ADVANCED TURF-TYPE BERMUDAGRASS AND ZOYSIAGRASS EXPERIMENTAL GENOTYPES SHOW MARKED VARIATION IN RESPONSES TO DROUGHT STRESS UNDER FIELD CONDITIONS

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Abstract: Bermudagrasses (*Cynodon* spps.) and zoysiagrasses (*Zoysia* spps.) are the most commonly used warm-season turfgrasses in the southern and transition zone areas of the United States. It is important to improve turfgrass drought resistance for water savings and persistence under drought stress. A number of experimental and commercially available turf bermudagrasses and zoysiagrasses were evaluated for drought response at the Oklahoma State University Turfgrass Research Center in Stillwater, Oklahoma during 2016. The trials were designed as randomized complete blocks with four replications for the zoysiagrass and one of the bermudagrass trials and three replications on another bermudagrass trial. Following a one-year period of establishing under regular irrigation, all trials were maintained under no irrigation and no rainfall upon the start of a dry down cycle. Polyethylene waterproof tarps were used to exclude rainfall from each trial. Entries were evaluated for turf quality (TQ), leaf firing (LF), normalized difference vegetation index (NDVI) and live green cover (LGC) at least once each week during the dry down cycle. Turf quality, LF, NDVI, and LGC were positive and highly correlated, suggesting that they were effective indicators for characterizing turfgrass drought response. Mean volumetric soil water content (MVSWC) had a positive and low to moderate correlation to LF, TQ, NDVI and LGC. Days after starting drought treatment (DAT) had a negative and moderate to high correlation to TQ, LF, NDVI, LGC and MVSWC. As DAT increased, all the testing parameters had decreased. ‘TifTuf’ bermudagrass had the highest rating of all parameters (indicating best drought response) on most dates during severe drought. ‘OSU1221’ bermudagrass provided better performance than other experimental genotypes on most dates during severe drought. All bermudagrass experimental genotypes showed equal or improved performance with respect to drought response than the standard ‘Tifway’ during most dates under severe drought. ‘DALZ1411’ had the overall best performance on all four parameters among all the zoysiagrass entries. Zoysiagrass standards ‘Empire’, ‘Zeon’, and ‘Palisade’ were not as drought resistant as most of the experimental genotypes. All zoysiagrass experimental genotypes except ‘FZ1223’ showed improvement in drought response over all standards.

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CHAPTER I

LITERATURE REVIEW

Drought

Drought is an extended and abnormal period of soil and atmospheric water deficit (Dracup et al., 1980). Drought is the consequence of a below-average amount of precipitation received for an extended period of time resulting in an insufficient water supply to meet normal requirements of specific crops (Dracup et al., 1980). All climatic regimes can have drought including both high and low rainfall areas. Drought can have a substantial impact on agriculture and ecosystems in the affected area and often draws attention due to its departure from average or normal rainfall and moisture conditions.

Drought is a major limiting abiotic factor for plant growth. When plant root zones lack suitable moisture for growth and development, several changes in physiological and biochemical processes will occur (Youngner, 1985). Sufficient soil moisture is required to sustain turfgrass growth, and to maintain both shoot density and minimal acceptable turf quality (Taliaferro, 2003). Plants subjected to drought stress show leaf rolling, leaf firing and their transpiration rate will decrease due to decreased leaf area (Carrow, 1996).

Water and Turfgrass

More than 71% of the earth's surface area is covered by water and according to the United States Geological Survey (USGS), there are 332.5 million cubic miles of water on earth. However, the usable fresh water is only 0.003% of the total water on earth. In the United States, nearly 306 billion gallons of freshwater are used each day with 115 billion gallons being used for irrigation. Due to increased acreage under irrigation with sprinkler and microirrigation systems, the irrigation usage of water in 2010 represented the lowest level since 1965 (Maupin et al., 2014). Only about 2.9% of all irrigation water is used in landscape management in the United States (Zoldoske, 2003). There are approximately 50 million acres of maintained turfgrass, including that on golf courses, sports fields and home lawns in urban areas. This substantial acreage of maintained turfgrass has the potential to incur large water usage and as such, intense focus on water conservation is necessary. By measures such as developing and using new turfgrass cultivars that require less water than the existing commercial ones, as well as implementation of more efficient irrigation systems and a better irrigation management plan, the goal of using less water can be achieved (Beard et al., 1989; Carrow et al., 2002).

California, known for its high water demand for agriculture, industrial, livestock, domestic, and thermoelectric water withdrawals, recently experienced a severe and extended drought (Shi et al., 2013). Once deeply into sustained drought, the state government in California banned residential irrigation of lawns and landscapes within 48 hours of measurable rainfall and required reduction of the lawn area of the yard for newly built housing. It is important to know whether the irrigation amounts used on turfgrass cause stress on community water supplies. Although concerns exist regarding effects of turfgrass irrigation on water supply, turfgrasses can provide many benefits in the urban environment. Bermudagrass transpirational cooling can reduce ambient air temperature up to 9 ^{o}C as compared to dry, bare soil and up to 21 ^{o}C as compared to a dormant brown turf (Beard et al., 1994). Also, turfgrass can reduce urban soil erosion, abate noise, and as well as offer improved aesthetic value (Beard et al., 1994).

Water availability is critically important to turfgrasses as 80-90% of total plant weight is comprised of water (Beard, 1989). Serving as an excellent solvent, water is a good medium to provide a stable environment for all physiological processes. Also, water is substrate in many reactions such as in photosynthesis where water can be broken down into oxygen, protons, and electrons in the photosynthesis reaction. When turfgrass lacks sufficient water, negative effects on its growth occur and when water deficit strain continues, the grass will go dormant and then eventually die if the stress continues for an extended period of time. Plants respond to water stress differently during various stages of drought. When drought stress first occurs in grasses, stomates will close to reduce water loss. After a few hours of drought, grasses may wilt, undergo osmotic adjustment, produce abscisic acid, heat shock proteins or dehydrins. When drought continues from several days to several weeks of duration depends on different soil types, leaves in the grass canopy will “fire” and the plants will go dormant (Passioura, 1996). The chlorosis and later browning of a leaf, due to destruction of the chromatophores in the leaf, which starts from the leaf tips and margins and gradually progress down the leaf, is known as leaf firing (Carrow, 1996).

Bermudagrass

Bermudagrasses (*Cynodon* spps.) are believed to have originated in southeastern Africa (Taliaferro et al., 2004). Grazing pressure from herbivorous mammals lead to early diversification of the genus. According to the biostematic and molecular phylogenetic research, the secondary origins are South Africa, India, and Afghanistan (Beard, 2012). Bermudagrasses can be found on six of the seven continents and are adapted to the tropical and subtropical climate zones, with some found approaching south and north 50-degrees latitude (Taliaferro et al., 2004). Common bermudagrass (*C. dactylon* (L.) Pers. var. *dactylon*) was first brought to the United States in the mid-1600's by Spanish conquistadors, and then widely spread and naturalized in the warm climatic regions (Beard, 2012). African bermudagrass (*C. transvaalensis* Burtt-Davy) was likely introduced to the United States by people from South Africa (Beard, 2012). Bermudagrasses are also known by several common names including couchgrass and quickgrass, 'kweek' and 'quick' grass in South Africa, 'dhoub' in India and 'dog's tooth grass' in China (Hurcombe, 1948; Kneebone, 1966).

Bermudagrass is a very economically important, widely used warm-season or C4 turfgrass (Moser et al., 2004). In C4 plants, the first stable carbon compound is oxaloacetic acid (OAA), a four carbon compound (Ghannoum, 2009). The first stable carbon compound produced in the Calvin cycle/C3 cycle is phosphoglyceric acid, a three carbon compound (Moser et al., 2004). Unlike cool-season or C3 plants, C4 plants do not have the photorespiration process, which is an advantage for C4 plants in stressed conditions such as drought and heat (Raven et al., 2005). The C4 plants use CO_2 more efficiently than C3 plants. This is achieved by hydrating CO_2 into bicarbonate in the mesophyll cells and releasing CO_2 in bundle sheath cells for fixing via the rubisco enzyme (Moser et al., 2004). Due to the more efficient way of using CO_2, C4 plants can maintain a minimal photosynthetic rate with closure of stomata under drought stress (Raven et al., 2005).

The taxonomic classification of *Cynodon* consists of nine species and ten botanical varieties according to Harlan et al. (1970). Only African bermudagrass, common bermudagrass and interspecific hybrid bermudagrass (*C. dactylon* x *C. transvaalensis*) are considered valued for turfgrass use (Taliaferro et al., 2004). African bermudagrass is diploid in chromosome number (2n=2x=18) and it is fine textured, with high shoot density and a yellow-green color (Hanna, 1986; Harlan et al., 1970). Common bermudagrass is typically tetraploid (2n=4x=36) but with instances of hexaploidy (Harlan et al., 1970; Wu et al., 2005).

Some common bermudagrasses can be propagated by seed. Seed is considered highly outcrossed due to a high degree of self-incompatibility and cross-pollination (Burton et al., 1967). Different from vegetative propagated common bermudagrass, seeded common bermudagrass varieties have a more upright growth habit and coarser texture due to increased internode length (Taliaferro et al., 2004). There is considerable variation among common bermudagrasses with respect to color, texture, density and environmental adaption (Turgeon, 1991). Interspecific hybrid bermudagrasses can occur due to the hybridization of either tetraploid (2n=4x) or hexaploid (2n=6x) common bermudagrass and diploid (2n=2x) African bermudagrass. 'Patriot' bermudagrass is a tetraploid (2n=4x=36 chromosomes) interspecific hybrid from a cross of *Cynodon dactylon* (2n=6x=54) by *C. transvaalensis* (2n=2x=18) (Taliaferro et al., 2006). 'Latitude 36' bermudagrass is a triploid hybrid from a cross of *Cynodon dactylon* (2n=4x=36) × *C. transvaalensis* (2n=2x=18) (Wu et al., 2014). The interspecific hybrids are highly infertile, rarely producing seeds. Following crossing, improved lines having darker green color, finer leaf texture and higher shoot density are selected, resulting in varieties with improved turf quality (Beard, 1973).

The growth habit of bermudagrass is stoloniferous and rhizomatous. Due to the fast growth rate, bermudagrass can quickly establish and recover from diseases and stresses. In addition, based on its growth habit, it has a tendency to have a thick thatch or mat layer (Wise, 1961). Bermudagrass grows best under high sunlight, moderate to high rainfall and mild winter conditions (Beard, 1973). Bermudagrass grows best between 24-37 degree and it gradually goes dormant after the first frost (Beard, 1973). Loam, loamy sand, and sandy loam soil are the best-growing medium for bermudagrass (Beard, 1973). Bermudagrass is popular in tropical and sub-tropical zones due to its ability to withstand extended drought periods and its performance under low-maintenance conditions (Christians, 2011).

Bermudagrass is widely used on athletic fields, golf courses and home lawns due to its excellent recuperative ability and wear tolerance. Some bermudagrasses can be used as forage grass since they have high biomass and desirable forage quality. Also, bermudagrass can be used for erosion prevention along roadsides and waterways (Moser et al., 2004).

Zoysiagrass

Zoysiagrass (*Zoysia* spp.) is a warm-season grass native to China, Japan and other parts of Southeast Asia (Hatch and White, 2004). In 1895, zoysiagrass was introduced into the

United States from Japan (Madison, 1971). In the United States, zoysiagrass can be found along Atlantic coast from Florida to New England, the Gulf Coast and in California (Duble, 2001). In its native habitat, zoysiagrass acts as a soil stabilizer. Zoysiagrass shoots contain high levels of silica, which suggests that herbivorous grazing animals may not help diversification and migration (Beard, 2012). *Zoysia japonica* is one of the most cold-hardy warm-season turfgrasses with the northern limit of adaptation around 40^{o} latitude (Beard, 1973; Hoover et al., 1948). Zoysiagrass grows best on well-drained soil and intolerant to the poor-drained soil (Beard, 1973). Zoysiagrass is considered more shade tolerant than other warm-season grasses and more drought resistant to other cool-season grasses. The drought resistance to zoysiagrass is intermediate to high compared to other warm-season grasses. However, zoysiagrass will go dormant during the extended dry period without irrigation (Moser et al., 2004).

The *Zoysia* genus consists of approximately 11 species (Anderson, 2000). The most important cultivated species that are used for turf includes *Zoysia japonica (*Steud.*), Z. matrella* (L.) Merr. and *Z. tenuifolia* Will. Ex Trin (Patton, 2010). *Zoysia japonica*, sometimes called "Japanese lawn grass," is a coarser textured zoysia species, but has more cold hardiness than *Z. matrella*. In the United States, *Z. japonica* could be expected to do very well as far north as Maryland (Moser et al., 2004). *Z. tenuifolia* is a very fine-textured species but is the least cold tolerant. It is native to the Far East and was introduced to the United States from the Mascarene Island (Unruh et al., 2000).

Forbes (1952), found that *Z. japonica, Z. matrella,* and *Z. tenuifolia* had 40 chromosomes that paired as 20 bivalents during meiosis. And the base chromosome number of the genus

Zoysia was x=20 but did not rule out x=5 or 10 (Forbes, 1952). Zoysiagrasses have a protogynous flowering behavior and are highly cross-pollinated (Forbes, 1952).

Zoysiagrasses are low-growing sod-forming grasses spreading by stolons and rhizomes. Zoysiagrass produces a dense sod that is very competitive with weeds, but this density makes mowing more difficult (Madison, 1971). This result in accumulation of organic matter at soil surface (Beard, 1973). Although these grasses are wear-tolerant, they recover from injury relatively slowly (Duble, 2001).

Zoysiagrass can be used for sports fields and lawns. Zoysiagrass was first used on golf courses in the 1950s and became popular because of the heat, drought and freezing tolerance in the transition zone. Because of the slow recovery from wear and other mechanical injury, zoysiagrass was not considered a good choice for use on intensively used sports field (Duble, 2001). The slow establishment rate from sprigs or sod plugs compared with other warm-season turfgrass species limited its use in the United States. Slow growth rate during establishment is the major weakness of zoysiagrass. The slow growth rate of sprigs and sod increased the cost of sprigs and sod production, making it more expensive for establishing a new turfgrass site (White et al., 2001).

Turfgrass Drought Response

Drought resistance is the ability of a plant to avoid dehydration or tolerate dehydration in plant tissue (Levitt, 1980). Perennial turfgrass can survive water stress with drought avoidance or/and drought tolerance mechanisms. Turfgrass may avoid drought damage by having deeper roots in the soil. It is common for soil drying to occur at the surface; consequently, the deeper, denser and more extensive the root system is, the more surface area the roots can provide for water and nutrient extraction to benefit the plant, even when part of the root system is under dry soil conditions (Huang, 2008). Additionally, deeper, more extensive root systems are established to absorb moisture from deeper soil to maintain water potential inside plant cells. Besides the capability to develop deep root systems, a variable, functional and multi-layered root system may affect drought avoidance once under drought stress (Huang et al., 1997). During the period of water stress, bermudagrass can regulate stomatal closure to slowing loss of water through leaves to avoid desiccation (Lambers et al., 2008). However, the closure of stomata will negatively affect photosynthetic activities. When respiration rate exceeds photosynthetic rate, available plant carbohydrate will decrease. The carbohydrate reserves are important for plant survival during drought periods (Smith, 1981). Bermudagrass leaves will fold under drought stress due to bulliform cells losing turgor pressure. Folded leaf blades will slow down transpiration water loss (Trenholm, 2000). Osmotic adjustment is an important mechanistic response in plants to tissue dehydration. The accumulation of solutes will reduce osmotic potential to maintain cellular turgor in a stressed leaf and thus maintain a sustained growth at lower water content (Huang, 2003). Dehydrin-like proteins are believed to be induced by osmotic adjustment. The role of the dehydrin-like proteins is thought to be one of protection, allowing other proteins to maintain the integrity of cells (Bray, 1993).

Response of Bermudagrass and Zoysiagrass Shoot System to Drought Stress

Chalmers et al. (2008) conducted research in San Antonio, TX to evaluate the drought resistance of the commonly used turfgrass species/cultivars used in Texas during an imposed 60-day drought. Eight cultivars of bermudagrass, seven cultivars of St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze], nine cultivars of zoysiagrass and one buffalograss [Buchloe dactyloides (Nutt.) Englem] were evaluated in 2006 and 2007 under field conditions. A movable rain-out shelter was used to exclude rainfall from the trial area. ‘Premier’ bermudagrasses (synonym ‘Oregon 2002’ and Premier Pro^{TM}) showed the lowest turf quality at the end of the 60 day drought period in both 2006 and 2007. There were no statistically differences for turf quality among the bermudagrass cultivars, ‘Celebration’, ‘Common’, ‘GN-1’, ‘Grimes EXP’, ‘Tex Turf’, ‘TifSport’ and ‘Tifway’ both in 2006 and 2007. Based on the leaf firing ratings, Premier was the most susceptible to leaf firing injury in response to soil moisture deficit in both the 2006 and 2007 trials. Tex Turf had the best leaf firing ratings at the end of the drought period in 2006. In 2007, at the end of study, there was no statistically difference in leaf firing among all the bermudagrass cultivars except for Premier which was the most susceptible to leaf firing. Among zoysiagrass cultivars, ‘Cavalier’, ‘El Toro’, Emerald’, ‘Jamur’, ‘Palisades’, ‘Y-2’, ‘Zeon’ and ‘Zorro’ showed no statistically differences in leaf firing at the end of 60 days of drought both in 2006 and 2007. In 2006, Empire had better turf quality than other zoysiagrass cultivars and in 2007 there was no statistically difference in turf quality among all the zoysiagrass cultivars. In both 2006 and 2007, Chalmers et al. (2008) found that no grass was able to survive (i.e. 100 % kill) the 60-day drought on a restricted root zone soil of only 10 cm (4 in) depth at San Antonio. All turfgrasses were able to survive (at least partial recovery) on native soil where the root zone depth was not restricted.

In research conducted at the University of Arkansas, Fayetteville, Richardson et al. (2010) evaluated 15 bermudagrass cultivars for drought tolerance with a fixed position rain-out shelter. Digital image analysis was used to record the live green cover (LGC) of the turfgrass canopy for each entry. Non-linear regression was used to fit sigmoidal decay equations to LGC with confidence interval (CI) calculation and subsequently CI overlap among entries used to measure the range of days required by bermudagrasses to lose LGC to points of 75, 50 and 25%. Bermudagrasses took over 40 days without water before losing significant LGC. Tifway was ranked in the top statistical group in days decreased to 75, 50 and 25% LGC during the study. Although there were significant differences between cultivars, the range between the best and worst cultivars was about 12 days to reach 25% LGC (Richardson et al., 2010).

Research conducted by Kim et al. (1988) compared the drought resistance of 11 major warm-season turfgrasses, including 22 bermudagrasses and six zoysiagrass cultivars. Drought resistance was measured by how well and quickly shoots recovered after the plants exposure to 48 days of drought stress. The results showed bermudagrass had relatively low leaf firing and high drought resistance among these widely used warm-season turfgrass species (Kim et al., 1988). Zoysiagrass 'Meyer' had relatively severe leaf firing and relatively good in drought resistance. 'Korean Common' had relatively severe leaf firing and relatively poor drought resistance adaptation (Kim et al., 1988).

In a study conducted by Poudel (2010) at Oklahoma State University, Stillwater, twenty-three experimental clonal bermudagrass genotypes were evaluated for drought performance under field conditions. After 28 days without irrigation, Poudel (2010) found Celebration as a good performer under drought conditions of the study and Premier as a poor performer under conditions of the study based on the response parameters of turf quality and leaf firing ratings as well as the normalized difference vegetation index. In another study conducted by Poudel (2015) 13 bermudagrasses, 13 zoysiagrass, 12 St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze], and 7 seashore paspalum (*Paspalum vaginatum* Swartz) genotypes were evaluated under drought stress in a greenhouse for 90 days. All of the grasses were completely fired at 28 days after stopping watering of the plants. The OSU experimental bermudagrass genotype 'OKC1302" was one of the best entries for drought resistance response compared to the rest of the entries of each species. The zoysiagrass cultivar 'Zeon' was the best performer among zoysiagrasses and as compared to all zoysiagrass experimental genotypes.

Baldwin et al. (2006) conducted a greenhouse study that included six bermudagrass entries Celebration, 'Arizona Common', 'Tift No.3', 'Tifsport', 'Aussie Green' and 'SWI-1012' for a two-year duration study in 2004 and 2004. Four watering interval treatments were tested and these included watering daily, and at 5-, 10-, and 15-d intervals. Only one cultivar, Tift No.3 was ranked in the bottom statistical group for turf quality ratings in the well-watered control treatment after four weeks of study. After four weeks of treatment, there were no statistical differences among the bermudagrass cultivars at 5-, 10- and 15-d intervals.

Goals and Objectives

This thesis presents the further testing of elite germplasm that has been developed and initially tested for turfgrass quality and drought response in single space plant trials at Stillwater, OK; Dallas and College Station, TX; Tifton, GA; Gainesville, FL and Raleigh, NC. Those trials were conducted under a Department of Agriculture (USDA) Specialty Crops Research Initiative (SCRI) project (No. 2010-51181-21064) Plant Genetics and Genomics to Improve Drought and Salinity Tolerance for Sustainable Turfgrass Production in the Southern United States. This 2010 – 2015 multi-state transdisciplinary effort was undertaken by the turfgrass programs at Oklahoma State University (OSU), Texas A&M University (TAMU), North Carolina State University (NCSU), the University of Georgia (UGA) and the University of Florida (UF). Over 1,900 experimental genotypes across the four species (bermudagrass, zoysiagrass, seashore paspalum and St. Augustinegrass) were developed during and 105 advanced drought resistance genotypes were under study during the project by over 20 investigators, 30 graduate students and support staff in five states. The specific goals of this advanced research were to evaluate:

(1) the drought response of elite bermudagrass germplasm for possible commercial release in the southern United States.
(2) the drought response of elite zoysiagrass germplasm for possible commercial release in the southern United States.

The objectives of this research project were to evaluate:

(1) the drought responses of bermudagrass entries under acute drought condition at Stillwater, OK.

(2) the drought responses of zoysiagrass entries under acute drought condition at Stillwater, OK.

Research Hypotheses

It was hypothesized that:

(1) the bermudagrass experimental genotypes are better in drought responses than the commercial standards Tifway and Celebration.

(2) the zoysiagrass experimental genotypes are better in drought responses than the commercial standards Zeon, Palisade and Empire.

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CHAPTER II

MATERIALS AND METHODS

Research site and plant materials establishment

The research site was located at the Oklahoma State University Turfgrass Research Center (36°07'27.4" N Lat, 97°06'07.1" W Long) research block (RB) F15 for experiment I and II; and RB BG3 for experiment III. The soil type was an Easpur loam (fine-loamy, mixed, superactive, thermic Fluventic haplustolls) for RB F15 and BG3 (USDA, 2016). The soil textural analysis for RB F15 showed the components to be 46.2% sand, 37.5% silt, and 16.2% clay. The analysis for RB BG3 soil found 56.2% sand, 30% silt, and 13.8% clay.

There were 13 bermudagrass entries evaluated which included 10 experimental genotypes previously selected for improved drought resistance and 3 standard cultivars in experiment I (Table 1). The ten elite bermudagrass experimental genotypes included five entries from the Oklahoma State University (OSU) turfgrass breeding program and the other five were from the University of Georgia (UGA) turfgrass breeding program (designated UGB genotypes). The 10 experimental genotypes evaluated in this research had been previously selected from more than 250 experimental genotypes planted in 2012 and evaluated for delayed leaf firing under drought in space plant nurseries during 2013. The standard 'TifTuf' bermudagrass was released in 2015 and was considered as an experimental genotype named 'DT1' when the plots were originally established. There were 15 entries of bermudagrass in experiment II and 13 of them were entries in experiment I (Table 1 and 2). Thirteen zoysiagrass entries were evaluated in experiment III (Table3). Five experimental genotypes were submitted by Texas A&M University and five experimental genotypes were submitted by the turfgrass breeder at The University of Florida. The 10 zoysiagrass experimental genotypes evaluated in this research had been previously selected from more than 250 experimental genotypes planted in 2012 and evaluated for delayed leaf firing under drought conditions in space plant nurseries during 2013.Trials in RB F15 and BG3 were planted in July 2014. Plots in experiments I and III (RB F15) measured 1.2 by 1.2 m. Eighteen 3 cm diameter plugs were planted in each plot. Experiment III (RB BG3) was established to 1.6 by 1.6 m square plots using twenty-four plugs per plot with each plug measuring 3 cm diameter.

Cultural Management

Before planting, the plot was sprayed with glyphosate to kill all the weeds and tilled in 2014. The granular form of Ronstar 2G herbicide [active ingredient oxidiazon] (Bayer Environment Science, NJ) was applied at 2.2 kg ha^{-1} of active ingredient (ai) at one day after planting for pre-emergence weed control. A basic soil test was conducted by the OSU Soil, Water and Forage Analytical Laboratory (SWFAL) for soil pH, nitrate nitrogen, as well as plant available phosphorus, and potassium. The soil test showed the pH of RB BG 3 was 7.3; the phosphorous index was 117 and potassium index was 368 using the Mehlich III method (Mehlich, 1984). Based on the OSU SWFAL lawn brochure, the optimum level of phosphorus and potassium would be an index of 65 and 350. Thus, no additional applications of phosphorous and potassium were needed. The nitrate nitrogen index was 13. Considering the value 43.5 represents 1 pound of nitrogen per 1000 square feet, based on 43,560 square feet per acre, the nitrogen was deficient, and the requirement was 37 kg of nitrogen per hectare. For the growing season from July to October 2014, 147 kg N ha^{-1} from urea (46-0-0, N-P-K) was applied. During 2015, a total of 147 kg N $ha^{-1}$from urea (46-0-0, N-P-K) was applied. In 2015 49 kg N ha^{-1} from urea (46-0-0, N-P-K) was applied at each application in the first week of April, the first week of May, the third week of June and the first week of September. No symptoms of nutrient deficiency were observed during the study. Ronstar 2G was applied at 2.2 kg ai ha^{-1} in spring and again in fall to prevent summer annual and winter annual grasses and broadleaves. The plots were maintained under simulated home lawn conditions. The mowing height of bermudagrass was 3.8 cm. In 2014 and 2015, plots were mowed with a rotary mower. However, due to the high shoot density of bermudagrass and zoysiagrass, scalping issues were sometimes present throughout the growing season. Consequently, a reel mower was used to maintain plots starting in 2016. A 23 cm wide bare soil border was maintained between each plot using glyphosate herbicide from a custom bordering machine to prevent cross contamination among entries. Research block F15 and BG3 were irrigated with irrigation system daily for 10 minutes to avoid any drought stress. Based on the reference ET rate for warm-season grasses calculated by an Oklahoma Mesonet station located approximately 0.4 km southeast of the research block, irrigation was adjusted to ensure the moisture need.

Implimentation of Drought Conditions

During summer of 2015, RB BG3 was maintain under ambient condition with irrigation only after fertilizer application to test the drought responses of bermudagrasses and zoysiagrasses. Research block F15 was maintain regularly without any drought research on it. In 2016 once plots in RB F15 and BG3 were fully greened up and had reached approxmitely 100% visually assessed green cover, drought conditions were implemented. In the week prior to starting drought treatment, more irrigation was applied to help drive water deeper into the soil profile due to the low infiltration rate of Easpur loam. One day before drought treatment, research plots were irrigated with four 15-minute duration irrigation applications with a 30 minute of interval between applications. Hand watering was applied if ununiformed volumetric soil water contents were detected. The volumetric soil water content of each entry was measured with a Stevens POGO HydraProbe (Stevens Water Monitoring Systems Inc., Portland, OR) to ensure saturated soil conditions with more than 37% volumetric soil water content at upper 6.4 cm soil profile. In 2016, one 600 square meters (30 by 20 m) high-density woven polyethylene waterproof tarp (Tarp Supply, Inc., Lombard, IL) was used in each trial as a rain cover during implementation of drought to prevent natural precipitation reaching the plots. The tarp was secured with ground stakes through metal gromets along the margins of the tarp.

The drought treatment on RB F15 started on 16 June 2016 and finished on 28 August 2016. During 72 days of drought, total precipitation measured by the local Stillwater Mesonet station was 300 mm. Research block BG3 started drought treatment on 17 July 2016 and finished on 15 October 2016. During 90 days of drought, total precipitation measured by the local Stillwater Mesonet station was 298 mm. However, on 9 August, RB F15 was exposed to a total of 3.3 mm of rain and RB BG3 received 5.8 mm of rain on 9 August and 27 August.

All trials were fertilized with 49 kg N ha^{-1} from urea (46-0-0, N-P-K) one week prior to drought treatment. No fertilizer or pesticides were applied during the drought stress treatment. Mowing was stopped at 45 days into the drought as mowing no longer became necessary due to reduced growth and also since preliminary studies had shown high potential for mechanical injury to leaves once wilting occurs.

Part of zoysiagrass, seashore paspalum and st. Augustinegrass trials in RB BG3 and part of seahore paspalum and St. Augustinegrass trials were flooded during the study by heavy rainfall. However, at least 3 m from edge of unflooded trial to wet spots, bermudagrass and zoysiagrass trials in RB F15 and bermudagrass trial in RB BG3 were survived during the drought study.

Data Collection

All parameters were assessed weekly during drought treament to evaluate the performance of bermudagrass as follows:

Turf Quality (TQ): Turf quality is an indirect indicator of the drought response. It is influenced by the combination of color, live green cover, density, texture, uniformity, pest injury and a large number of abiotic and biotic factors (Morris and Shearman, 2000). During a prolonged dry period, the drought sensitive entries will lose green cover due to wilting and subsequent leaf firing which will reflect negatively on overall turf quality. However, if diseases or pests damage plants while drought stress is imposed on plants, the confounding and additive stress can devastate the overall turf quality and make the drought response evaluation more complicated (Dennis Martin, personal communications, Oklahoma State University). A scale of 1-9 was used, where 1 represented completely dead or dormant turf, 9 represented outstanding turf, and 6 represented acceptable quality turf.

Leaf Firing (LF): LF symptoms are the chlorosis and eventual browning of leaves, starting from the leaf tips and margins and gradually progressing down the leaf blades towards the leaf sheath, eventually encompasing the whole leaf (Carrow, 1996). Leaf firing ratings account for the amount of browning that has occurred on the turfgrass canopy due to drought injury on the stand. LF was rated on a 1-9 scale, 1 represented completely straw colored leaves and 9 represented completely green leaves.

Normalized Difference Vegetation Index (NDVI): NDVI was measured using a GreenSeeker Handheld Crop Sensor (Trimble Navigation Limited, Sunnyvale, CA) on a scale of 0-0.99 where 0 = no green cover and 0.99 = complete green cover (Bremer et al., 2011). The equation used in calculation of the NDVI value is as follows: NDVI=(NIR-VIS)/(NIR+VIS), where NIR is the energy reflected in a near-infrared wave band and VIS is the energy reflected in a red wave band (Xiong et al., 2007). The NDVI values gave a relative measurement of the greenness of the leaves. Data were taken at 3 to 4 pm at the same center spot of the plots to minimize errors. The GreenSeeker was held at the same height around 70 cm above the grass canopy.

Live Green Cover (LGC): Digital photos were taken to measure the percent green cover present in the plots. A custom-built light box with four 800 lumens 5000 K compact fluorescent light (CFL) bulbs (LEDVANCE LLC., Wilmington, MA) was used to maintain the consistency of daylight-like light resource. Digital images were obtained with a Canon Powershot G15 (Canon U.S.A., Inc., Melville, NY) digital camera on auto setting with 0 on white balance. The collected digital images were cropped and resized to 780 by 1000 pixels using Windows Picture manager from Microsoft Office 2010 (Microsoft, Inc., Redmond, WA). Photos were analyzed using SigmaScan Pro software (v. 5.0, SPSS, Inc., Chicago, IL) by calculating the ratio of green pixels of total pixels of the selected image. The hue setting of SigmaScan for all pictures ranged from 40 to 140 with the saturation threshold setting ranging from 0 to 100 (Karcher and Richardson, 2003).

Volumetric Soil Water Content (VSWC): VSWC is the fraction of the total volume of the soil that is occupied by the water. The VSWC of each plot was measured weekly with a Stevens POGO HydraProbe (Stevens Water Monitoring Systems Inc., Portland, OR). The VSWC values show the progression of soil moisture deficit at the top 6.4 cm soil. The VSWC was taken until the soil became so hard that the probe could not be inserted without it being damaged.

Experimental Design and Statistical Analysis

The field plantings were randomized complete block designs with four replications of entries on RB F15 and three replications on RB BG3. Analysis of variance (ANOVA) was conducted on TQ, LF rating, LGC and NDVI using Statistical Analysis System (SAS) Software 9.3 (SAS Institute Inc., Cary, NC). The analytical design for the ANOVA was a randomized complete block with split-plot in time arrangement of treatments where entries within blocks were the main plot and rating dates within entries were non-randomized subplots. A General Linear Models Procedure (Proc GLM) was utilized in SAS to conduct the ANOVA. When the entry x date interaction was found significant at $p \leq 0.05$, means of entries were separated within sampling dates using Fisher's protected least significant difference test (LSD) at the 95% significance level.

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Table 1. Bermudagrass cultivars and experimental selections tested for drought responses in experiment I.

Entry[†]	Species	Note
Celebration	*Cynodon dactylon* x *C. transvaalensis*	Drought resistant standard
OSU1220	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1221	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1225	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1257	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1273	*C. dactylon* x *C. transvaalensis*	OSU experimental
TifTuf	*C. dactylon* x *C. transvaalensis*	Drought resistance standard
Tifway	*C. dactylon* x *C. transvaalensis*	Industry standard
UGB103	Not disclosed	UGA experimental
UGB117	Not disclosed	UGA experimental
UGB118	Not disclosed	UGA experimental
UGB120	Not disclosed	UGA experimental
UGB136	Not disclosed	UGA experimental

[†]Entries with an OSU prefix indicates an experimental genotype from Oklahoma State University and an UGB prefix indicates an experimental genotype from University of Georgia.

Table 2. Bermudagrass cultivars and experimental selections tested for drought responses in experiment II.

Entry[†]	Species	Note
Astro	*Cynodon dactylon* x *C. transvaalensis*	Local standard
Celebration	*C. dactylon* x *C. transvaalensis*	Drought resistant standard
OSU1220	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1221	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1225	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1257	*C. dactylon* x *C. transvaalensis*	OSU experimental
OSU1273	*C. dactylon* x *C. transvaalensis*	OSU experimental
U-3	*C. dactylon*	Local standard
TifTuf	*C. dactylon* x *C. transvaalensis*	Drought resistance standard
Tifway	*C. dactylon* x *C. transvaalensis*	Industry standard
UGB103	Not disclosed	UGA experimental
UGB117	Not disclosed	UGA experimental
UGB118	Not disclosed	UGA experimental
UGB120	Not disclosed	UGA experimental
UGB136	Not disclosed	UGA experimental

[†]Entres with an OSU prefix indicates an experimental genotype from Oklahoma State University and an UGB prefix indicates an experimental genotype from University of Georgia.

Table 3. Zoysiagrass cultivars and experimental selections tested for drought responses in experiment III.

Entry[†]	Species	Note
DALZ1407	Not disclosed	Texas A&M experimental
DALZ1408	Not disclosed	Texas A&M experimental
DALZ1409	Not disclosed	Texas A&M experimental
DALZ1410	Not disclosed	Texas A&M experimental
DALZ1411	Not disclosed	Texas A&M experimental
Empire	*Z. japonica*	Drought resistance standard
FZ1201	Not disclosed	UF experimental
FZ1223	Not disclosed	UF experimental
FZ1231	Not disclosed	UF experimental
FZ1244	Not disclosed	UF experimental
FZ1252	Not disclosed	UF experimental
Palisade	*Z. japonica*	Drought resistance standard
Zeon	*Z. matrella*	Drought resistance standard

[†]Entres with a DALZ prefix indicates an experimental genotype from Texas A&M University AgriLife Research and Extension Center and a FZ prefix indicates an experimental genotype from University of Florida.

CHAPTER III

RESULTS AND DISCUSSION

Results

Environmental Conditions

The lengths of drought treatment were 72 days for experiment I (16 June – 28 August) and experiment III (16 June – 28 August, 2016) while the length of experiment II was 90 days (17 July- 15 October, 2016). The maximum and minimum temperatures during experiment I and III were 39 and 12 ^{o}C respectively (Figure 1) while in experiment II they were 39 and 5 ^{o}C, respectively (Figure 1). The average total solar radiation during experiment I and III were 22.1 MJ m^{-2} d^{-1} with the highest and the lowest being 28.8 and 6.4 MJ m^{-2} d^{-1}, respectively (Figure 2). The average daily total solar radiation of experiment II was 20.1 MJ m^{-2} d^{-1} while the highest and lowest were 27.9 and 3.5 MJ m^{-2} d^{-1} respectively (Figure 2). The cumulative ET estimated by the Stillwater Mesonet station by using Standardized Reference Evapotranspiration Equation multiply by the warm-season grass crop coefficient during experiment I and III was 300 mm while it was 298 mm during experiment II (Figure 3).

Results for Experiment I

Soil Moisture Content

A significant entry, date, and block effect were present with respect to the mean volumetric soil water content (MVSWC) in experiment I (Table 4). No significant entry by date interaction was found. The overall entry means were separated by LSD test ($p=0.05$) and are shown in Table 5. The MVSWC of plots in experiment I was 39.9% at 0 days after treatment (DAT) (Figure 4). As the field capacity of sandy loam soil is approximately 35% (Cornell, 2010), the MVSWC recorded in the plots at 0 DAT suggests that they were fully saturated in the upper soil profile at 6.4 cm. The MVSWC measurements were taken at 7, 14, 19, 23, 30, 36, 43, and 50 DAT in experiment I. Due to the problem with the very hard, dry soil being highly resistant to penetration with the soil probe and the likelihood of probe damage when inserting into hard soils, the MVSWC measurements were discontinued after 50 DAT. The MVSWC at each measurement date was 39.9a, 26.4b, 22.3c, 16.8d, 14.2e, 12.5f, 12.5f, and 11.2g%, respectively (Figure 4). The MVSWC had decreased rapidly from 0 to 7 days and after 7 days the MVSWC decreased at a slower rate. Since the measurements were only to a 6.4 cm depth, the MVSWC values shown can only provide insights as to soil moisture within this upper zone of the soil.

Turf Quality

Highly significant ($p<0.001$) effects of entry, rating date, and their interaction on TQ, LF, NDVI and LGC were found (Table 6). Entry means were separated using Fisher's protected least significant difference test within each rating date for each parameter evaluated.

Mean TQ for entries within each rating date are reported in Table 7. Before drought treatment, all bermudagrass entries had a mean TQ ranging from 7 to 8. There were significant differences (P=0.05) among entries for TQ at 0 DAT due to the variability of bermudagrass in color, density, texture, and uniformity. These factors as well as varietal response to chronic drought stress and its influence on live green cover led to differences among entries throughout the trial. At 30 DAT, the TQ of all bermudagrass entries remained acceptable (acceptable $\geq$ 6) with TQ means ranging from 6 to 7. At 34 DAT, OSU1220, Tifway, UGB117, UGB120, and UGB136 had TQ below acceptable. TifTuf had the highest TQ that was statistically higher TQ than all other entries at 34 DAT. At 44 DAT, TifTuf had significantly higher TQ than all other entries and had an acceptable TQ mean of 6. On that day Tifway and UGB117 were in the lowest ranking group for TQ. At 47 DAT, all entries had TQ means below acceptable, ranging from 3.8 to 5.8. On the final rating date of 72 DAT, the TQ means ranged from 2.8 to 5.5. At 72 DAT, TifTuf, OSU1221, OSU1225, OSU1257, and UGB103 ranked in the top statistical group with Tifway and UGB117 ranking in the bottom statistical group.

NDVI

Table 8 provides a comparison of the mean NDVI values of entries within rating dates. At 0 DAT, the mean NDVI ranged from 0.76 to 0.81. On that date all the experimental genotypes other than OSU1225, OSU1257 and OSU1273 were ranked in the top statistical group. From 0 DAT to 7 DAT, the mean NDVI of many entries increased numerically. This suggests that during this time drought stress was not having a large effect on NDVI. At 0 DAT, the industry standard bermudagrass Tifway ranked in the bottom statistical group and did so through the end of study. At 37 DAT, TifTuf as well as eight other bermudagrasses ranked in the top statistical group. At the end of the study at 72 DAT, UGB103, OSU1221, OSU1225, UGB136, UGB118, UGB120, and TifTuf, were ranked in the top statistical group having NDVI values from 0.55 to 0.65 NDVI with Tifway and UGB117 in the bottom statistical group with NDVI of 0.32 to 0.41.

Leaf Firing

Means of leaf firing for each entry during drought treatment were reported in Table 9. No leaf firing was found before initiating the drought treatment. At 27 DAT, UGB117 was the first entry to show leaf firing symptoms with a mean LF rating of 8.8. At 34 DAT, all entries were suffering some leaf firing with ratings ranging from 7 to 8.8. At the end of this study, mean LF ratings ranged from 3.3 to 8.5. At 72 DAT, Celebration, OSU1221, OSU1225, TifTuf, and UGB120 were ranked in the top statistical group. At that time Tifway and UGB117 were ranked in the bottom statistical group and other than for UGB117, all OSU and UGA experimental genotypes demonstrated higher resistance to leaf firing under drought than did Tifway bermudagrass.

Live Green Cover

The live green cover of bermudagrass entries determined by DIA was reported in Table 10. At 0 DAT, all entries had mean live cover more than 99.2% and OSU1220 had mean LGC of 99.8% and ranked in the top statistical group with OSU1257, UGB103, UGB117 and UGB120. At 23 DAT, the live green cover had suffered an average decline of 5% in LGC. The means of LGC ranged from 85.4 to 98.2% at that time. Beginning at 12 DAT for Tifway and at 27 DAT for UGB117, these two entries ranked in the bottom statistical group through the end of the study. At 72 DAT, means of LGC ranged from 34% to 91.4%. At the end of the study, Celebration, TifTuf, OSU1221, OSU1225, UGB103, UGB118, UGB120, and UGB136 ranked in the top statistical group. Tifway and UGB117 ranked in the bottom statistical group at 72 DAT.

Correlation Analysis

Visual parameters of turf quality (TQ), leaf firing (LF) and the quantitative, objectively assessed parameters live green cover (LGC), normalized difference vegetation index (NDVI) and mean volumetric soil water content (MVSWC) were analyzed by Pearson's Correlation analysis (Table 11). Highly significant and positive correlation was observed (ranged from r=0.83*** to r=0.93***) among the canopy assessed parameters of TQ, LF, LGC and NDVI. The TQ and LF had lower correlation coefficients, likely due to TQ being affected by genetic color, texture, density, uniformity, seedheads and drought effects collectively. The quantitative parameters of LGC and NDVI which were assessed by instrumentation and which would have been expected to have the highest amount of repeatability of measure had the highest correlation coefficients.

The correlation between MVSWC and the canopy parameters was statistically significant, positive in sign, and ranged from a low of 0.48*** for MVSWC on LF rating to moderately high (0.69***) for MVSWC on TQ rating. The generally lower correlation coefficients among MVSWC and canopy sensed parameters in contrast to the higher correlation coefficients amongst canopy sensed parameters is not surprising. Only a single depth (to 6 cm) and relative shallow volume of soil was assessed for MVSWC. Different entries may have different drought tolerance or avoidance mechanisms that might include surviving at lower moisture content or the development of a deeper root system to have access to moisture at deeper soil depths.

The correlation between DAT and other parameters was statistically significant and negative in significant and ranged from moderate (-0.65***) for DAT and LF and LGC to high (-0.88***) for DAT and MVSWC.

Results for Experiment II

Soil Moisture Content

The MVSWC measurements were taken at 0, 8, 15, 22, and 29 DAT (Figure 5). ANOVA revealed a significant Entry and Date effect with respect to the MVSWC in experiment II (Table 4). The overall entry means are presented in Table 5. OSU1257, OSU1221, UGB118, UGB120 and Celebration had statistically higher MVSWC than other entries in experiment II. Due to the problem with the very hard, dry soil being highly resistant to penetration with the soil probe and the likelihood of probe damage when inserting into hard soils, the MVSWC measurements were discontinued after 29 DAT. The MVSWC at each measurement date were 43.1a, 16.6b, 13.9c, 12.1d, and 11.9d% (p=0.05) respectively (Figure 5). The MVSWC had a rapid decreasing from 0 to 7 days and after 7days the MVSWC decreased at a slower rate. Since the measurements were only to a 6.4 cm depth, the MVSWC values shown can only provide insights as to soil moisture within this upper zone of the soil.

Turf Quality

The analysis of variance indicates that the effects of entry, rating date and their interaction were significant ($p<0.001$) for TQ, LF, NDVI and LGC (Table 12). Entry means were separated using Fisher's protected least significant difference test within each rating date for each parameter evaluated. Means of TQ for each entry during the drought treatment were reported in Table 13. Before drought treatment, all bermudagrass entries had TQ means ranging from 5.7 to 7.7. Entry Astro was the only entry below acceptable (acceptable ≥ 6) TQ at 0 DAT. At 36 DAT, all bermudagrass entries had TQ means below acceptable. TifTuf, Celebration and all the OSU experimental genotypes besides OSU1273 as well as all the UGA experimental genotypes other than UGB120 were ranked in the top statistical group on that day. Starting at 44 DAT, Astro and Tifway ranked in the bottom statistical group through the end of the study. At 90 DAT, the TQ means ranged from a low of 2.0 for Astro to a high of 5.3 for TifTuf. OSU1221 performed statistically better than all other entries except for TifTuf from which it did not differ in TQ. At the end of the study, TifTuf and OSU1221 were ranked in the top statistical group while Astro and Tifway ranked in the bottom statistical group.

NDVI

Table 14 provides a comparison of the mean NDVI values of entries within rating dates. At 0 DAT, the mean NDVI ranged from 0.65 for Celebration to 0.80 for UGB118 and UGB136. Celebration was the only entry that ranked in the bottom statistical group at 0 DAT. By 8 DAT Tifway and Astro ranked in the bottom statistical group and did so through the end of the study. At 44 DAT, there was an average increase in the NDVI by 0.04 due to the inability to tarp the trial in time to prevent exposure due to an unexpected 4 mm rain event at 42 DAT. From 44 DAT through 90 DAT, TifTuf and OSU1221 ranked in the top statistical group. At 90 DAT, the mean NDVI ranged from 0.28 to 0.68. TifTuf and OSU1221 ranked in the top statistical group while Astro and Tifway ranked in the bottom statistical group on that date. At 90 DAT TifTuf, OSU1221, OSU1257, and OSU1273 ranked statistically higher than Celebration which is considered a long term standard of drought resistance.

Leaf Firing

Means of leaf firing for each entry during drought treatment are reported in Table 15. No leaf firing symptoms were observed at 0 DAT. At 8 DAT, Astro showed leaf firing symptoms with a LF mean of 8.7 that statistically differed from all other entries. At 29 DAT, every entry besides TifTuf had leaf firing symptoms although TifTuf did not rank different from five other entries on that date. TifTuf remained unfired until 50 DAT and ranked in the top statistical group with OSU1221 on that date. At the end of this study, mean LF ranged from 2.3 to 8.0. At 90 DAT, TifTuf and OSU1221 ranked in the top statistical group while Astro and Tifway ranked in the bottom statistical group. The balance of OSU and UGA experimental genotypes did not differ in their LF ratings from the long-term drought resistant standard Celebration at 90 DAT.

Live Green Cover

The live green cover means of bermudagrass entries determined by DIA are reported in Table 16. At 0 DAT, the live cover of all entries ranged from 95.5 to 99.2%. Astro ranked in the bottom statistical group at the beginning of the study. The LGC of all entries declined in the first week of drought treatment. The decrease in LGC continued through 36 DAT for all entries. On that date, TifTuf had significantly greater LGC than all other entries. Between 36 and 44 DAT there was an increase in LGC of most entries due to an unexpected rainfall event of 2 mm on 42 DAT. Only Astro did not show any increase in LGC 44 DAT and that may have been due to Astro having been under severe drought stress prior to the event. At 63 DAT, Astro, Tifway and UGB120 had LGC of less than 50%. However, Steinke et al. (2011) found bermudagrass never decreased to 50% green coverage during 60 days of drought in two years of study. At 90 DAT, means of LGC ranged from 28.5 to 91.9%. TifTuf and OSU1221 ranked in the top statistical group and had over 20% more LGC than the entry with the next highest LGC. Tifway and Astro ranked in the bottom statistical group at 90 DAT.

Correlation Analysis

Visual parameters of turf quality (TQ), leaf firing (LF) and digital parameters live green cover (LGC), and normalized difference vegetation index (NDVI) were analyzed by Pearson's Correlation analysis. Highly significant and highly positive correlation was observed (ranged from r=0.82*** to r=0.94***) among these parameters (Table 17). The relationship between LGC and LF was lower (0.82***) than that between LGC and NDVI (0.94***). This was not surprising as instrumentation methods are generally considered more accurate than visual rating methods. Xiong et al. (2007) found that NDVI has stronger correlation with turf quality than green normalized difference vegetation index, green light reflectance in relation to near infrared reflectance and red light reflectance in relation to near infrared reflectance.

The correlation between MVSWC and the canopy parameters was statistically significant and positive in sign. and ranged from low 0.41*** for MVSWC and LF to a high of (0.81***) for MVSWC and NDVI. The correlation between LF and MVSWC was low in both bermudagrass trials. Bermudagrass might have a deep root system that can pull moisture from deeper soil when MVSWC in shallow soil was decreasing. Since only a single and relative shallow volume of soil was assessed for MVSWC, we can never know the actual MVSWC in deeper soil.

The correlation between DAT and other parameters was statistically significant and negative in significant and ranged from moderate (-0.61***) for DAT and NDVI to high (-0.85***) for DAT and MVSWC.

Results for Experiment III

Soil Moisture Content

There was a significant Entry and Date effect with respect to the mean volumetric soil water content (MVSWC) in experiment III (Table 4). The overall entry means were separated by LSD test (p=0.05) and are shown in Table 5. The good performer DALZ1411 had high MVSWC but not statistically higher than other entries. The MVSWC measurements were taken at 0, 7, 14, 19, 30, 36, 43, and 50 DAT. The MVSWC at each measurement date was 38.8a, 20.9b, 14.1c, 10.0cd, 8.2d, 7.5de, 6.7ef and 6.2f% respectively. The MVSWC had a rapid decrease from 0 to 7 days and after seven days the MVSWC decreased at a slower rate. Compared to bermudagrass in the same RB but in a different experiment, the MVSWC of zoysiagrass decreased faster although the design of the separate experiments do not allow statistical comparison. Kim and Beard (1988) pointed out that the zoysiagrass cultivar ‘Emerald’ had an ET rate of 6.0 mm d^{-1}, which was the highest ET among the C-4 grasses in their trial. Bermudagrass ‘Arizona Common,’ ‘Tifgreen,’ and Tifway had ET rate of 5.1, 5.2, and 5.2 mm d^{-1} respectively, in their experiment. Thus, the more rapid decrease in soil moisture under zoysiagrass as compared to bermudagrass may be due to zoysiagrass having a higher ET rate than bermudagrass.

Turf Quality

Highly significant ($p<0.001$) effects of entry, rating date, and their interaction were found on TQ, LF, NDVI and LGC (Table 18). Entry means were separated using Fisher’s protected least significant difference test within each rating date for each parameter evaluated. Means of TQ for entries during the drought treatment were reported in Table 19. Before drought treatment, all zoysiagrass entries had TQ means ranging from 2.0 to 5.0. Entry FZ1231 had severe winterkill and was not at fully LGC at the beginning of the study. From 0 to 12 DAT, the TQ means of many entries increased numerically. This suggests that during this time drought stress was not having a large effect on TQ. DALZ1411, DALZ1407 and FZ1201 ranked in the top statistical group throughout the study. At 41 DAT, DALZ1410 started ranking in the top statistical group throughout the end of the study. At 47 DAT, FZ1223 had a TQ mean of 1.0. It was the first zoysiagrass entry to completely turn brown under extended drought in this trial. At 72 DAT, the TQ means ranged from 1.0 to 2.3. At the end of the study, DALZ1409, DALZ1410, DALZ1411, FZ1201, and FZ1231 ranked in the top statistical group while DALZ1407, DALZ1408, Empire, FZ1223, FZ1244, FZ1252, Palisade, and Zeon ranked in the bottom statistical group.

NDVI

Means of NDVI for entries during the drought treatment were reported in Table 20. At the beginning of the study, DALZ1409, Empire, FZ1252, Palisade and Zeon performed better than other entries with respect to NDVI. The commercially available standards, which were Empire, Palisade, and Zeon, ranked in the top statistical group at 0 DAT. DALZ1411 and FZ1201 ranked in the top statistical group at 7 DAT through the rest of the study. DALZ1407 ranked in the top statistical group at 18 DAT through the end of the study. At 72 DAT, the NDVI means ranged from 0.21 to 0.40. DALZ1407, DALZ1411, and FZ1201 ranked in the top statistical group at the end of the study at 72 DAT while DALZ1408, Empire, FZ1223, FZ1231, FZ1244, Palisade and Zone ranked in the bottom statistical group on that date.

Leaf Firing

Means of LF for entries during the drought treatment were reported in Table 21. No leaf firing was found before initiating drought treatment. DALZ1407, DALZ1409, DALZ1411, FZ1201 and FZ1231 ranked in the top statistical group throughout the study. At 12 DAT, leaf firing was found on Empire, FZ1223, FZ1231, Palisade, and Zeon. DALZ1407 experienced no leaf firing at 18 DAT but was not statistically different from DALZ1409, DALZ1411, FZ1201 and FZ1244 with respect to LF on that date. FZ1231, DALZ1409, DALZ1411 and FZ1201 ranked in the top statistical group for LF at each rating date. At 72 DAT, LF means ranged from 1.0 to 2.8. At trial termination, 72 DAT, DALZ1411 and FZ1231 had statistically better performance than DALZ1408, Empire, FZ1223, FZ1244, FZ1252, Palisade and Zeon as indicated by LF.

Live Green Cover

The live green cover (LGC) means of zoysiagrass entries determined by digital image analysis was reported in Table 22. At 0 DAT, all entries had LGC of more than 93.6% and had statistically higher LGC than DALZ1410 and FZ1231. At 18 DAT, the mean LGC of all entries started to decline. At 30 DAT, the LGC ranged from 48.4 to 93.7%. DALZ1407, DALZ1408, DALZ1409, DALZ1411, FZ1201 and FZ1244 performed better than other entries on that date. At 72 DAT, LGC means ranged from 16.1 to 52.4%. The DALZ1411 ranked in the top statistical group at 72 DAT and was the only entry with LGC greater than 50% at the end of the experiment. DALZ1408, FZ1223, FZ1223, FZ1244, Palisade, and Zeon ranked in the bottom statistical group at the end of the study. The LGC of DALZ1411 declined 45.8% during 72 days of drought and FZ1231 only declined 5.7%. While the minor live green cover loss of FZ1231 might due to good drought resistance It is important to note that at the beginning of the study, FZ1231 only had 39.7% LGC due to winter kill. This fact positioned FZ1231 to display the worst LGC until 61 DAT. Furthermore, with so little LGC within its designated plot, it is likely that FZ1231 had more soil moisture available per unit surface area of live green tissue since it has so little LGC present. Thus, drought avoidance due to low canopy biomass present to transpire may in fact be what was witnessed in this trial.

Correlation Analysis

Visual parameters of turf quality (TQ), leaf firing (LF) and the quantitative, objectively assessed parameters live green cover (LGC), normalized difference vegetation index (NDVI) and mean volumetric soil water content (MVSWC) were analyzed by Pearson's

Correlation analysis (Table 11). Highly significant and positive correlation was observed (ranged from r=0.86*** to r=0.98***) among the canopy assessed parameters of TQ, LF, LGC and NDVI. The quantitative parameters of LGC and NDVI which were assessed by instrumentation had the highest amount of correlation at 0.98***.

The correlation between MVSWC and the canopy parameters was statistically significant, positive in sign. and ranged from moderate 0.51*** for MVSWC and TQ to moderately high (0.71***) for MVSWC and LF. In contrast to the bermudagrass trials, in this zoysiagrass trial, LF had the highest correlation coefficient with MVSWC. This suggests zoysiagrass LF responds more quickly to decreased MVSWC in shallow soil compared to that zoysiagrasses do not have as deep of a root system as bermudagrass.

Discussion

Turfgrass shoot system (canopy) response is often used to assess drought resistance (Huang et al., 1997; Chalmers et al., 2008). In this research, TQ, LF, NDVI, and LGC were used to evaluate the shoot system response of later stage alleged drought resistant germplasm relative to long-term industry standards as well as recent industry standards. In experiment I, all canopy assessed indicators of drought injury remained relatively unchanged or had minor decreases from 0 to 30 DAT. Between 30 to 34 DAT, all the bermudagrasses started having leaf firing symptoms when the MVSWC fell to between 12.5 to 14.2% in the top 6.4 cm of soil. In experiment II, bermudagrass started leaf firing between 14 to 21 DAT when the MVSWC fell to between 12.1 to 13.9%. Most zoysiagrasses started showing leaf firing symptoms between 12 to 18 DAT when MVSWC in the top 6.4 cm fell to a value between 12.1 to 14.1%. Marcum et al. (1995) reported on 25 different zoysiagrass genotypes having an average maximum rooting depth of 151 to 381 mm depth under greenhouse conditions. Hays et al. (1991) reported roots of 10 bermudagrass genotypes were found with roots up to 150 cm long in a greenhouse study. Zoysiagrass and bermudagrass leaves in this trial started wilting at soil moisture content between 12 to 14%. However, most of the bermudagrasses tested in this work were found to survive 90 days of drought, and many of the zoysiagrasses fired all leaves after 45 days of drought.

In experiment I, the order of the drought responses of entries from best performer to worst were: TifTuf, OSU1221, OSU1225, OSU1257, UGB136, Celebration, UGB118, UGB120, OSU1220, OSU1273, UGB117, and Tifway (Table 24) base on the number of time that the entry's mean ranked in the top statistical group for TQ, LF, NDVI and LGC. TifTuf and OSU1221 ranked in the top statistical group for TQ, LF, NDVI, and LGC at the end of the study, indicating they offered the best drought response of all entries. Yurisic (2016) reported TifTuf had better drought response compared to Latitude 36 and Tifway. The root length did not statistically differ among TifTuf, Latitude 36, and Tifway in 45 cm long lysimeters (Yurisic, 2016). However, in that research TifTuf produced more total root biomass at 15 to 45 cm soil. Superior rooting ability is another important drought avoidance mechanism compared to rooting depth. Yurisic (2016) also reported that TifTuf used 21% more water compared to Latitude 36 and Tifway by calculating soil moisture content at the end of the study. However, in my study, the VSWC in the top 6.4 cm under TifTuf was higher than that present under Tifway bermudagrass at each data collection date. It is reasonable to assume that with a non-restricted rooting depth, TifTuf tended to draw more water from deeper in the soil other than shallow soil when the surface was dry. The longer term drought resistance standard Celebration was ranked in the top statistical group for

LGC at the end of the study (Chalmers et al., 2008). However, the TQ of Celebration was not ranked in the top statistical group at the end of the study due to the color of Celebration changing drastically when drought stress lead to a color change from bluish green to gray-green. Industry standard Tifway was the worst performer compared with all the bermudagrass entries in this study and this was consistent with what Kim et al. (1988) reported. OSU1221 was the better performer when the parameters TQ, LF, NDVI and LGC were considered and comparison with other experimental genotypes was made. OSU1225, OSU1257, and UGB136 showed improved drought response compared to Celebration as a drought resistant standard. Tifway has been widely used in the southern U.S. for over 50 years. In comparison to Tifway, all experimental bermudagrass genotypes had better performance when TQ, LF, NDVI and LGC were considered and thus showed improved drought response over Tifway.

In experiment II, Astro showed leaf firing symptoms at only 8 DAT. Based on the volumetric soil water content present at 8 DAT, 16.6%, it was a little higher than that widely considered (Tolk, 2003) to be the permanent wilting point. However, compared with other bermudagrass entries, Celebration, OSU1220, OSU1225, OSU1273 and U-3 started show leaf firing symptoms at around 12% VSWC. This indicates that Astro was the most drought sensitive among all the entries tested. In experiment II, the order of the drought responses of entries from best performer to worst were: TifTuf, OSU1221, OSU1257, OSU1220, UGB136, UGB103, UGB118, UGB117, Celebration, U-3, OSU1225, Tifway, UGB120, OSU1273, and Astro base on the number of time that the entry's mean ranked in the top statistical group on TQ, LF, NDVI and LGC (Table 25). Compared to the ranking of bermudagrass from experiment I, there was a little inconsistency. OSU1225 was a good performer in experiment I. However, in experiment II, OSU1225 appeared less often in the top statistical group. Comparing the environmental conditions of the two RB, there was a tree line west of RB BG3. Bermudagrasses in experiment I received more sunlight than the bermudagrasses in experiment II. Afternoon sunlight is more important to warm-season turfgrass than morning sunlight since warm-season grasses have a higher photosynthesis rate at a warmer temperature (Bell, 2011). Afternoon shade may have caused the declinate in the performance of OSU1225. Tifway appeared more times in the top statistical group than UGB120 and OSU1220. However, most of the times when Tifway ranked in the top group were before drought symptoms occurred, indicating Tifway was still a good performing cultivar when enough moisture was present in the soil. When severe drought was imposed, Tifway's performance declined rapidly.

Based on the Stillwater Mesonet station estimation, the cumulative ET for experiment I and experiment II was 300 and 298 mm respectively (Figure 3). After subtracting the unexpected rain events during drydown, the accumulated ET for experiment I and II were 297 and 292 mm respectively following 72 and 90 days of drought, respectively. At the end of each study, TifTuf, OSU1221, and Tifway had approxmately same percent live cover compared with experiment I and II. Due to the different soil texture, the volumtric soil water content in experiment II decreased faster than experiment I. It was reasonable to assume that at the end of experiment II, the mean volumetric soil water content was lower than experiment I. Celebration, OSU1225, UGB118, UGB120, and UGB136 had more than 30% loss of green cover at the end of the study compared to experiment I. TifTuf and

OSU1221 might be able to tolerant low volumetric soil water content compared to Celebration, OSU1225, UGB118 and UGB136.

In experiment III, the order of the drought responses of entries from best performer to worst: DALZ1411, FZ1201, DALZ1409, DALZ1407, DALZ1408, DALZ1410, FZ1231, FZ1244, FZ1252, Empire, Zeon, Palisade, FZ1223 (Table 26). Most of the experimental genotypes had improved drought responses compared with the standards. DALZ1411 ranked in the top statistical group for all four testing parameters at the end of 72 days of drought treatment. Fuentealba et al. (2015) found that *Z. japonica* had a higher percentage root dry weight at 60 to 120 cm than *Z. matrella*. The difference in root distribution among different genotypes may result in differences in response to drought stress. All experimental genotypes besides FZ1223 showed improved drought response relative to the standard Empire, Zeon and Palisade. However, Poudel (2015) reported that the zoysiagrass Zeon was the most drought resistant zoysiagrass. The contradiction may be due to the fact that she used 45cm PVC tubes as growing container. Limitation of root length expansion might be the reason of different in drought response rank of Zeon. When compared with bermudagrass, zoysiagrass is not considered drought resistant. In the future, zoysiagrass breeders should work on rooting characteristics such as root length, weight, and surface area in selecting for the best drought resistant genotypes.

Future studies should involve both soil moisture measurements at different depths as well as assessments of root characteristics by destructive sampling. Lysimeters at 1.2 meters or longer are valuable to evaluate bermudagrass rooting ability. As shade and drought are often happening at the same time, it is necessary for development teams to look at how drought and shade combined effect turfgrass performance.

Conclusions

Findings of this research indicate that substantial improvements in drought responses have been made by the breeders of the experimental entries evaluated in this research. All the bermudagrass experimental genotypes showed improved drought responses compare to Tifway in experiment I. All the bermudagrass genotypes except OSU1273 and UGB120 showed improvement in drought responses compared to Tifway in experiment II. Bermudagrass TifTuf had the best drought response cultivar evaluated in experiments I and II. OSU1221 was the best drought response experimental genotype tested and performed better than Celebration and Tifway under severe drought in the two trials. Findings of this work demonstrate that the bermudagrasses TifTuf and OSU1221 can survive and maintain acceptable turf quality for approximately 72 to 90 days of drought. Astro bermudagrass is a popular commercially available cultivar in Oklahoma (Martin et al., 2014). Astro had good cold tolerance (Gopinath, 2015) but based on the findings of this research it ranks low in drought response among bermudagrasses. Zoysiagrass is not as good in drought response as bermudagrass based on generalized observations in this research. DALZ1411 was the most drought resistant zoysiagrass experimental genotype. All the zoysiagrass experimental genotypes except FZ1231 showed improved drought responses compared to all the zoysiagrasses standard.

Table 4. Analysis of variance for the effects of entry, date, block and their interaction on volumetric soil water content in experiments I, II and III.

	Experiment I				Experiment II				Experiment III			
Source	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**
Entry	12	199	16.6	2.2*	14	184	13.1	2.6*	12	252	21	2.4*
Block	3	176	58.8	7.7***	2	4	2.1	0.4NS	3	2	0.7	0.2NS
Error A	36	276	7.7		28	143	5.1		34	307	9	
Date	7	30612	4373.2	1217.0***	4	23233	5808.4	1269.3***	6	36766	6127.6	1196.5***
Date*Entry	83	288	3.5	1.0NS†	56	195	3.5	0.8NS	69	325	4.7	0.9NS
Error B	225	809	3.6		54	247	4.6		154	794	5.2	
Total	366				158				278			

†NS, *, **, ***Not significant or significantly different at P = 0.05, 0.01, or 0.001, respectively.

Table 5. The overall entry means volumetric soil water content (MVSWC) in experiments I, II and III during the drydown.

Experiment I		Experiment II		Experiment III	
Entry	MVSWC†	Entry	MVSWC	Entry	MVSWC
TifTuf	21.7a‡	Celebration	25.2a	DALZ1407	18.8a
OSU1257	21.5ab	OSU1257	25.1a	DALZ1409	17.6ab
OSU1221	21.5ab	UGB118	25.1a	FZ1201	17.2abc
UGB118	21.4ab	OSU1220	24.9a	DALZ1411	17.2abc
UGB120	21.1abc	Tifway	24.7a	DALZ1408	17.1abc
UGB136	21.0a-d	OSU1221	24.2ab	Palisade	16.5bcd
UGB103	20.8a-e	UGB120	24.2ab	FZ1252	16.5bcd
Celebration	20.2a-e	OSU1273	23.5abc	FZ1223	16.4bcd
Tifway	20.1b-e	TifTuf	22.5bcd	FZ1231	16.2bcd
OSU1273	19.9c-f	U-3	21.8cd	Empire	16.0bcd
UGB117	19.6def	UGB136	21.6cde	Zeon	15.7cd
OSU1225	19.5ef	UGB117	21.1de	DALZ1410	15.6cd
OSU1220	18.6f	OSU1225	20.6de	FZ1244	15.1d
		UGB103	19.7ef		
		Astro	17.8f		
LSD Value	1.5		2.1		1.8

†Volumetric soil water content was measured with a Stevens POGO HydraProbe.

‡Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 6. Analysis of variance for the effects of entry, date, block and their interaction, on turf quality (TQ), leaf firing (LF), normalized difference Vegetation Index (NDVI), and live green cover (LGC) response during the drydown cycles for experiment I.

	TQ†				LF‡				NDVI§				LGC¶			
Source	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**
Entry	12	117	9.8	11***	12	386	32.2	21***	12	2	0.169	15***	12	47098	3925	10***
Block	3	4	1.2	1NS	3	8	2.6	2NS	3	0.1	0.042	4*	3	3418	1139	3*
Error A	36	32	0.9		36	55	1.5		36	0.4	0.011		36	13550	376	
Date	18	1371	76.2	575***	18	811	45.1	277***	18	9.1	0.507	564***	18	106292	5905	219***
Date*Entry	216	140	0.6	5***	216	305	1.4	9***	216	1	0.04	5***	216	31246	145	5***
Error B	702	93	0.1		702	114	0.2		702	0.6	0.001		702	18931	27	
Total	987				987				987				987			

NS, *, **, ***, Non-significant (NS) or significant at 5% (*), 1% (**) or 0.1% (***).

†TQ = Turf Quality was rated on a scale from 1-9 during drydown where 1 = lowest quality and 9 = excellent quality.

‡LF = Leaf Firing was rated on a scale from 1-9 during drydown where 1= all leaves fired and 9 = no leaf firing.

§NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

¶LGC = Live Green Cover measure by digital image analysis calculating the percent live cover on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

Table 7. Comparison of mean turf quality amongst bermudagrass entries during the drydown of experiment I.

	Turf Quality†								
Entry	**0DAT‡**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**
Celebration	8.0a§	7.0d	7.0d	7.0c	6.3cd	6.0d	6.0c	6.0b	5.0cd
OSU1220	7.8ab	7.5bc	7.3cd	7.5b	7.0a	7.0a	6.8ab	5.8bc	5.0cd
OSU1221	7.5abc	7.3cd	7.0d	7.0c	7.0a	7.0a	7.0a	6.0b	5.8ab
OSU1225	7.0c	7.0d	7.0d	7.0c	7.0a	6.8ab	7.0a	6.0b	5.5bc
OSU1257	8.0a	8.0a	7.8ab	7.8ab	6.8ab	6.8ab	7.0a	6.0b	5.5bc
OSU1273	7.3bc	7.0d	7.0d	7.0c	7.0a	7.0a	6.5abc	6.0b	5.8ab
TifTuf	8.0a	7.0d	7.0d	7.0c	7.0a	7.0a	7.0a	7.0a	6.3a
Tifway	7.8ab	7.0d	7.0d	7.0c	7.0a	7.0a	6.0c	5.3c	4.8d
UGB103	7.5abc	7.8ab	7.8ab	7.8ab	7.0a	6.8ab	6.8ab	6.3b	5.5bc
UGB117	8.0a	8.0a	8.0a	8.0a	7.0a	7.0a	6.3c	5.8bc	4.8d
UGB118	7.5abc	7.8ab	7.5bc	7.0c	6.0d	6.0d	6.0c	6.0b	5.3bcd
UGB120	7.5abc	8.0a	8.0a	7.8ab	6.8ab	6.5bc	6.0c	5.8bc	5.0cd
UGB136	7.0c	7.5bc	7.5bc	7.5b	6.5bc	6.3cd	6.3c	5.8bc	5.8ab

†Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 7. (Continued) Comparison of mean turf quality amongst bermudagrass entries during the drydown of experiment I.

	Turf Quality†									
Entry	**41DAT‡**	**44DAT**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
Celebration	5.0bc§	5.0b	5.0bc	5.0bcd	5.0bc	5.0ab	4.8bc	4.8bc	4.5bc	4.5b
OSU1220	5.0bc	4.8bc	4.8c	4.3ef	4.5c	4.5bc	4.0de	4.0de	4.0c	4.0b
OSU1221	5.5b	5.3b	5.5ab	5.5ab	5.5ab	4.8bc	4.8bc	4.8bc	4.8b	4.8ab
OSU1225	5.5b	5.3b	5.3abc	5.3abc	5.0bc	4.8bc	4.8bc	4.8bc	4.8b	4.8ab
OSU1257	5.3b	5.0b	5.3abc	5.0bcd	5.0bc	5.0ab	5.0ab	5.0ab	4.8b	4.8ab
OSU1273	5.3b	5.0b	5.0bc	5.0bcd	5.0bc	4.8bc	4.5bcd	4.5bcd	4.5bc	4.0b
TifTuf	6.3a	6.0a	5.8a	5.8a	5.8a	5.5a	5.5a	5.5a	5.5a	5.5a
Tifway	4.0d	4.0d	4.0d	3.3g	3.3d	3.3e	3.0f	3.0f	3.0d	2.8c
UGB103	5.3b	5.0b	5.0bc	5.0bcd	5.0bc	5.0ab	4.8bc	4.8bc	4.8b	4.8ab
UGB117	4.5cd	4.3cd	3.8d	3.8fg	3.8d	3.8de	3.8e	3.5ef	3.0d	3.0c
UGB118	5.0bc	5.0b	5.0bc	4.5de	4.5c	4.5bc	4.5bcd	4.5bcd	4.5bc	4.5b
UGB120	5.0bc	5.0b	5.0bc	5.0bcd	4.8c	4.3cd	4.3cde	4.3cd	4.0c	4.0b
UGB136	5.5b	5.0b	4.8c	4.8cde	4.8c	4.8bc	4.8bc	4.8bc	4.5bc	4.3b

†Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 8. Comparison of mean normalized difference vegetation index amongst bermudagrass entries during the drydown of experiment I.

	Normalized difference Vegetation Index (NDVI)†								
Entry	**0DAT‡**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**
Celebration	0.78bcd§	0.81cd	0.80bcd	0.79cd	0.74de	0.70cd	0.71bc	0.66ab	0.63abc
OSU1220	0.81a	0.82ab	0.82a	0.81ab	0.78ab	0.72abc	0.73ab	0.66ab	0.63abc
OSU1221	0.79ab	0.82abc	0.81abc	0.81ab	0.78a	0.73abc	0.75a	0.68a	0.65ab
OSU1225	0.78bcd	0.81bc	0.81abc	0.80abc	0.77ab	0.72abcd	0.73ab	0.66ab	0.63abc
OSU1257	0.76de	0.82abc	0.82a	0.81ab	0.78a	0.71abcd	0.74ab	0.65ab	0.63abc
OSU1273	0.77cde	0.81abc	0.80abcd	0.80abc	0.75cd	0.69d	0.69c	0.63b	0.61c
TifTuf	0.76e	0.79de	0.79de	0.80abc	0.76abc	0.70cd	0.72abc	0.65ab	0.66a
Tifway	0.76de	0.79e	0.78e	0.76e	0.72e	0.66e	0.64d	0.56c	0.52d
UGB103	0.80ab	0.81abc	0.82a	0.80bc	0.77ab	0.73ab	0.72abc	0.66ab	0.63abc
UGB117	0.79abc	0.81abc	0.79cd	0.78d	0.73de	0.66e	0.65d	0.57c	0.53d
UGB118	0.80a	0.83a	0.81ab	0.80bc	0.77abc	0.73ab	0.74ab	0.68a	0.64abc
UGB120	0.79ab	0.83a	0.81ab	0.82a	0.76bc	0.70bcd	0.72ab	0.66ab	0.61bc
UGB136	0.80ab	0.81bc	0.81abc	0.79cd	0.77ab	0.73a	0.73ab	0.67a	0.65a

†NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 8. (Continued) Comparison of mean normalized difference vegetation index amongst bermudagrass entries during the drydown of experiment I.

	Normalized difference Vegetation Index (NDVI)†									
Entry	**41DAT‡**	**44DAT**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
Celebration	0.62abc§	0.64ab	0.65ab	0.66a-d	0.65a	0.63a	0.61ab	0.60abc	0.59ab	0.52bc
OSU1220	0.61bc	0.57c	0.58c	0.58e	0.55c	0.53b	0.52c	0.50d	0.49c	0.50cd
OSU1221	0.65a	0.64ab	0.66ab	0.69ab	0.65a	0.62a	0.59abc	0.59abc	0.59ab	0.61ab
OSU1225	0.64ab	0.65a	0.65ab	0.69abc	0.64a	0.62a	0.61ab	0.59abc	0.57ab	0.61ab
OSU1257	0.60c	0.60bc	0.59c	0.63b-e	0.60abc	0.59ab	0.57abc	0.56bcd	0.55abc	0.55bc
OSU1273	0.59c	0.59bc	0.60bc	0.62de	0.60abc	0.57ab	0.55bc	0.54cd	0.53bc	0.52bc
TifTuf	0.65a	0.65a	0.67a	0.70a	0.65a	0.63a	0.63a	0.63a	0.62a	0.65a
Tifway	0.48d	0.47d	0.44d	0.43f	0.42d	0.40c	0.37d	0.365e	0.34d	0.32e
UGB103	0.61bc	0.61abc	0.61bc	0.63cde	0.60abc	0.57ab	0.55bc	0.55bcd	0.52bc	0.55abc
UGB117	0.50d	0.49d	0.46d	0.48f	0.46d	0.43c	0.40d	0.41e	0.41d	0.41de
UGB118	0.61abc	0.63ab	0.62abc	0.65a-d	0.63ab	0.63a	0.61ab	0.61ab	0.61a	0.62ab
UGB120	0.60c	0.60bc	0.62abc	0.65a-d	0.58bc	0.58ab	0.57abc	0.56bcd	0.55abc	0.58abc
UGB136	0.64ab	0.63ab	0.64abc	0.64bcd	0.62ab	0.61a	0.58abc	0.59abc	0.57ab	0.58abc

†NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.
‡DAT = Days after starting drought treatment.
§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 9. Comparison of mean leaf firing amongst bermudagrass entries during the drydown of experiment I.

	Leaf Firing[†]								
Entry	**0DAT[‡]**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**
Celebration	9.0a[§]	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.0bc	8.0b
OSU1220	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	7.8bc	7.3c
OSU1221	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.8ab	8.0bc	8.0b
OSU1225	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.0bc	8.0b
OSU1257	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.0bc	8.0b
OSU1273	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.8ab	8.0bc	7.5bc
TifTuf	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.8a	8.8a
Tifway	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.3b	7.0d	6.5d
UGB103	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.0bc	7.5bc
UGB117	9.0a	9.0a	9.0a	9.0a	9.0a	8.8b	8.8ab	7.5cd	7.0cd
UGB118	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.0bc	8.0b
UGB120	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.8ab	8.3ab	8.0b
UGB136	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	8.3ab	8.0b

[†]Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.
[‡]DAT = Days after starting drought treatment.
[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 9. (Continued) Comparison of mean leaf firing amongst bermudagrass entries during the drydown of experiment I.

	Leaf Firing†									
Entry	**41DAT‡**	**44DAT**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
Celebration	7.5bc§	7.5abc	8.0b	7.8bc	7.8b	7.8abc	7.8abc	7.8ab	7.5ab	7.5ab
OSU1220	7.0cd	7bc	7.3c	7.3c	7.3b	6.8d	6.5d	6.5c	6.5b	6.5b
OSU1221	7.8abc	7.3bc	8.0b	8.0b	7.8b	7.5bcd	7.5bc	7.5abc	7.5ab	7.5ab
OSU1225	8.0ab	7.3bc	8.0b	8.0b	7.8b	7.8abc	7.5bc	7.5abc	7.5ab	7.5ab
OSU1257	7.5bc	7.0bc	8.0b	8.0b	8.0ab	7.8abc	7.5bc	7.5abc	7.5ab	7.3b
OSU1273	7.3bc	6.8cd	8.0b	8.0b	7.8b	7.0cd	6.5d	6.5c	6.5b	6.5b
TifTuf	8.5a	8.3a	8.8a	8.8a	8.8a	8.5a	8.5a	8.5a	8.5a	8.5a
Tifway	6.3d	6.0de	5.3d	5.0d	4.0d	3.8f	3.8e	3.8d	3.5c	3.3c
UGB103	7.5bc	7.0bc	7.8bc	7.5bc	7.5b	7.3bcd	7.3bcd	7.0bc	7.0b	7.3b
UGB117	6.3d	5.8e	5.5d	5.5cd	5.3c	5.0e	4.5e	4.3d	4.3c	4.3c
UGB118	7.5bc	7.3bc	7.5bc	7.3c	7.3b	7.0cd	7.0cd	7.0bc	7.0b	7.0b
UGB120	8.0ab	7.8ab	8.0b	8.0b	8.0ab	8.0ab	8.0ab	8.0ab	7.3b	7.5ab
UGB136	7.3bc	7.3bc	7.5bc	7.5bc	7.5b	7.3bcd	7.0cd	7.0bc	7.0b	7.0b

†Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.
‡DAT = Days after starting drought treatment.
§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 10. Comparison of mean live green cover amongst bermudagrass entries during the drydown of experiment I.

	Live Green Cover (%) †								
Entry	**0DAT‡**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**
Celebration	99.4bcd§	99.4ab	99.4abc	99.1cde	94.2ef	91.3bcd	94.2b-e	83.7ab	80.1cd
OSU1220	99.8a	99.8a	99.7a	99.7a	96.9abc	92.9abc	94.8a-e	80.6bc	81.1cd
OSU1221	99.5abcd	99.6a	99.7ab	99.5abc	99.0a	96.5a	98.2a	89.1a	88.2ab
OSU1225	99.5bcd	99.1abc	99.6abc	99.7a	97.9ab	93.8abc	96.3abc	84.4ab	85.0abc
OSU1257	99.7ab	98.5bc	99.8a	99.8a	99.0a	95.1ab	97.4ab	81.3bc	81.8bcd
OSU1273	99.5bcd	98.1c	99.4abc	99.4abcd	96.5bcd	90.7bcd	93.2c-f	80.8bc	76.3de
TifTuf	99.3de	99.0abc	98.8d	99.0de	97.9ab	94.8ab	96.9abc	89.1a	89.1a
Tifway	99.2e	99.6a	99.2cd	98.9e	95.4cdef	89.1cd	89.6f	71.8e	69.8f
UGB103	99.5abcd	99.1abc	99.6abc	99.5a	97.9ab	93.1abc	95.3a-e	80.0bcd	79.4cde
UGB117	99.7abc	99.1abc	99.3abc	99.4abc	96.0bcde	87.1d	85.4g	68.8e	63.0g
UGB118	99.4de	99.4ab	99.4abc	98.9de	93.7f	89.8cd	92.2def	75.2cde	76.3de
UGB120	99.7ab	99.3ab	99.0abc	99.5abc	94.5def	87.1d	91.5ef	73.3de	73.2ef
UGB136	99.4cde	99.6a	99.3bc	99.2bcde	97.6abc	94.0abc	95.6a-d	86.0ab	84.6abc

† Live cover is the result of digital image analysis (DIA) via SigmaScan software with results presented as a percentage.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 10. (Continued) Comparison of mean live green cover amongst bermudagrass entries during the drydown of experiment I.

	Live Green Cover (%) †									
Entry	**41DAT‡**	**44DAT**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
Celebration	81.5bcd§	86.3a-d	86.4abc	90.7abc	89.8ab	86.5abc	84.0ab	82.5abc	82.5ab	84.2a-d
OSU1220	78.5cd	78.8de	78.2cd	79.1d	74.7de	69.4e	65.8d	66.1d	63.5c	68.3de
OSU1221	91.1a	93.6a	93.2a	95.9a	91.1ab	87.2ab	83.6ab	86.4ab	84.2ab	88.1ab
OSU1225	85.8abc	89.5abc	88.4ab	91.7abc	87.5abc	84.6a-d	81.6abc	82.2abc	81.8ab	85.3abc
OSU1257	76.8d	78.3de	77.5cd	83.9bcd	84.3a-d	79.5a-e	74.0bcd	75.0bcd	71.0bc	74.0bcd
OSU1273	75.4de	80.6cde	77.9cd	83.3cd	81.8b-e	76.5b-e	70.9bcd	69.8cd	65.6c	69.9cd
TifTuf	88.2ab	92.4ab	91.8a	94.2ab	92.7a	89.0a	88.1a	89.4a	88.8a	91.4a
Tifway	66.3f	62.8f	55.9e	56.0e	55.2f	50.9f	44.4e	40.1e	36.8d	34.0f
UGB103	78.6cd	80.9cde	79.9bcd	85.7a-d	81.2b-e	74.2de	71.8bcd	72.0cd	70.2bc	77.2a-d
UGB117	63.6f	61.1f	58.0e	63.6e	61.3f	53.5f	50.4e	51.1e	47.2d	53.6e
UGB118	76.8d	77.1de	76.0d	80.1d	79.3cde	75.5cde	75.7a-d	78.5a-d	77.2abc	84.0a-d
UGB120	69.0ef	75.5e	77.5cd	81.4cd	72.2e	69.3e	69.2cd	72.2cd	70.9bc	79.3a-d
UGB136	85.9ab	83.1b-e	83.3a-d	85.1bcd	83.0a-d	79.5a-e	75.1a-d	73.9cde	73.1abc	80.8a-d

† Live cover is the result of digital image analysis (DIA) via SigmaScan software with results presented as a percentage.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 11. Pearson's Correlation Analysis amongst leaf firing (LF), turf quality (TQ), live green cover (LGC), normalized difference vegetation index (NDVI), mean volumetric soil water content (MVSWC) and days after starting drought treatment collected during drydown in experiment I.

Parameter	TQ‡	NDVI§	LGC¶	MVSWC#	DAT††
LF†	0.84***	0.89***	0.89***	0.48***	-0.65***
TQ		0.90***	0.83***	0.69***	-0.86***
NDVI			0.93***	0.62***	-0.79***
LGC				0.56***	-0.65***
MVSWC					-0.88***

*** Significant at $P = 0.001$.
†LF = Leaf Firing was rated on a scale from 1-9 during drydown where 1= all leaves fired and 9 = no leaf fired.
‡TQ = Turf Quality was rated on a scale from 1-9 during drydown cycles where 1 = lowest quality and 9 = excellent quality.
§NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.
¶ LGC = Live Green Cover measure by digital image analysis calculating the percent live cover on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.
#MVSWC=Mean Volumetric Soil Water Content was measured with a Stevens POGO HydraProbe.
††DAT=Days after starting drought treatment.

Table 12. Analysis of variance for the effects of entry, date, block and their interaction on bermudagrass turf quality (TQ), leaf firing (LF), normalized difference vegetation index (NDVI) and live green cover (LGC) response during the drydown cycle for experiment II.

	TQ†				LF‡				NDVI§				LGC¶			
Source	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**
Entry	14	221.8	15.8	14.6***	14	443	31.7	17.9***	14	2.66	0.189	12.5***	14	70800	5057	9.9***
Block	2	0.2	0.1	0.1NS	2	2	1.1	0.6NS	2	0.02	0.012	0.8NS	2	622	311	0.6NS
Error A	28	30.4	1.1		28	49	1.8		28	0.43	0.015		28	14269	510	
Date	13	695.3	53.5	351.2***	13	1011	77.7	404.3***	13	3.98	0.306	300.5***	13	79261	6097	271.8***
Date*Entry	182	99.2	0.5	3.6***	182	284	1.6	8.1***	182	0.97	0.005	5.3***	182	23256	128	5.7***
Error B	390	59.4	0.2		390	75	0.2		390	0.40	0.001		390	8749	22	
Total	629				629				629				629			

NS, *, **, ***, Non-significant (NS) or significant at 5% (*), 1% (**) or 0.1% (***).

†TQ = Turf Quality was rated on a scale from 1-9 during drydown where 1 = lowest quality and 9 = excellent quality.

‡LF = Leaf Firing was rated on a scale from 1-9 during drydown where 1= all leaves fired and 9 = no leaf fired.

§NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

¶ LGC = Live Green Cover measure by digital image analysis calculating the percent live cover on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

Table 13. Comparison of mean turf quality amongst bermudagrass entries during the drydown of experiment II.

	Turf Quality†						
Entry	**0DAT‡**	**8DAT**	**15DAT**	**22DAT**	**29DAT**	**36DAT**	**44DAT**
Astro	5.7f§	5.3c	5.0c	5.0c	4.3d	3.7d	3.7e
Celebration	6.0ef	5.7bc	5.7ab	5.0c	5.0c	5.0abc	5.0bc
TifTuf	7.0bc	6.0abc	6.0a	6.0a	5.7ab	5.7a	5.7ab
OSU1220	7.0bc	6.0abc	6.0a	6.0a	6.0a	5.0abc	5.0bc
OSU1221	7.0bc	6.0abc	6.0a	6.0a	6.0a	5.3ab	6.0a
OSU1225	7.0bc	6.0abc	6.0a	6.0a	6.0a	5.3ab	5.3abc
OSU1257	7.0bc	6.0abc	5.7ab	5.7ab	5.7ab	5.3ab	5.3abc
OSU1273	6.3de	6.7a	6.0a	5.3bc	5.3bc	4.7bc	4.7cd
U-3	6.3de	6.0abc	5.7ab	5.0c	5.3bc	4.7bc	4.0de
Tifway	7.0bc	6.0abc	6.0a	5.7ab	5.0c	4.3cd	3.7e
UGB103	7.3ab	6.3ab	6.0a	6.0a	6.0a	5.3ab	5.3abc
UGB117	7.7a	6.0abc	6.0a	6.0a	6.0a	5.0abc	4.7cd
UGB118	6.7cd	6.3ab	6.0a	5.7ab	5.7ab	5.0abc	4.7cd
UGB120	7.3ab	6.0abc	5.3bc	5.0c	5.3bc	4.7bc	4.7cd
UGB136	7.0bc	6.0abc	6.0a	5.0c	6.0a	5.3ab	5.3abc

†Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 13. (Continued) Comparison of mean turf quality amongst bermudagrass entries during the drydown of experiment II.

	Turf Quality[†]						
Entry	**50DAT[‡]**	**56DAT**	**63DAT**	**68DAT**	**75DAT**	**82DAT**	**90DAT**
Astro	2.3f[§]	2.3e	2.0f	2.0f	2.0f	2.0f	2.0d
Celebration	4.3cd	4.0cd	4.0bc	4.0bc	4.0bc	3.3d	3.0bc
TifTuf	5.7a	5.7a	5.7a	5.7a	5.7a	5.3a	5.3a
OSU1220	4.3cd	4.3cd	4.3b	4.3b	4.3b	3.7cd	3.7b
OSU1221	5.7a	5.3ab	5.3a	5.3a	5.3a	5.0ab	5.0a
OSU1225	4.7bc	4.3cd	4.3b	4.0bc	4.0bc	3.3d	3.3b
OSU1257	4.7bc	4.7bc	4.3b	4.3b	4.3b	4.3bc	3.7b
OSU1273	4.0cd	3.7d	3.3cd	3.3cd	3.0de	3.0de	3.0bc
U-3	4.0cd	3.7d	3.0de	3.0de	3.0de	3.0de	3.0bc
Tifway	3.0ef	2.7e	2.3ef	2.3ef	2.3ef	2.3ef	2.3cd
UGB103	4.7bc	4.7bc	4.0bc	4.0bc	4.0bc	3.7cd	3.3b
UGB117	4.3cd	4.3cd	3.3cd	3.3cd	3.3cd	3.0de	3.0bc
UGB118	4.0cd	4.3cd	4.3b	3.7bcd	3.7bcd	3.7cd	3.3b
UGB120	3.7de	3.7d	3.3cd	3.3cd	3.3cd	3.3d	3.0bc
UGB136	5.3ab	4.7bc	4.0bc	4.0cb	3.3cd	3.3d	3.3b

[†]Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

[‡]DAT = Days after starting drought treatment.

[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 14. Comparison of mean normalized difference vegetation index amongst bermudagrass entries during the drydown of experiment II.

	Normalized difference Vegetation Index[†]						
Entry	**0DAT[‡]**	**8DAT**	**15DAT**	**22DAT**	**29DAT**	**36DAT**	**44DAT**
Astro	0.76a[§]	0.62b-e	0.57def	0.51hi	0.49e	0.38g	0.38e
Celebration	0.65b	0.68ab	0.65ab	0.64ab	0.61bc	0.53cde	0.58bcd
TifTuf	0.76a	0.67ab	0.64abc	0.64a	0.7a	0.66a	0.7a
OSU1220	0.76a	0.63a-d	0.58def	0.57d-g	0.61bc	0.54b-e	0.58bcd
OSU1221	0.78a	0.62a-d	0.6cd	0.57c-g	0.66ab	0.59b	0.7a
OSU1225	0.74ab	0.57edf	0.59de	0.59b-e	0.6bc	0.53cde	0.57bcd
OSU1257	0.74ab	0.62a-d	0.6cd	0.61a-d	0.62bc	0.57bc	0.63b
OSU1273	0.78a	0.61cde	0.6cd	0.53f-i	0.54de	0.52def	0.55cd
U-3	0.78a	0.65abc	0.61bcd	0.61a-d	0.61bc	0.53cde	0.55cd
Tifway	0.75ab	0.58def	0.54ef	0.5i	0.51e	0.46f	0.44e
UGB103	0.78a	0.64abc	0.61bcd	0.58c-f	0.58cd	0.51def	0.56bcd
UGB117	0.78a	0.56ef	0.54ef	0.53ghi	0.57cd	0.49ef	0.53d
UGB118	0.80a	0.68ab	0.66a	0.62abc	0.61bc	0.55bcd	0.6bc
UGB120	0.74ab	0.54f	0.54f	0.53ghi	0.58cd	0.49ef	0.53d
UGB136	0.80a	0.57def	0.56def	0.55e-h	0.62bc	0.51def	0.61bc

[†]NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.
[‡]DAT = Days after starting drought treatment.
[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 14. (Continued) Comparison of mean normalized difference vegetation index amongst bermudagrass entries during the drydown of experiment II.

	Normalized difference Vegetation Index[†]						
Entry	**50DAT[‡]**	**56DAT**	**63DAT**	**68DAT**	**75DAT**	**82DAT**	**90DAT**
Astro	0.34f[§]	0.33f	0.29f	0.26g	0.28f	0.27e	0.28d
Celebration	0.54cde	0.53cde	0.49cde	0.47c-f	0.45de	0.44cd	0.43c
TifTuf	0.69a	0.68a	0.64a	0.66a	0.66a	0.66a	0.68a
OSU1220	0.54cde	0.51cde	0.48cde	0.49cde	0.49cde	0.5bc	0.5bc
OSU1221	0.64ab	0.64ab	0.59ab	0.62ab	0.64ab	0.65a	0.66a
OSU1225	0.56bcd	0.54cde	0.48cde	0.51cd	0.51cd	0.49bc	0.5bc
OSU1257	0.59bc	0.57bc	0.54bc	0.55bc	0.56bc	0.54b	0.54b
OSU1273	0.54cde	0.51cde	0.44de	0.46def	0.45de	0.43cd	0.45b
U-3	0.5de	0.49de	0.44de	0.45def	0.44de	0.43cd	0.42c
Tifway	0.39f	0.37f	0.31f	0.31g	0.31f	0.3e	0.31d
UGB103	0.52cde	0.52cde	0.47cde	0.47c-f	0.48cde	0.46bcd	0.45bc
UGB117	0.48e	0.47e	0.41e	0.41f	0.41e	0.41d	0.42c
UGB118	0.52cde	0.55cd	0.49cd	0.49c-f	0.48cde	0.49bcd	0.5bc
UGB120	0.49de	0.49de	0.41e	0.42ef	0.42e	0.43cd	0.45c
UGB136	0.52cde	0.53cde	0.46de	0.45def	0.46de	0.49bcd	0.5bc

[†]NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.
[‡]DAT = Days after starting drought treatment.
[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 15. Comparison of mean leaf firing ratings amongst bermudagrass entries during the drydown of experiment II.

	Leaf Firing[†]						
Entry	**0DAT[‡]**	**8DAT**	**15DAT**	**22DAT**	**29DAT**	**36DAT**	**44DAT**
Astro	9.0a[§]	8.7b	8.3bc	7.3d	7.3d	6.7d	6.7c
Celebration	9.0a	9.0a	8.3bc	8.0c	8.0bcd	7.3c	7.7bc
TifTuf	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a	9.0a
OSU1220	9.0a	9.0a	8.7ab	8.7ab	8.0bcd	8.0b	8.0ab
OSU1221	9.0a	9.0a	9.0a	9.0a	8.7ab	8.7a	8.7ab
OSU1225	9.0a	9.0a	8.3bc	8.3bc	8.0bcd	8.0b	8.0ab
OSU1257	9.0a	9.0a	9.0a	9.0a	8.0bcd	8.0b	8.0ab
OSU1273	9.0a	9.0a	8.3bc	8.3bc	8.3abc	8.0b	7.7bc
U-3	9.0a	9.0a	8.3bc	8.0c	7.7cd	7.0cd	7.7bc
Tifway	9.0a	9.0a	9.0a	8.0c	8.0bcd	7.0cd	6.7c
UGB103	9.0a	9.0a	9.0a	9.0a	8.0bcd	8.0b	8.0ab
UGB117	9.0a	9.0a	9.0a	9.0a	8.7ab	8.0b	8.0ab
UGB118	9.0a	9.0a	9.0a	8.0c	8.0bcd	8.0b	8.0ab
UGB120	9.0a	9.0a	9.0a	8.3bc	8.3abc	8.0b	8.0ab
UGB136	9.0a	9.0a	9.0a	9.0a	8.7ab	8.0b	8.0ab

[†]Leaf firing (LF) was rated on a scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.
[‡]DAT = Days after starting drought treatment.
[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 15. (Continued) Comparison of mean leaf firing ratings amongst bermudagrass entries during the drydown of experiment II.

	Leaf Firing[†]						
Entry	**50DAT[‡]**	**56DAT**	**63DAT**	**68DAT**	**75DAT**	**82DAT**	**90DAT**
Astro	4.3e[§]	3.7f	2.7f	3.7de	2.7f	2.3e	2.3d
Celebration	7.0c	7.0cd	7.0b	7.0ab	7.0abc	6.3b	5.3bc
TifTuf	8.7a	8.3a	8.0a	8.0a	8.0a	8.0a	8.0a
OSU1220	7.3bc	7.3bc	6.0cd	6.3bc	6.7bcd	6.3b	6.0bc
OSU1221	8.0ab	8ab	8.0a	8.0a	8.0a	8.0a	8.0a
OSU1225	7.7bc	7.3bc	6.7bc	6.7ab	6.7bcd	6.3b	6.3b
OSU1257	7.7bc	7.3bc	7.3ab	7.3ab	7.3ab	6.3b	6.3b
OSU1273	7.0c	6.3de	5.3de	5.0cd	5.0e	5.3bcd	4.7c
U-3	6.0d	6.0e	5.7de	5.0cd	5.0e	5.0cd	4.7c
Tifway	5.3d	4.0f	3.0f	2.3ef	2.3f	2.3e	2.3d
UGB103	7.7bc	7.3bc	6.7bc	6.7ab	6.3bcd	5.7bcd	5.0bc
UGB117	7.3bc	6.3de	5.0e	5.0cd	5.0e	4.7d	4.7c
UGB118	7.0c	7.0cd	7.0b	6.7ab	6.3bcd	6.0bc	5.7bc
UGB120	7.3bc	7.0cd	6.7bc	6.0bc	5.7de	5.3bcd	5.0bc
UGB136	7.3bc	7.3bc	7.0b	6.7ab	6.0cde	5.7bcd	5.7bc

[†]Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.
[‡]DAT = Days after starting drought treatment.
[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test.

Table 16. Comparison of mean live green cover amongst bermudagrass entries during the drydown of experiment II.

	Live Green Cover (%) †						
Entry	**0DAT‡**	**8DAT**	**15DAT**	**22DAT**	**29DAT**	**36DAT**	**44DAT**
Astro	96.1de§	76.7b-e	76.8de	64.2e	58.3g	43.7g	43.5f
Celebration	98.2abc	90.2a	92.9a	90.2a	82a-d	71.1bc	78.1bcd
TifTuf	98.2abc	89ab	88.9ab	89.4a	91.5a	87.6a	94.1a
OSU1220	97.6a-d	80.4a-d	75.9e	74.5bcd	78.6b-e	68.3bcd	77.3bcd
OSU1221	97.4a-d	81.2a-d	81.9b-e	78bcd	86.9ab	76b	93.7a
OSU1225	98.0abc	71.3de	75.3e	76bcd	77.8b-f	70.1bc	77.1bcd
OSU1257	97.1cde	80.6a-d	85.2a-d	82abc	82.5abc	75.7b	85.4ab
OSU1273	96.9cde	76.6b-e	78.6cde	70.1de	70.9c-f	63.2cde	71.9cde
U-3	98.4abc	88.8ab	86.3abc	83.1ab	81a-e	67.9bcd	75.8bcd
Tifway	97.2bcde	79.4a-d	76.8de	70.2de	66.6fg	58.4ef	60.2e
UGB103	98.1abc	78.4a-d	83.3b-e	72.6cde	70.3def	60edf	68.9de
UGB117	99.0ab	73.1cde	75.4e	69.2de	70.1efg	57.1ef	67.7de
UGB118	98.4abc	84.4abc	85a-d	77.7bcd	72.8c-f	62.4cde	70.9de
UGB120	95.5e	64.3e	63.3f	62.7e	66.7fg	52.2fg	63.3e
UGB136	99.2a	71.8cde	74.9e	71.3de	80.2a-e	64.5cde	83.6abc

†Live cover is the result of digital image analysis (DIA) via SigmaScan software with results presented as a percentage.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 16. (Continued) Comparison of mean live green cover amongst bermudagrass entries during the drydown of experiment II.

	Live Green Cover (%) †						
Entry	**50DAT‡**	**56DAT**	**63DAT**	**68DAT**	**75DAT**	**82DAT**	**90DAT**
Astro	40.6g§	36.3h	31.5g	28.5g	26.1g	26.9e	28.5e
Celebration	72.5cde	72cd	68.2c	66.2cd	61.7c	53.2bc	54.9bc
TifTuf	94.1a	93a	92.2a	92.2a	91.4a	89.7a	91.9a
OSU1220	70.4cde	67.3cde	66.9c	65.4cd	62.6c	56bc	59.2bc
OSU1221	86.7ab	87.5ab	86.6ab	86.9ab	85.2ab	84.3a	88a
OSU1225	73.1cd	68.9cd	68.8c	67.8cd	61.8c	56.2bc	60.9bc
OSU1257	79.3bc	77.7bc	74.7bc	75.1bc	69.5bc	62b	67.9b
OSU1273	69.8cde	64.1def	61.9cde	59.1cde	55.1cde	52.7bc	53.7bc
U-3	70.8cde	65.7c-f	63.9cd	64.6cd	58.6cd	53.9bc	57.1bc
Tifway	55.4f	49.3g	45.1fg	39.6fg	35.6fg	34.2de	35.8de
UGB103	65.8def	62.2def	60.2c-f	60cde	57.7cd	48.7bcd	54.1bc
UGB117	61.7ef	53.6fg	49.8def	47.6ef	41.4efg	44.5cd	45.5cd
UGB118	65.6def	62.6def	59.3c-f	55.7def	56.9cde	55.4bc	57.1bc
UGB120	56.8f	55.2efg	47.9ef	45.6ef	43.8def	43cd	49.8cd
UGB136	69.9cde	69.7cd	63.1cde	60.7cde	54.8cde	55.4bc	57.4bc

†Live cover is the result of digital image analysis (DIA) via SigmaScan software with results presented as a percentage.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 17. Pearson's Correlation Analysis amongst leaf firing (LF), turf quality (TQ), live green cover (LGC), normalized difference vegetation index (NDVI), mean volumetric soil water content (MVSWC) and days after starting drought treatment collected during drydown in experiment II.

Parameter	TQ‡	NDVI§	LGC¶	MVSWC#	DAT††
LF†	0.89***	0.83***	0.82***	0.41***	-0.73***
TQ		0.87***	0.84***	0.67***	-0.78***
NDVI			0.94***	0.81***	-0.61***
LGC				0.77***	-0.58***
MVSWC					-0.85***

*** Significant at $P = 0.001$.

†LF = Leaf Firing was rated on a scale from 1-9 during drydown where 1= all leaves fired and 9 = no leaf fired.

‡TQ = Turf Quality was rated on a scale from 1-9 during drydown cycles where 1 = lowest quality and 9 = excellent quality.

§NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

¶LGC = Live Green Cover measure by digital image analysis calculating the percent live cover on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

#MVSWC=Mean Volumetric Soil Water Content was measured with a Stevens POGO HydraProbe.

††DAT=Days after starting drought treatment.

Table 18. Analysis of variance for the effects of entry, date, block and their interaction on turf quality (TQ), leaf firing (LF), normalized difference Vegetation Index (NDVI), and live green cover (LGC) response during the drydown cycles for experiment III.

	TQ†				LF‡				NDVI§				LGC¶			
Source	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**	**df**	**SS**	**MS**	**F**
Cultivar	12	240	20.0	3.7**	12	512	42.7	6***	12	4.6	0.38	6.9***	12	105537	8795	5.8***
Block	3	17	5.6	1.1NS	3	30	9.9	1NS	3	0.1	0.05	0.9NS	3	5312	1770	1.2NS
Error A	36	193	5.4		36	260	7.2		36	2.0	0.06		36	54668	1519	
Date	18	1064	59.1	320.8***	18	7503	417	1161***	18	25	1.37	991.9***	18	531084	29505	712.2***
Date*Cult.	216	218	1.0	5.5***	216	237	1.1	3***	216	2.5	0.01	8.2***	216	51013	236	5.7***
Error B	702	129	0.2		702	252	0.4		702	1.0	0.01		702	20908	41	
Total	987				987				987				987			

NS, *, **, ***, Non-significant (NS) or significant at 5% (*), 1% (**) or 0.1% (***).

†TQ = Turf Quality was rated on a scale from 1-9 during drydown where 1 = lowest quality and 9 = excellent quality.

‡LF = Leaf Firing was rated on a scale from 1-9 during drydown where 1= all leaves fired and 9 = no leaf firing.

§NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

¶LGC = Live Green Cover measure by digital image analysis calculating the percent live cover on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

Table 19. Comparison of mean turf quality amongst zoysiagrass entries during the drydown of experiment III.

	Turf Quality[†]									
Entry	**0DAT[‡]**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**	**41DAT**
DALZ1407	3.8cd[§]	3.8de	4.5b-e	4.8ab	4.5abc	4.5ab	4.3ab	4.3a	4.0a	3.3a
DALZ1408	4.5abc	4.5a-d	5.0abc	5.0a	4.75ab	4.5ab	3.8abc	3.8abc	3.3a-d	3.0ab
DALZ1409	5.0ab	5.3a	5.8a	5.3a	5.0a	5.0a	4.5a	4.3a	3.5abc	3.3a
DALZ1410	3.0de	3.3e	3.8e	3.8cd	3.8bcd	4.0bcd	3.3bcd	3.0cde	3.0b-e	3.0ab
DALZ1411	4.3abc	4.8abc	5.0abc	5.0a	4.8ab	4.5ab	4.5a	4.0ab	3.8ab	3.5a
Empire	5.0ab	5.0ab	4.5b-e	3.5d	3.5cd	3.0e	3.0cde	2.5def	2.3ef	2.0c
FZ1201	4.3abc	4.3bcd	4.5b-e	4.5abc	4.3a-d	4.3abc	3.8abc	3.8abc	3.8ab	3.3a
FZ1223	4.5abc	4.3bcd	4.3cde	3.3d	3.3d	3.0e	2.3de	2.3ef	2.3ef	2.0c
FZ1231	2.0e	2.0f	2.0f	2.0e	2.0e	2.0f	2.0e	2.0f	2.0f	2.0c
FZ1244	4.0bcd	4.0cde	4.0de	3.5d	3.8bcd	3.3de	3.3bcd	3.3bcd	3.3a-d	2.5bc
FZ1252	5.0ab	5.3a	5.3ab	4.5abc	4.3a-d	4.0bcd	3.3bcd	3.3bcd	3.3a-d	2.3c
Palisade	5.0ab	5.0ab	4.8bcd	4.0bcd	3.8bcd	3.5cde	2.8cde	2.5def	2.5def	2.0c
Zeon	5.3a	5.0ab	4.8bcd	3.8cd	3.8bcd	3.3de	2.8cde	2.8def	2.8c-f	2.3c

[†]Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

[‡]DAT = Days after starting drought treatment.

[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 19. (Continued) Comparison of mean turf quality amongst zoysiagrass entries during the drydown of experiment III.

	Turf Quality†								
Entry	**44DAT‡**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
DALZ1407	2.8ab§	3.0a	3.0a	2.5abc	2.0a-d	2.3ab	2.0ab	1.5bcd	1.5bcd
DALZ1408	2.3bcd	2.0a-d	2.0a-d	1.8bcd	1.8bcd	1.5bcd	1.3bc	1.3cd	1.3cd
DALZ1409	2.8ab	2.8ab	2.5abc	2.5abc	2.5abc	2.3ab	2.0ab	1.8abc	1.8abc
DALZ1410	2.5abc	2.3abc	2.0a-d	2.0a-d	2.0a-d	2.0abc	2.0ab	2.0ab	2.0ab
DALZ1411	3.5a	3.0a	3.0a	3.0a	3.0a	2.5a	2.5a	2.3a	2.3a
Empire	2.0bcd	1.8bcd	1.8bcd	1.8bcd	1.8bcd	1.8a-d	1.8abc	1.3cd	1.3cd
FZ1201	2.8ab	2.8ab	2.8ab	2.8ab	2.8ab	2.5a	2.3a	2.0ab	2.0ab
FZ1223	1.3d	1.0d	1.0d	1.0d	1.0d	1.0d	1.0c	1.0d	1.0d
FZ1231	2.0bcd	2.0a-d	2.0a-d	2.0a-d	2.0a-d	2.0abc	2.0ab	2.0ab	2.0ab
FZ1244	2.0bcd	2.0a-d	1.8bcd	1.5cd	1.5cd	1.5bcd	1.3bc	1.0d	1.0d
FZ1252	2.3bcd	1.8bcd	1.5cd	1.5cd	1.5cd	1.25cd	1.3bc	1.3cd	1.3cd
Palisade	2.0bcd	1.5cd	1.5cd	1.3d	1.3d	1.0d	1.0c	1.0d	1.0d
Zeon	1.5cd	1.3cd	1.3d	1.3d	1.3d	1.3cd	1.3bc	1.3cd	1.3cd

†Turf quality was rated on the scale of 1 to 9, where 1 = dead or dormant turf, 6 = acceptable turf and 9 = excellent turf.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 20. Comparison of mean normalized difference vegetation index amongst bermudagrass entries during the drydown of experiment III.

	Normalized difference Vegetation Index†									
Entry	**0DAT‡**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**	**41DAT**
DALZ1407	0.69c§	0.73b	0.73bc	0.73a	0.70a	0.65ab	0.66ab	0.60ab	0.53a	0.49ab
DALZ1408	0.71bc	0.75ab	0.76ab	0.69abc	0.67ab	0.63abc	0.60a-d	0.52bcd	0.46a-d	0.39b-e
DALZ1409	0.78a	0.80a	0.80a	0.73a	0.70a	0.67a	0.65ab	0.59ab	0.53a	0.45abc
DALZ1410	0.59d	0.65c	0.67d	0.65bcd	0.62bcd	0.58bcd	0.57bcd	0.51bcd	0.46abc	0.41a-d
DALZ1411	0.71bc	0.76ab	0.76abc	0.72a	0.70ab	0.67a	0.67a	0.63a	0.57a	0.52a
Empire	0.74abc	0.77ab	0.76abc	0.64cd	0.59cde	0.52de	0.47e	0.40ef	0.35def	0.29ef
FZ1201	0.70bc	0.75ab	0.75abc	0.69abc	0.67ab	0.64bc	0.62abc	0.55abc	0.51ab	0.45abc
FZ1223	0.71bc	0.74b	0.70cd	0.60d	0.54e	0.48e	0.46e	0.37ef	0.33ef	0.27f
FZ1231	0.31e	0.32d	0.33e	0.33e	0.33f	0.32f	0.31f	0.32f	0.29f	0.28ef
FZ1244	0.69c	0.76ab	0.78ab	0.72ab	0.67ab	0.64abc	0.61abc	0.55abc	0.49abc	0.41a-d
FZ1252	0.76ab	0.78ab	0.78ab	0.70abc	0.65abc	0.60a-d	0.55cde	0.47cde	0.41b-e	0.34c-f
Palisade	0.78a	0.80a	0.77ab	0.67a-d	0.63bcd	0.57cd	0.5de	0.43de	0.39c-f	0.33def
Zeon	0.73abc	0.77ab	0.76ab	0.66a-d	0.57de	0.57cd	0.54cde	0.47cde	0.41b-e	0.33def

†NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 20. (Continued) Comparison of mean normalized difference vegetation index amongst bermudagrass entries during the drydown of experiment III.

	Normalized difference Vegetation Index†								
Entry	**44DAT‡**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
DALZ1407	0.47ab§	0.42ab	0.42ab	0.42ab	0.39ab	0.38ab	0.34abc	0.33abc	0.33ab
DALZ1408	0.37b-e	0.33b-e	0.33b-f	0.31b-e	0.31b-e	0.29b-e	0.27b-e	0.26b-e	0.26b-e
DALZ1409	0.44abc	0.41abc	0.38a-d	0.36bcd	0.35bcd	0.33bcd	0.31bcd	0.30bcd	0.30bc
DALZ1410	0.4a-d	0.36bcd	0.36b-e	0.34b-e	0.31b-e	0.31b-e	0.31b-e	0.29b-e	0.29bcd
DALZ1411	0.51a	0.48a	0.48a	0.49a	0.47a	0.43a	0.42a	0.40a	0.40a
Empire	0.32de	0.30cde	0.31b-f	0.30cde	0.30b-e	0.27cde	0.26cde	0.25b-e	0.24cde
FZ1201	0.44abc	0.40abc	0.40abc	0.40abc	0.37abc	0.36abc	0.35ab	0.33ab	0.33ab
FZ1223	0.27e	0.23e	0.23f	0.23e	0.22e	0.22e	0.22e	0.21e	0.21e
FZ1231	0.27e	0.26de	0.26ef	0.27de	0.29cde	0.26cde	0.25de	0.26b-e	0.26b-e
FZ1244	0.38bcd	0.32b-e	0.30c-f	0.30cde	0.28cde	0.27cde	0.27b-e	0.25b-e	0.25b-e
FZ1252	0.35cde	0.31cde	0.33b-f	0.32b-e	0.30b-e	0.28cde	0.29b-e	0.28b-e	0.29bcd
Palisade	0.31de	0.29de	0.29def	0.29cde	0.26de	0.25de	0.26cde	0.25cde	0.25b-e
Zeon	0.30de	0.28de	0.28def	0.28de	0.26de	0.25de	0.23de	0.23de	0.22de

†NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 21. Comparison of mean leaf firing amongst zoysiagrass entries during the drydown of experiment III.

	Leaf Firing†									
Entry	**0DAT‡**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**	**41DAT**
DALZ1407	9.0a§	9.0a	9.0a	9.0a	8.8a	8.8a	8.3a	7.0ab	5.8ab	5.0ab
DALZ1408	9.0a	9.0a	9.0a	8.0bcd	8.3abc	7.8ab	7.3abc	5.8b-e	5.0abc	3.8bcd
DALZ1409	9.0a	9.0a	9.0a	8.8ab	8.3abc	8.0a	7.5ab	6.5abc	5.5abc	4.5abc
DALZ1410	9.0a	9.0a	9.0a	7.5cd	7.5cd	6.8bc	7.0bc	6.0a-d	5.0abc	4.0abc
DALZ1411	9.0a	9.0a	9.0a	8.8ab	8.5ab	8.3a	8.0ab	7.5a	6.5a	5.5a
Empire	9.0a	9.0a	8.5bc	7.3d	6.3f	5.5d	4.5ef	3.3g	2.5e	2.0e
FZ1201	9.0a	9.0a	9.0a	8.8ab	8.5ab	8.0a	7.3abc	6.8abc	5.8ab	4.5abc
FZ1223	9.0a	9.0a	8.3cd	7.3d	6.5ef	5.5d	3.8f	3.0g	2.8de	2.0e
FZ1231	9.0a	9.0a	8.0d	7.5cd	8.0a-d	7.8ab	7.5ab	6.5abc	5.3abc	5.0ab
FZ1244	9.0a	9.0a	8.8ab	8.3abc	7.8bcd	6.8bc	6.3cd	5.3c-f	4.3bcd	3.0cde
FZ1252	9.0a	9.0a	9.0a	8.0bcd	7.8bcd	7.8ab	5.8d	4.5d-g	4.0cde	3.0cde
Palisade	9.0a	9.0a	8.0d	7.5cd	7.3de	6.8bc	5.3de	4.0fg	3.3de	2.3de
Zeon	9.0a	9.0a	8.3cd	7.3d	7.3de	5.8cd	5.3de	4.3efg	3.3de	2.3de

†Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.
‡DAT = Days after starting drought treatment.
§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 21. (Continued) Comparison of mean leaf firing amongst zoysiagrass entries during the drydown of experiment III.

	Leaf Firing†								
Entry	**44DAT‡**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
DALZ1407	4.0abc§	3.5ab	3.0abc	2.8abc	2.5abc	2.5abc	2.3abc	1.8abc	1.8abc
DALZ1408	2.8b-e	2.5bcd	2.0cd	1.8cde	1.8bcd	1.5bcd	1.3cd	1.3bc	1.3bc
DALZ1409	4.3ab	3.3abc	3.0abc	3.0abc	3.0ab	2.8ab	2.3abc	2.0abc	1.8abc
DALZ1410	3.3a-d	2.8a-d	2.3bcd	2.0be	2.0bcd	2.0a-d	2.0bcd	2.0abc	2.0abc
DALZ1411	5.0a	4.3a	4.0a	3.8a	3.8a	3.3a	3.3a	2.8a	2.8a
Empire	2.3cde	2.3bcd	2.0cd	1.8cde	1.8bcd	1.8bcd	1.8bcd	1.3bc	1.3bc
FZ1201	4.0abc	3.3abc	3.0abc	2.5a-d	2.5abc	2.5abc	2.5ab	2.3ab	2.3ab
FZ1223	1.3e	1.3d	1.0d	1.0e	1.0d	1.0d	1.0d	1.0c	1.0c
FZ1231	4.0abc	3.5ab	3.5ab	3.3ab	2.8ab	2.3a-d	2.3abc	2.3ab	2.8a
FZ1244	2.8b-e	2.0bcd	1.8dc	1.3de	1.3cd	1.3cd	1.3cd	1.0c	1.0c
FZ1252	2.8b-e	2.5bcd	2.3bcd	2.0b-e	1.8bcd	1.5bcd	1.5bcd	1.3bc	1.3bc
Palisade	2.0de	1.8cd	1.8cd	1.8cde	1.8bcd	1.3cd	1.3cd	1.0c	1.0c
Zeon	1.5de	1.5d	1.3d	1.3de	1.3cd	1.3cd	1.3cd	1.3bc	1.3bc

†Leaf firing (LF) was rated on the scale of 1 to 9, where 1 = total leaf firing, and 9 = no leaf firing.
‡DAT = Days after starting drought treatment.
§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 22. Comparison of mean live green cover amongst zoysiagrass entries during the drydown of experiment III.

	Live Green Cover (%) †									
Entry	**0DAT‡**	**7DAT**	**12DAT**	**18DAT**	**23DAT**	**27DAT**	**30DAT**	**34DAT**	**37DAT**	**41DAT**
DALZ1407	96.7a§	98.1ab	99.0a	97.6a	94.8ab	92.4a	89.9a	77.0ab	70.2ab	63.5ab
DALZ1408	97.2a	98.5ab	98.9a	95.9ab	84.8a-e	82.6ab	78.8a-d	62.6bcd	58.5bcd	46.7b-e
DALZ1409	99.6a	99.7a	99.8a	98.2a	93.1ab	92.1a	88.4ab	73.2ab	69.7ab	60.7ab
DALZ1410	82.0b	90.3b	92.9ab	88.3abc	73.3def	73.0bc	69.9cde	55.9cde	54.9b-e	48.3bcd
DALZ1411	98.2a	99.2a	99.5a	98.5a	95.5a	95.6a	93.7a	82.0a	77.6a	69.4a
Empire	97.2a	97.1ab	95.1ab	82.3cd	66.3fg	58.1de	54.7ef	44.0e	35.9ef	28.9ef
FZ1201	95.1a	98.1ab	98.7a	95.7ab	86.6a-d	85.7ab	81.2abc	69.4abc	64.4abc	58.7abc
FZ1223	93.6a	95.0ab	89.6b	73.5d	56.6gh	52.9de	50.9f	41.3e	33.3f	25.1f
FZ1231	39.7c	43.9c	48.0c	47.9e	44.7h	46.8e	48.4f	43.6e	38.6ef	36.6def
FZ1244	95.0a	97.4ab	97.9ab	95.4ab	87.8abc	83.1ab	82.3abc	68.9abc	61.0a-d	49.5bcd
FZ1252	98.7a	98.8a	98.7a	94.3ab	81.7b-e	76.9bc	71.6b-e	53.7cde	47.8c-f	39.5c-f
Palisade	98.8a	98.6ab	95.2ab	86.2bc	71.5ef	66.8cd	63.7def	50.3de	44.1def	35.8def
Zeon	99.0a	99.1a	98.6a	89.7abc	75.7c-f	72.1bc	68.6cde	50.7de	43.9def	31.7def

†Live cover is the result of digital image analysis (DIA) via SigmaScan software with results presented as a percentage.

‡DAT = Days after starting drought treatment.

§Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 22. (Continued) Comparison of mean live green cover amongst zoysiagrass entries during the drydown of experiment III.

	Live Green Cover (%) [†]								
Entry	**44DAT[‡]**	**47DAT**	**50DAT**	**54DAT**	**57DAT**	**61DAT**	**64DAT**	**68DAT**	**72DAT**
DALZ1407	58.5a[§]	51.5abc	50.3ab	52.1ab	44.8a-d	40.1abc	38.0a-d	34.3abc	34.0bcd
DALZ1408	43.6bcd	37.0b-e	36.0bcd	39.0b-e	32.7b-f	31.9b-e	28.4b-f	27.5bcd	27.1b-e
DALZ1409	58.3ab	52.9ab	49.0ab	52.4ab	46.0ab	43.5ab	40.8ab	36.9ab	36.8bc
DALZ1410	44.5bcd	41.3b-e	39.0bc	41.6bcd	36.2b-e	32.2b-e	32.2b-e	30.4bc	32.6bcd
DALZ1411	69.0a	61.3a	64.0a	65.0a	58.6a	53.9a	50.8a	48.7a	52.4a
Empire	28.7de	32.3def	33.5bcd	34.1b-e	28.3de	27.5cde	24.9c-f	24.2bcd	22.4cde
FZ1201	54.1abc	49.1a-d	48.9ab	50.3abc	45.1abc	42.2abc	39.1abc	37.7ab	37.1b
FZ1223	21.5e	18.0f	17.8d	21.6e	17.4f	17.3e	13.4f	15.4d	16.1e
FZ1231	35.5cde	33.4c-f	34.4bcd	38.2b-e	33.7b-f	33.2bcd	31.7b-e	31.9bc	34.0bcd
FZ1244	41.2b-e	37.1b-e	33.1bcd	33.8b-e	28.6c-f	27.7cde	24.3c-f	24.7bcd	22.4de
FZ1252	41.8bcd	38.7b-e	39.6bc	40.3b-e	35.8b-e	35.0bcd	31.1b-e	30.4bcd	33.7bcd
Palisade	32.0de	30.4ef	28.8cd	31.9cde	27.3ef	27.4cde	23.3def	23.8bcd	23.2b-e
Zeon	29.5de	28.2ef	26.6cd	29.2de	25.4ef	24.3de	22.5ef	21.1cd	20.5de

[†]Live cover is the result of digital image analysis (DIA) via SigmaScan software with results presented as a percentage.

[‡]DAT = Days after starting drought treatment.

[§]Means within the same column having a letter in common are not significantly different at the p=0.05 level using Fisher's protected least significant difference (LSD) test. A dash appearing between two letters means all the letters between those two letters are included.

Table 23. Pearson's Correlation Analysis amongst leaf firing (LF), turf quality (TQ), live green cover (LGC), normalized difference vegetation index (NDVI), mean volumetric soil water content (MVSWC) and days after starting drought treatment collected during drydown in experiment III.

Parameter	TQ‡	NDVI§	LGC¶	MVSWC#	DAT††
LF†	0.86***	0.9***	0.92***	0.71***	-0.89***
TQ		0.93***	0.92***	0.51***	-0.74***
NDVI			0.98***	0.59***	-0.81***
LGC				0.62***	-0.80***
MVSWC					-0.82***

*** Significant at $P = 0.001$.

†LF = Leaf Firing was rated on a scale from 1-9 during drydown where 1= all leaves fired and 9 = no leaf fired.

‡TQ = Turf Quality was rated on a scale from 1-9 during drydown cycles where 1 = lowest quality and 9 = excellent quality.

§NDVI= Normalized Difference Vegetation Index measured by Trimble GreenSeeker handheld sensor on a scale 0-1, where 0= no green cover and 1= complete green cover.

¶LGC = Live Green Cover measure by digital image analysis calculating the percent live cover on a scale from 0-100 where 0 = no green cover and 100 = all the leaves are green.

#MVSWC=Mean Volumetric Soil Water Content was measured with a Stevens POGO HydraProbe.

††DAT=Days after starting drought treatment.

Table 24. Ranking of drought response of bermudagrass entries in experiment I using four assessment parameters.

Entry	Times in top LGC Statistical Group†	Times in top NDVI Statistical Group	Times in top TQ Statistical Group	Times in top LF Statistical Group	Total times in top Statistical Group
TifTuf	16	15	16	19	66
OSU1221	19	19	9	11	58
OSU1225	18	17	6	10	51
OSU1257	8	12	12	11	43
UGB136	13	16	1	8	38
Celebration	12	11	2	11	36
UGB103	8	11	9	7	35
UGB118	6	18	2	7	33
UGB120	5	12	5	10	32
OSU1220	7	9	4	6	26
OSU1273	2	5	4	10	21
UGB117	4	2	6	6	18
Tifway	1	0	3	4	10

†Number of times that the entry's mean ranked in the top statistical ranking group (according to Fisher's protected least significant difference at the P=0.05 level) for the categories over a total of 19 times. Measures of drought response included leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI) and live green cover (LGC).

Table 25. Ranking of drought response of bermudagrass entries in experiment II using four assessment parameters.

Entry	Times in top LGC Statistical Group[†]	Times in top NDVI Statistical Group	Times in top TQ Statistical Group	Times in top LF Statistical Group	Total times in top Statistical Group
TifTuf	13	14	14	14	55
OSU1221	13	14	11	11	49
OSU1257	6	7	5	3	21
OSU1220	5	5	2	6	18
UGB136	6	6	3	2	17
UGB103	7	5	2	2	16
UGB118	5	4	3	4	16
UGB117	6	6	1	1	14
Celebration	1	2	5	5	13
U-3	2	2	5	3	12
OSU1225	6	3	1	1	11
Tifway	3	3	1	1	8
UGB120	2	5	0	0	7
OSU1273	2	3	0	1	6
Astro	0	1	0	1	2

[†]Number of times that the entry's mean ranked in the top statistical ranking group (according to Fisher's protected least significant difference at the P=0.05 level) for the categories over a total of 19 times. Measures of drought response included leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI) and live green cover (LGC).

Table 26. Ranking of drought response of bermudagrass entries in experiment III using four assessment parameters.

Entry	Times in top LGC Statistical Group[†]	Times in top NDVI Statistical Group	Times in top TQ Statistical Group	Times in top LF Statistical Group	Total times in top Statistical Group
DALZ1411	19	19	19	18	75
FZ1201	17	19	18	17	71
DALZ1409	19	19	18	16	69
DALZ1407	14	19	18	16	67
DALZ1408	12	7	7	4	30
DALZ1410	10	10	2	4	26
FZ1231	8	17	0	1	26
FZ1244	2	4	9	8	23
FZ1252	6	4	4	6	20
Empire	4	2	3	3	12
Zeon	2	2	4	4	12
Palisade	2	2	3	4	11
FZ1223	1	2	2	0	5

[†]Number of times that the entry's mean ranked in the top statistical ranking group (according to Fisher's protected least significant difference at the P=0.05 level) for the categories over a total of 19 times. Measuring of drought response include leaf firing (LF), turf quality (TQ), normalized difference vegetation index (NDVI) and live green cover (LGC).

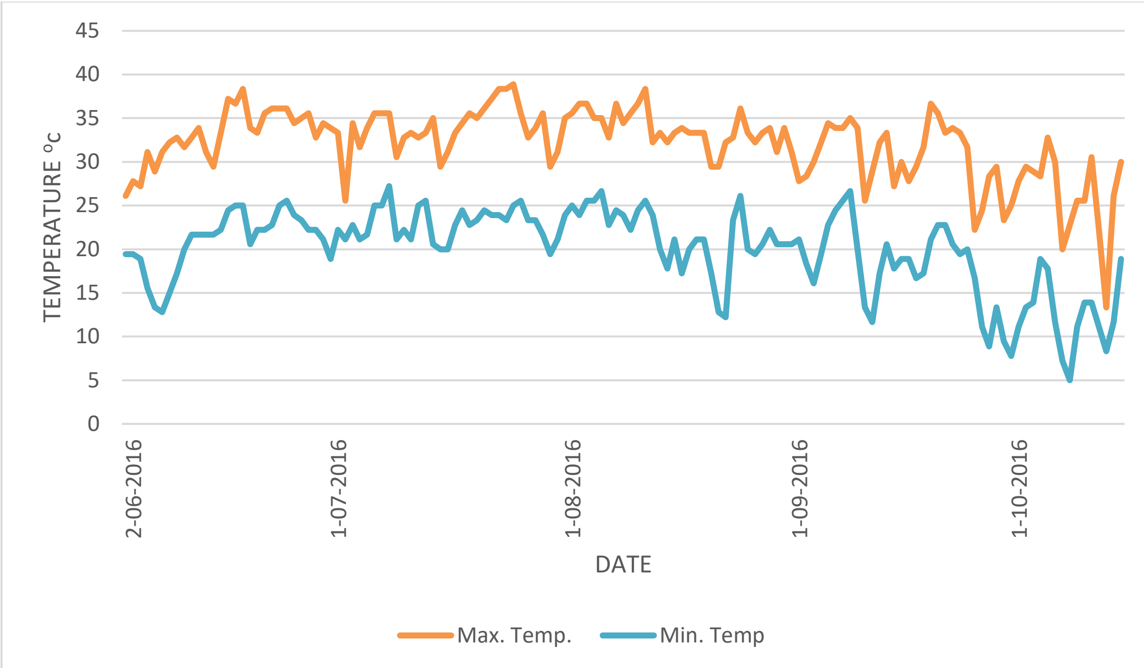

Figure 1. Daily average maximum and minimum air temperature during drydown of experiment I, II and III (12 June 2016 – 15 October 2016).

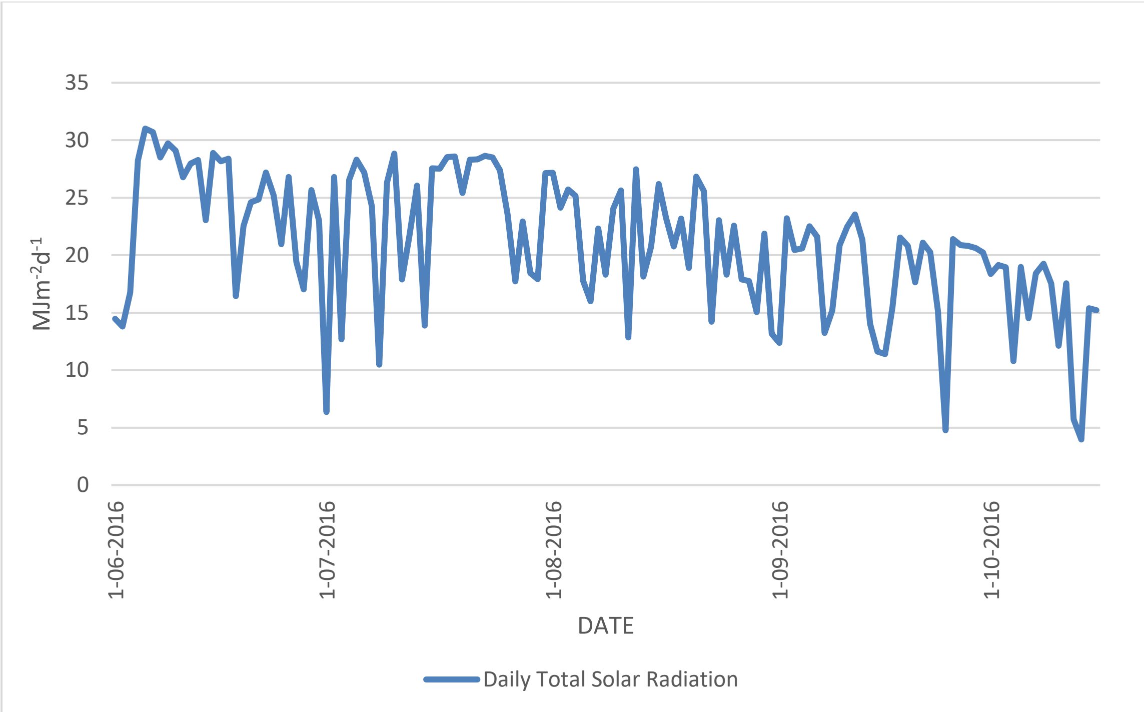

Figure 2. Total daily solar radiation ($MJm^{-2}d^{-1}$) during 1 June through 15 October 2016 measured by the Stillwater Mesonet station located east of cow creek.

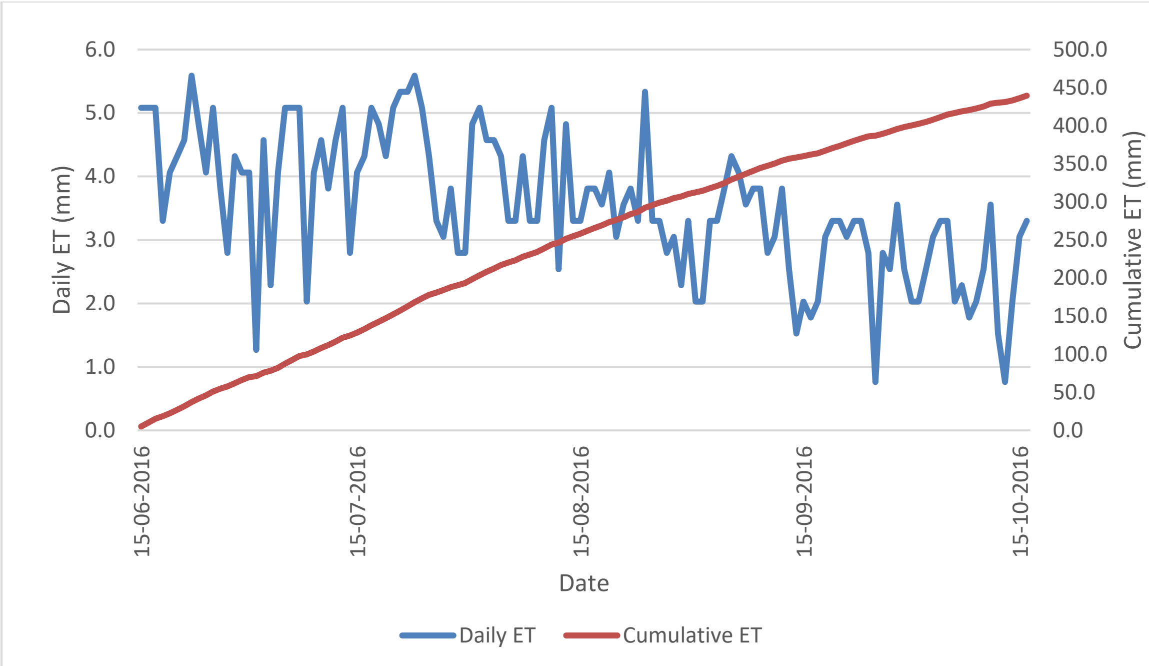

Figure 3. Daily evapotranspiration (ET) rate and cumulative ET rate estimated by Stillwater Mesonet station during drydown of experiment I, II and III (16 June 2016 – 15 October 2016).

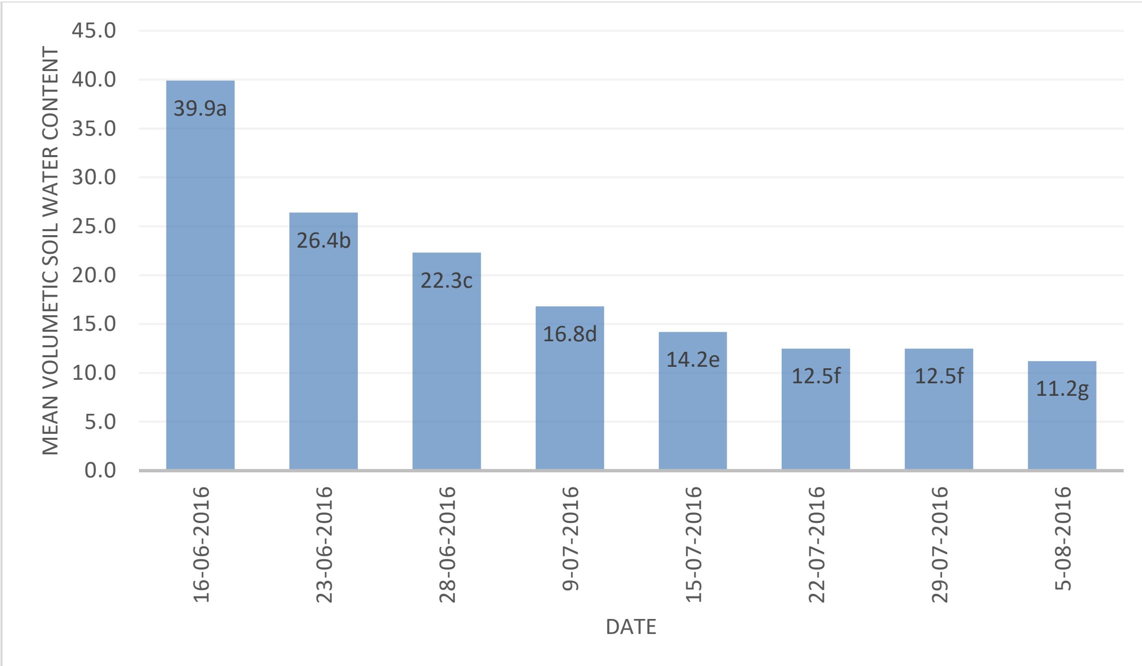

Figure 4. Mean volumetric soil water content measured by a 6.4 cm-long time domain-reflectometer (TDR) probe during the drydown cycle of experiment I. Soil moisture was measured on nine different dates.

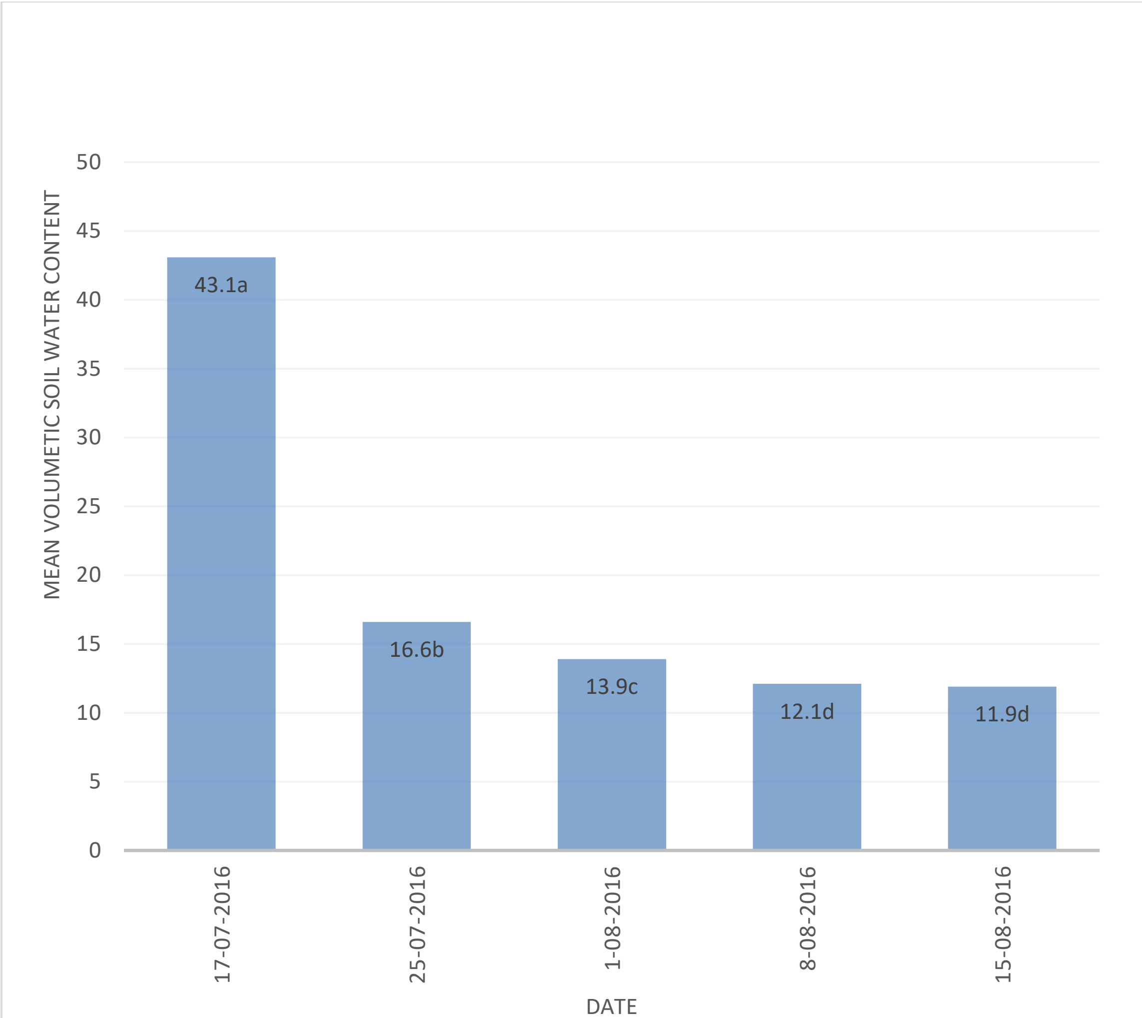

Figure 6. Mean volumetric soil water content measured by a 6.4 cm-long time domain-reflectometer (TDR) probe during the drydown cycle of experiment II. Soil moisture was measured on five different dates.

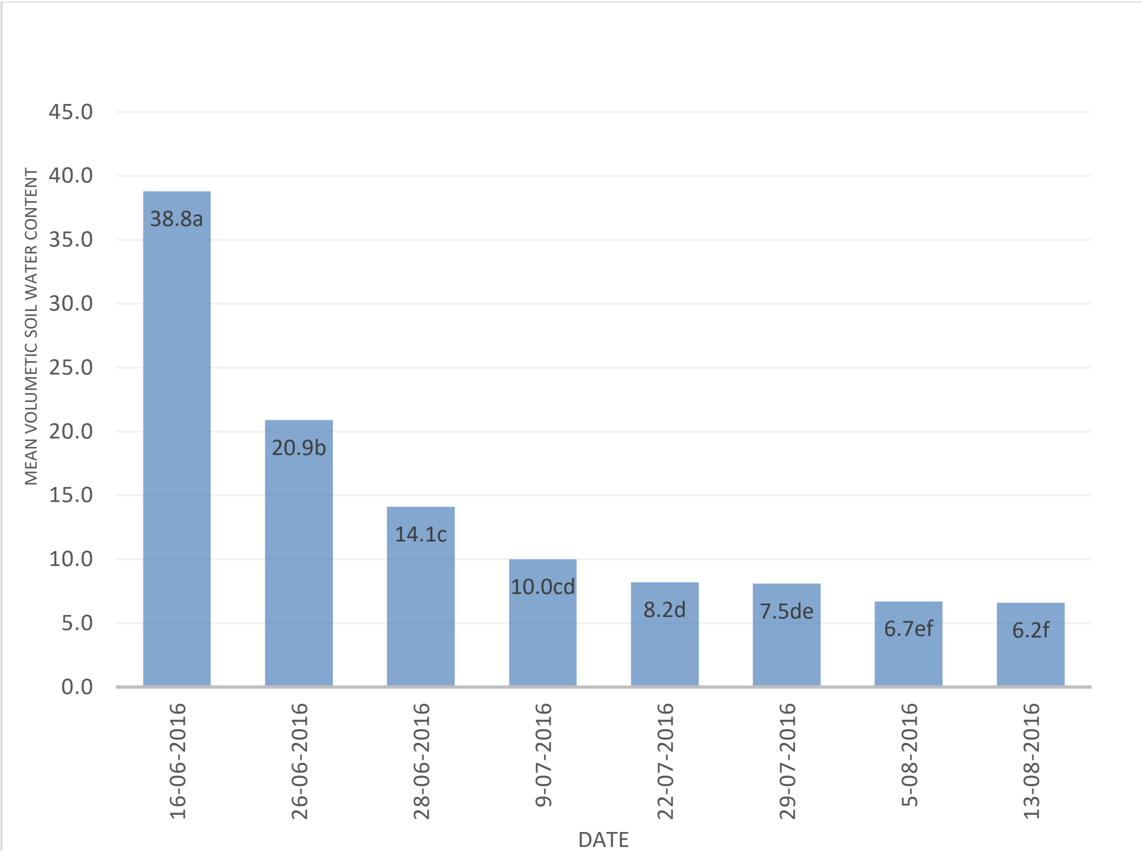

Figure 5. Mean volumetric soil water content measured by a 6.4 cm-long time domain-reflectometer (TDR) probe during the drydown cycle of experiment III. Soil moisture was measured on nine different dates.

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