereof) we observed over the previous season.

Table 1. Treatments combinations imposed on 22 turfgrass varieties in the linear gradient irrigation study at Dallas. Varieties, cutting heights, and fertility rates represent main plots, subplots, and sub-subplots, respectively.

| Species | Variety | Fertility | Cutting Heights |
|---|---|---|---|
| | | lbs N / 1000 sq. ft. / year | inches |
| Bermudagrass | Common | 3 and 6 | 1 and 2 |
| | GrimesEXP | | |
| | Tifton10 | | |
| | | | |
| Bermudagrass | Celebration | 3 and 6 | ½ and 2 |
| | Premier | | |
| | Tifsport | | |
| | Tifway 419 | | |
| | | | |
| Zoysiagrass | El Toro | 2 and 4 | 1 and 2 |
| (*japonica* type) | Empire | | |
| | JaMur | | |
| | Palisades | | |
| | | | |
| Zoysiagrass | Cavalier | 2 and 4 | ½ and 2 |
| (*matrella* type) | Emerald | | |
| | Zeon | | |
| | Zorro | | |
| | | | |
| Tall fescue | Paladin | 3 and 6 | 2 and 3 |
| | | | |
| Buffalograss | 609 | 1 and 2 | 2 and 3 |
| | Prairie | | |
| | | | |
| St. Augustinegrass | Common | 2 and 4 | 2 and 3 |
| | Raleigh | | |

Table 2. Turf quality of 20 turfgrasses in LGIS on **10 May 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant. 1= dead, brown turf, 5= minimally acceptable quality, and 9 = perfect quality.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| | | | | | |
| Bermudagrass | Common | 3.2 | 3.2 | 3.2 | 3.5 |
| | GrimesEXP | 3.6 | 3.7 | 4.1 | 5.0 |
| | Tifton10 | 3.8 | 3.9 | 4.0 | 4.7 |
| | | | | | |
| Bermudagrass | Celebration | 4.5 | 4.7 | 4.7 | 5.1 |
| | Premier | 4.8 | 4.7 | 5.1 | 6.1 |
| | Tifsport | 5.5 | 5.6 | 5.7 | 6.2 |
| | Tifway 419 | 5.3 | 5.4 | 5.7 | 6.0 |
| | | | | | |
| Zoysiagrass | El Toro | 5.0 | 4.8 | 4.7 | 5.1 |
| (*japonica* type) | Empire | 5.0 | 5.1 | 4.9 | 5.2 |
| | JaMur | 5.2 | 5.4 | 5.9 | 6.0 |
| | Palisades | 4.3 | 4.7 | 5.3 | 5.9 |
| | | | | | |
| Zoysiagrass | Cavalier | 5.7 | 6.0 | 6.6 | 7.2 |
| (*matrella* type) | Emerald | 6.1 | 6.1 | 6.6 | 6.8 |
| | Zeon | 5.7 | 6.5 | 7.1 | 7.5 |
| | Zorro | 5.8 | 6.3 | 7.1 | 7.7 |
| | | | | | |
| Tall fescue | Paladin | 4.0 | 4.0 | 4.5 | 5.6 |
| | | | | | |
| Buffalograss | 609 | 5.6 | 5.4 | 5.3 | 5.3 |
| | Prairie | 4.9 | 4.8 | 4.8 | 4.9 |
| | | | | | |
| St. Augustinegrass | Common | 1.9 | 1.8 | 1.8 | 2.9 |
| | | | | | |
| | Raleigh | 2.6 | 2.1 | 1.9 | 2.5 |
| LSD (0.05) | | ------------------------ 0.4 -------------------------- | | | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line

Table 3. Turf quality of 20 turfgrass in LGIS on **10 May 2010**. Data for the variety-by-cutting height-by-N fertility interactions are provided since that source of variation was significant. 1= dead, brown turf, 5= minimally acceptable quality, and 9 = perfect quality.

| | | Short Cutting Height ‡ | | Tall Cutting Height | |
|---|---|---|---|---|---|
| Species | Variety † | Low N § | High N | Low N | High N |
| | | | | | |
| Bermudagrass | Common | 2.9 | 3.3 | 3.4 | 3.5 |
| | GrimesEXP | 3.9 | 4.2 | 3.9 | 4.3 |
| | Tifton10 | 4.0 | 4.0 | 4.0 | 4.4 |
| | | | | | |
| Bermudagrass | Celebration | 4.7 | 4.8 | 4.4 | 5.2 |
| | Premier | 5.4 | 5.4 | 4.7 | 5.3 |
| | Tifsport | 5.9 | 5.9 | 5.4 | 5.7 |
| | Tifway 419 | 5.5 | 5.7 | 5.3 | 5.7 |
| | | | | | |
| Zoysiagrass | El Toro | 4.8 | 4.9 | 4.7 | 5.3 |
| (*japonica* type) | Empire | 4.7 | 5.1 | 5.4 | 5.1 |
| | JaMur | 5.6 | 5.6 | 5.7 | 5.6 |
| | Palisades | 4.7 | 5.4 | 5.2 | 5.3 |
| | | | | | |
| Zoysiagrass | Cavalier | 6.6 | 6.6 | 5.8 | 6.5 |
| (*matrella* type) | Emerald | 6.1 | 6.7 | 6.4 | 6.4 |
| | Zeon | 6.8 | 6.9 | 6.7 | 6.4 |
| | Zorro | 7.1 | 6.9 | 6.6 | 6.5 |
| | | | | | |
| Tall fescue | Paladin | 4.3 | 4.8 | 4.1 | 4.7 |
| | | | | | |
| Buffalograss | 609 | 5.3 | 5.4 | 5.5 | 5.4 |
| | Prairie | 4.6 | 4.6 | 4.9 | 5.1 |
| | | | | | |
| St. Augustinegrass | Common | 2.3 | 2.5 | 1.8 | 1.8 |
| | | | | | |
| | Raleigh | 2.3 | 2.3 | 2.3 | 2.3 |
| LSD (0.05) | | ------------------------ 0.4 -------------------------- | | | |

† The Variety-by-Cutting height-by-N fertility interaction was significant ($P < 0.05$)

‡Height of cut for buffalograss, tall fescue, and St. Augustinegrass, were 2-inch and 3-inch. Height of cut for amenity bermugrass and *Zoysia japonica*et, were 1-inch and 2-inch. Height of cut for sports-type bermumagrass and *Zoysia matrella* were 0.5-inch and 2-0 inch.

§ N fertility rates for the bermudagrass and tall fescue was 3 and 6 lbs N per 1000 sq. ft per year. N fertility for the zoysiagrass and St. Augustinegrass was 2 and 4 lbs N per 1000 sq. ft per year. N fertility for buffalograss was 1 and 2 lbs N per 1000 sq. ft. per year.

Table 4. Turf quality of 20 turfgrass in LGIS on **1 July 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant. 1= dead, brown turf, 5= minimally acceptable quality, and 9 = perfect quality.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| Bermudagrass | Common | 3.8 | 3.8 | 4.4 | 4.9 |
| | GrimesEXP | 4.7 | 4.7 | 5.3 | 5.6 |
| | Tifton10 | 4.9 | 4.9 | 5.1 | 5.2 |
| Bermudagrass | Celebration | 4.7 | 4.8 | 5.1 | 5.4 |
| | Premier | 4.6 | 4.9 | 5.7 | 6.5 |
| | Tifsport | 5.7 | 5.9 | 6.6 | 6.9 |
| | Tifway 419 | 5.7 | 5.7 | 6.3 | 6.7 |
| Zoysiagrass | El Toro | 3.9 | 4.1 | 4.7 | 5.2 |
| (*japonica* type) | Empire | 4.2 | 4.4 | 5.3 | 5.6 |
| | JaMur | 4.2 | 4.6 | 5.4 | 5.8 |
| | Palisades | 4.2 | 4.2 | 5.2 | 5.6 |
| Zoysiagrass | Cavalier | 3.6 | 4.1 | 6.0 | 6.6 |
| (*matrella* type) | Emerald | 4.1 | 4.6 | 5.9 | 6.5 |
| | Zeon | 3.7 | 4.1 | 5.7 | 6.7 |
| | Zorro | 3.6 | 3.8 | 6.3 | 7.1 |
| Tall fescue | Paladin | 3.0 | 3.0 | 4.0 | 5.6 |
| Buffalograss | 609 | 5.0 | 5.0 | 5.0 | 5.0 |
| | Prairie | 4.3 | 4.3 | 4.3 | 4.3 |
| St. Augustinegrass | Common | 2.4 | 2.6 | 3.0 | 5.4 |
| | Raleigh | 3.2 | 3.2 | 3.4 | 5.0 |
| LSD (0.05) | | ------------------------ 0.4 -------------------------- | | | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line

Table 5. Turf quality of 20 turfgrass in LGIS on **12 Aug 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant. 1= dead, brown turf, 5= minimally acceptable quality, and 9 = perfect quality.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| Bermudagrass | Common | 2.8 | 3.0 | 4.0 | 5.2 |
| | GrimesEXP | 3.0 | 3.7 | 4.7 | 6.0 |
| | Tifton10 | 2.5 | 2.9 | 4.1 | 5.6 |
| Bermudagrass | Celebration | 2.8 | 3.1 | 5.1 | 6.4 |
| | Premier | 2.4 | 2.9 | 4.9 | 6.7 |
| | Tifsport | 3.3 | 3.9 | 5.9 | 7.1 |
| | Tifway 419 | 2.6 | 2.8 | 5.1 | 6.5 |
| Zoysiagrass | El Toro | 2.0 | 2.2 | 4.1 | 5.4 |
| (*japonica* type) | Empire | 2.4 | 2.7 | 5.3 | 6.4 |
| | JaMur | 2.2 | 2.2 | 4.9 | 6.7 |
| | Palisades | 2.3 | 2.5 | 5.0 | 6.0 |
| Zoysiagrass | Cavalier | 2.3 | 2.7 | 4.8 | 6.9 |
| (*matrella* type) | Emerald | 2.3 | 2.4 | 4.4 | 7.0 |
| | Zeon | 2.2 | 2.3 | 4.4 | 6.7 |
| | Zorro | 2.5 | 2.7 | 4.8 | 7.1 |
| Tall fescue | Paladin | 1.4 | 1.4 | 2.1 | 4.5 |
| Buffalograss | 609 | 3.3 | 3.3 | 4.7 | 5.6 |
| | Prairie | 2.7 | 2.8 | 3.8 | 4.4 |
| St. Augustinegrass | Common | 1.3 | 2.0 | 3.8 | 6.5 |
| | Raleigh | 1.8 | 1.9 | 3.6 | 6.1 |
| LSD (0.05) | | ------------------------ 0.6 -------------------------- | | | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line

Table 6. Effect of a linear gradient irrigation system (LGIS) on the distance from the center watering line where transition from acceptable to unacceptable turf quality was visually apparent. Entries included 20 turfgrass varieties with mowing heights and fertility levels as subplots and subsubplot, respectively. Data were collected on **8 June 2010** between 1200 and 1500 hours on 80 plots. A larger distance value corresponds to more drought tolerance.

| | | Distance from Center | |
|---|---|---|---|
| Species | Variety | Short Mowing Height | Tall Mowing Height |
| | | --------------------- feet | ---------------------- |
| Bermudagrass | Common | 60 | 60 |
| | GrimesEXP | 60 | 60 |
| | Tifton10 | 60 | 60 |
| | | | |
| Bermudagrass | Celebration | 60 | 60 |
| | Premier | 60 | 60 |
| | TifSport | 60 | 60 |
| | Tifway 419 | 60 | 60 |
| | | | |
| Zoysiagrass | El Toro | 28 | 27 |
| (*japonica* type) | Empire | 39 | 38 |
| | JaMur | 31 | 31 |
| | Palisades | 32 | 32 |
| | | | |
| Zoysiagrass | Cavalier | 31 | 29 |
| (*matrella* type) | Emerald | 31 | 30 |
| | Zeon | 24 | 25 |
| | Zorro | 31 | 30 |
| | | | |
| Tall fescue | Paladin | 30 | 30 |
| | | | |
| Buffalograss | 609 | 60 | 60 |
| | Prairie | 60 | 60 |
| | | | |
| St. Augustinegrass | Common | 39 | 34 |
| | Raleigh | 34 | 34 |
| LSD (0.05) | | ---------------------------- 2 | ------------------------- |

Table 7. Effect of a linear gradient irrigation system (LGIS) on the distance from the center watering line where transition from acceptable to unacceptable turf quality was visually apparent. Entries included 20 turfgrass varieties with mowing heights and fertility levels as subplots and subsubplot, respectively. Data were collected on **12 Aug 2010** between 1200 and 1500 hours on 80 plots. A larger distance value corresponds to more drought tolerance.

| | | Distance from Center | |
|---|---|---|---|
| Species | Variety | Short Mowing Height | Tall Mowing Height |
| | | ---------------------- feet | ----------------------- |
| Bermudagrass | Common | 34 | 33 |
| | GrimesEXP | 36 | 41 |
| | Tifton10 | 27 | 27 |
| | | | |
| Bermudagrass | Celebration | 35 | 33 |
| | Premier | 32 | 35 |
| | TifSport | 36 | 36 |
| | Tifway 419 | 31 | 32 |
| | | | |
| Zoysiagrass | El Toro | 21 | 24 |
| (*japonica* type) | Empire | 32 | 32 |
| | JaMur | 32 | 30 |
| | Palisades | 34 | 33 |
| | | | |
| Zoysiagrass | Cavalier | 27 | 27 |
| (*matrella* type) | Emerald | 29 | 28 |
| | Zeon | 21 | 24 |
| | Zorro | 27 | 27 |
| | | | |
| Tall fescue | Paladin | 21 | 21 |
| | | | |
| Buffalograss | 609 | 30 | 28 |
| | Prairie | 27 | 26 |
| | | | |
| St. Augustinegrass | Common | 25 | 27 |
| | Raleigh | 28 | 27 |
| LSD (0.05) | | ---------------------------- 4 | -------------------------- |

Table 8. Effect of a linear gradient irrigation system (LGIS) on the distance from the center watering line where transition from acceptable to unacceptable turf quality was visually apparent. Entries included 20 turfgrass varieties with mowing heights and fertility levels as subplots and subsubplot, respectively. Data were collected on **31 Aug 2010** between 1200 and 1500 hours on 80 plots. A larger distance value corresponds to more drought tolerance.

| | | Distance from Center | |
|---|---|---|---|
| Species | Variety | Short Mowing Height | Tall Mowing Height |
| | | --------------------- feet | ---------------------- |
| Bermudagrass | Common | 28 | 43 |
| | GrimesEXP | 33 | 35 |
| | Tifton10 | 28 | 28 |
| | | | |
| Bermudagrass | Celebration | 31 | 30 |
| | Premier | 29 | 30 |
| | TifSport | 36 | 35 |
| | Tifway 419 | 30 | 29 |
| | | | |
| Zoysiagrass | El Toro | 28 | 28 |
| (*japonica* type) | Empire | 33 | 34 |
| | JaMur | 31 | 31 |
| | Palisades | 33 | 33 |
| | | | |
| Zoysiagrass | Cavalier | 29 | 29 |
| (*matrella* type) | Emerald | 29 | 29 |
| | Zeon | 25 | 28 |
| | Zorro | 26 | 24 |
| | | | |
| Tall fescue | Paladin | 16 | 16 |
| | | | |
| Buffalograss | 609 | 31 | 31 |
| | Prairie | 27 | 27 |
| | | | |
| St. Augustinegrass | Common | 27 | 27 |
| | Raleigh | 28 | 29 |
| LSD (0.05) | | --------------------------- 4 | ------------------------- |

Table 9. Canopy temperatures of 20 turfgrasses in LGIS on **26-28 May 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| | | | | | |
| Bermudagrass | Common | 113 | 112 | 113 | 106 |
| | GrimesEXP | 112 | 105 | 103 | 100 |
| | Tifton10 | 110 | 107 | 103 | 99 |
| | | | | | |
| Bermudagrass | Celebration | 103 | 104 | 103 | 101 |
| | Premier | 116 | 115 | 111 | 108 |
| | Tifsport | 108 | 109 | 106 | 103 |
| | Tifway 419 | 111 | 110 | 105 | 102 |
| | | | | | |
| Zoysiagrass | El Toro | 122 | 121 | 110 | 99 |
| (*japonica* type) | Empire | 122 | 117 | 108 | 106 |
| | JaMur | 129 | 122 | 113 | 107 |
| | Palisades | 127 | 122 | 111 | 108 |
| | | | | | |
| Zoysiagrass | Cavalier | 126 | 124 | 114 | 106 |
| (*matrella* type) | Emerald | 128 | 125 | 117 | 106 |
| | Zeon | 128 | 122 | 116 | 109 |
| | Zorro | 127 | 119 | 110 | 98 |
| | | | | | |
| Tall fescue | Paladin | 100 | 98 | 93 | 91 |
| | | | | | |
| Buffalograss | 609 | 111 | 112 | 109 | 107 |
| | Prairie | 113 | 109 | 110 | 106 |
| | | | | | |
| St. Augustinegrass | Common | 121 | 114 | 116 | 105 |
| | | | | | |
| | Raleigh | 118 | 120 | 118 | 109 |
| LSD (0.05) | | ------------------------ | 4 | -------------------------- | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line

Table 10. Canopy temperatures of 20 turfgrasses in LGIS on **17-23 June 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| | | | | | |
| Bermudagrass | Common | 119 | 119 | 111 | 100 |
| | GrimesEXP | 116 | 116 | 108 | 99 |
| | Tifton10 | 119 | 117 | 110 | 101 |
| | | | | | |
| Bermudagrass | Celebration | 111 | 105 | 101 | 98 |
| | Premier | 125 | 123 | 115 | 105 |
| | Tifsport | 117 | 115 | 105 | 97 |
| | Tifway 419 | 119 | 119 | 113 | 100 |
| | | | | | |
| Zoysiagrass | El Toro | 139 | 140 | 130 | 112 |
| (*japonica* type) | Empire | 129 | 127 | 114 | 101 |
| | JaMur | 133 | 128 | 126 | 107 |
| | Palisades | 135 | 133 | 122 | 107 |
| | | | | | |
| Zoysiagrass | Cavalier | 139 | 133 | 122 | 106 |
| (*matrella* type) | Emerald | 133 | 129 | 121 | 102 |
| | Zeon | 136 | 134 | 125 | 109 |
| | Zorro | 132 | 128 | 116 | 100 |
| | | | | | |
| Tall fescue | Paladin | 126 | 120 | 110 | 96 |
| | | | | | |
| Buffalograss | 609 | 119 | 115 | 107 | 101 |
| | Prairie | 121 | 121 | 116 | 105 |
| | | | | | |
| St. Augustinegrass | Common | 133 | 132 | 129 | 106 |
| | | | | | |
| | Raleigh | 132 | 130 | 129 | 104 |
| LSD (0.05) | | ------------------------ 6 -------------------------- | | | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line.

Table 11. Canopy temperatures of 20 turfgrasses in LGIS on **13-15 July 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| Bermudagrass | Common | 113 | 110 | 109 | 108 |
| | GrimesEXP | 108 | 107 | 107 | 106 |
| | Tifton10 | 109 | 107 | 106 | 104 |
| Bermudagrass | Celebration | 103 | 102 | 102 | 99 |
| | Premier | 114 | 116 | 111 | 109 |
| | Tifsport | 106 | 105 | 102 | 100 |
| | Tifway 419 | 113 | 111 | 110 | 107 |
| Zoysiagrass | El Toro | 123 | 116 | 106 | 102 |
| (*japonica* type) | Empire | 111 | 105 | 104 | 99 |
| | JaMur | 114 | 108 | 105 | 102 |
| | Palisades | 113 | 113 | 108 | 105 |
| Zoysiagrass | Cavalier | 124 | 123 | 113 | 108 |
| (*matrella* type) | Emerald | 122 | 122 | 112 | 108 |
| | Zeon | 118 | 116 | 109 | 104 |
| | Zorro | 120 | 117 | 106 | 101 |
| Tall fescue | Paladin | 111 | 109 | 105 | 96 |
| Buffalograss | 609 | 104 | 108 | 104 | 101 |
| | Prairie | 108 | 109 | 106 | 105 |
| St. Augustinegrass | Common | 121 | 119 | 115 | 105 |
| | Raleigh | 119 | 120 | 114 | 109 |
| LSD (0.05) | | ------------------------ 4 -------------------------- | | | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line

Table 12. Soil moisture of 20 turfgrasses in LGIS on **20-26 Aug 2010**. Data for the variety-by-water interactions are provided since that source of variation was significant.

| Species | Variety † | Dry ‡ | SemiDry | SemiWet | Wet |
|---|---|---|---|---|---|
| | | -------- % Volumetric Water Content (%) ------- | | | |
| Bermudagrass | Common | 13 | 20 | 36 | 50 |
| | GrimesEXP | 14 | 19 | 34 | 46 |
| | Tifton10 | 14 | 17 | 30 | 42 |
| | | | | | |
| Bermudagrass | Celebration | 12 | 14 | 31 | 47 |
| | Premier | 12 | 16 | 26 | 39 |
| | Tifsport | 16 | 18 | 29 | 45 |
| | Tifway 419 | 11 | 13 | 27 | 40 |
| | | | | | |
| Zoysiagrass | El Toro | 8 | 10 | 23 | 39 |
| (*japonica* type) | Empire | 11 | 16 | 34 | 47 |
| | JaMur | 10 | 14 | 25 | 39 |
| | Palisades | 12 | 14 | 34 | 46 |
| | | | | | |
| Zoysiagrass | Cavalier | 9 | 12 | 19 | 39 |
| (*matrella* type) | Emerald | 10 | 14 | 23 | 40 |
| | Zeon | 12 | 17 | 25 | 40 |
| | Zorro | 12 | 16 | 23 | 36 |
| | | | | | |
| Tall fescue | Paladin | 13 | 16 | 36 | 46 |
| | | | | | |
| Buffalograss | 609 | 14 | 17 | 27 | 40 |
| | Prairie | 16 | 20 | 30 | 46 |
| | | | | | |
| St. Augustinegrass | Common | 11 | 13 | 26 | 45 |
| | | | | | |
| | Raleigh | 12 | 13 | 34 | 46 |
| LSD (0.05) | | ------------------------ 5 -------------------------- | | | |

† The Variety-by-Water Level interaction was significant (P <0.05)
‡Wet, SemiWet, SemiDry, and Dry designate positions within plots that were 15, 30, 45, and 60 feet from the center irrigation line

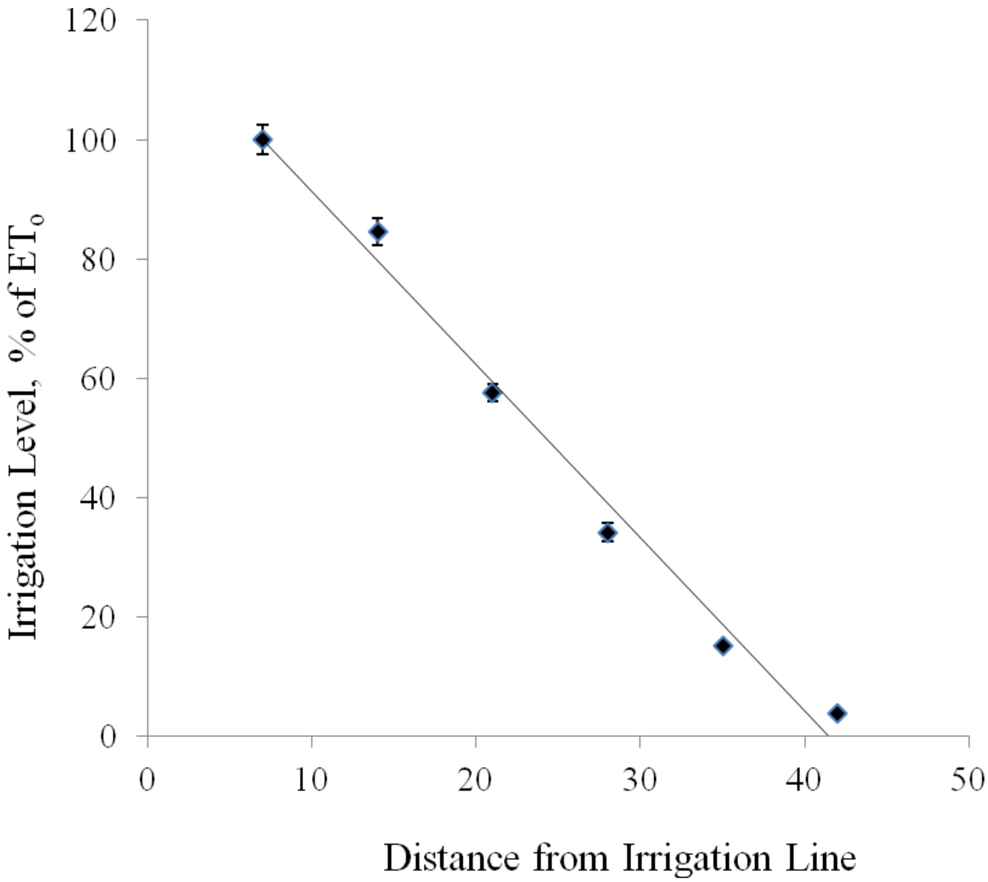


Figure 1. Irrigation distribution of the linear gradient irrigation system (LGIS) as a function of distance from the center irrigation line. Data represent means of 11 collection dates from 2008 through 2010. Data were obtained from rain gauges positioned at 7 ft. increments from the center irrigation line. Fitted equation: Irrigation level (% $ET_o$) = -2.9064 (distance in feet) + 120.46. $R^2 = 0.99$. Error bars denote standard error.

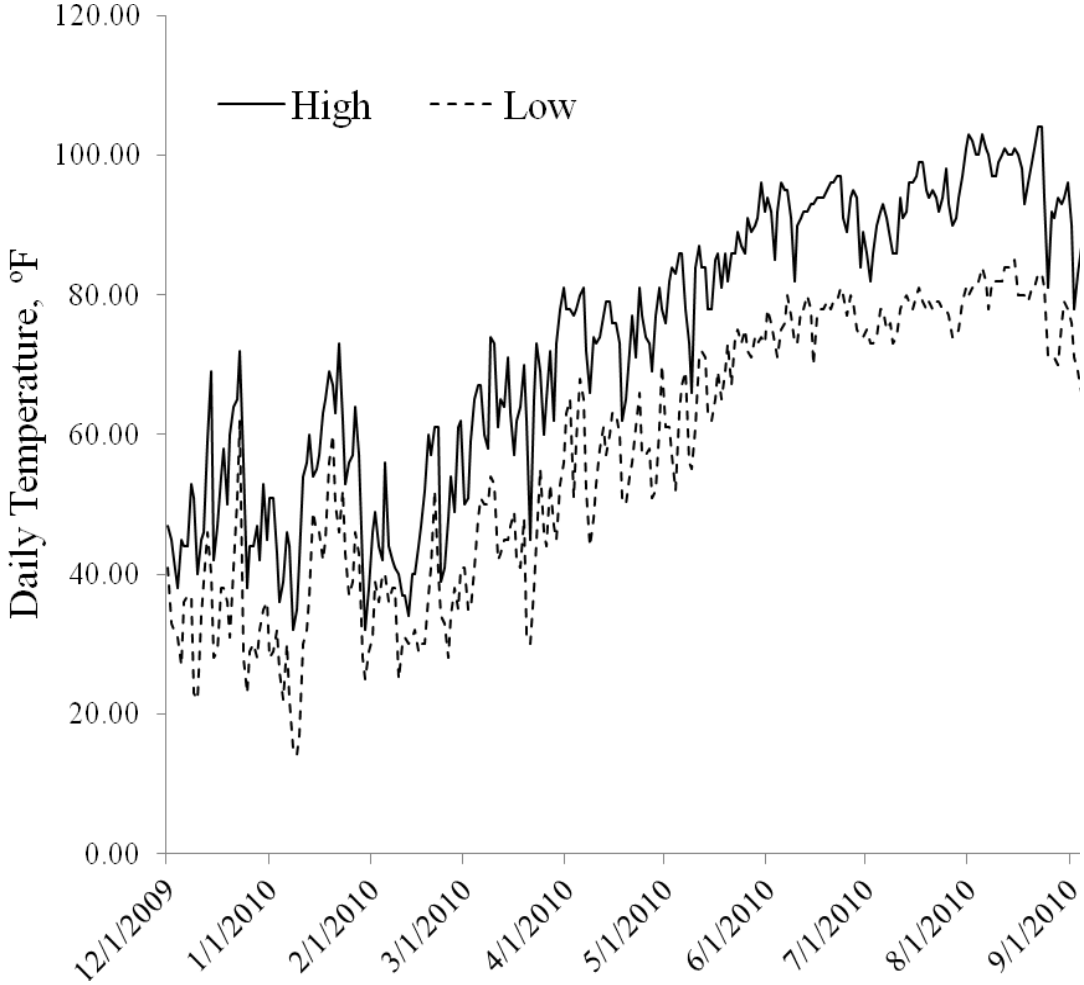


Figure 2. Daily high and low temperatures for the Dallas site during late 2009 and 2010. Data were collected from an onsite weather station.

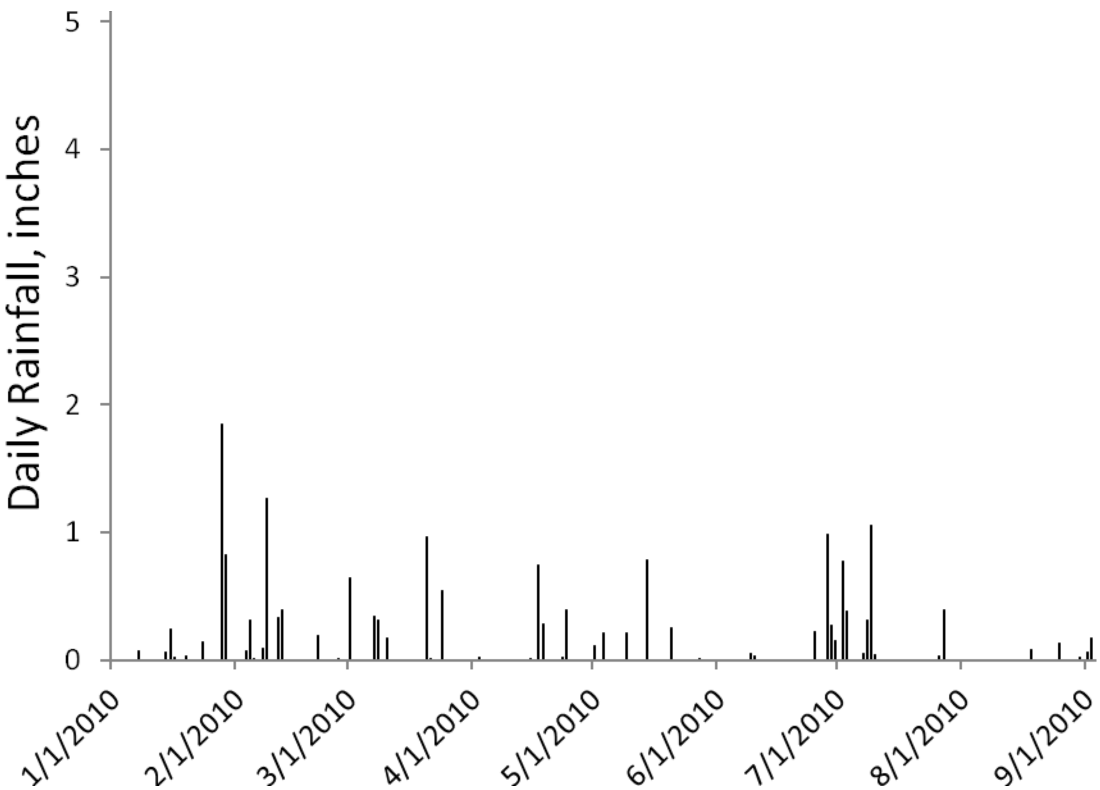


Figure 3. Daily rainfall totals for the 2010 LGIS study. Irrigation requirements were adjusted to account for rainfall events.

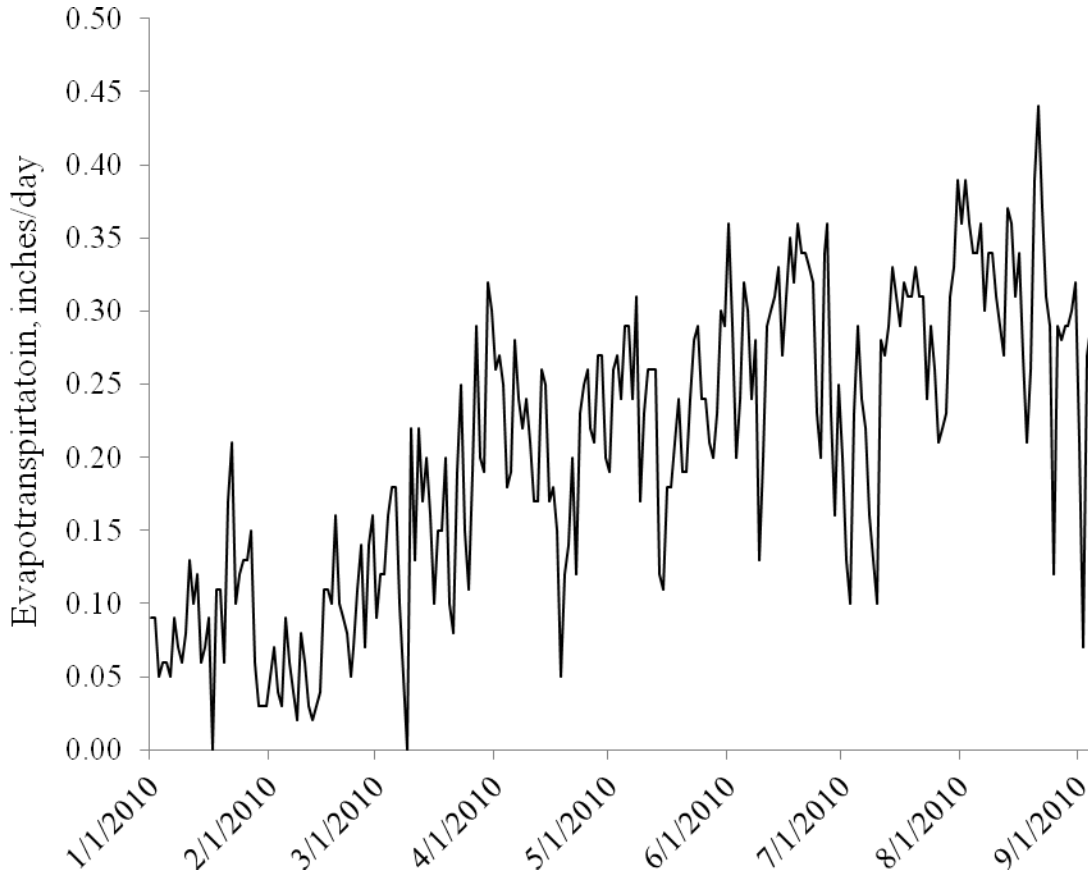


Figure 4. Reference evapotranspiration ($ET_o$) for 2010 season at Texas AgriLife, Dallas. Data were obtained from on-site weather station and used to calculate bi-weekly irrigation events for LGIS.

Figure 5. Photo of of LGIS plots taken June 12, 2010 during initial summer drought period. Contrasting turfgrass quality can be seen between distant, non-irrigated zones of tall fescue (left) and buffalograss (right). Photo was taken from center irrigation line.